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PREPARATION OF FUELS

STEAM POWER PRODUCTION

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WATER POWER PRODUCTION—GENERAL

CHAIRMAN: DR. F. A. GABY (Canada)
Hydro-Electric Power Commission
of Ontario

THE INFLUENCE OF LARGE WATER POWER INSTALLATIONS ON THE REGIME OF FLOW

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The term " River Regime " may to-day be considered as embracing not only the relations regarding fluctuations in the rate of flow but also the influence of the flow on changes in channel bed and on the transport of detritus and silt. A neglect of this study has led to serious changes in the river bed on many rivers where artificial works have been constructed for the regulation or utilisation of the water for power purposes.

The lowering or raising of the river bed on a large scale has caused serious damage to land, to navigation and to power schemes and, without entering into detail, it may be stated that on certain rivers the construction of main regulation works has rendered absolutely necessary the adoption of remedial measures, if damage is to be avoided. An increasing knowledge of the cause of the trouble has enabled these measures to be made effective, and it should be the duty of the Government to enforce the adoption of similar measures, as far as possible, in connection with new undertakings.

Water power works are essentially projects which, by their interference with normal conditions of flow, owing to storage of water with retention of silt in the reservoirs, or to abstraction of water from the river channel, tend to cause disturbances which act upon the normal state of the river bed. It is necessary, therefore, to visualise the nature of these disturbances and to provide special counter measures for the prevention of damage.

In order to arrive at some understanding of the results produced by the somewhat complicated interaction of the effects produced by alterations in the natural conditions, it is necessary to consider those effects individually. It is assumed, therefore, that the river course is in a condition of equilibrium and that before any interference with the channel is made, the continuity of silt transport is maintained. This transport is a perfectly natural process in all stretches of a river.

The construction of water power works may entail changes in

the water level or in the discharge of a river and also may effect the complete or partial removal of detritus. These may result from

(*a*) The narrowing or widening of the river bed.

(*b*) The withdrawal of water out of the river channel for power purposes.

(*c*) The averaging of the river discharge owing to storage.

(*d*) The holding up of detritus by settlement in reservoirs.

All these may cause disturbances of pre-existing states of equilibrium and such disturbances will result in the raising or lowering of the river bed according as the detritus coming with the stretch of the river considered is greater or less than the amount carried away.

The measurement of change in the river bottom can be gauged as the difference in volume of detritus carried in and swept out of a river stretch during a certain interval, generally a year, or by calculating the heightening or deepening required for an ultimate state of equilibrium. The first method is based on the assumption that any accumulation of detritus is at once removed and any shortage made up. This, as will be shown later, it is possible to effect by counter measures, and the assumption must be made else it would be impossible to assume a constant gradient for the river surface. The second method, on the contrary, corresponds to natural conditions and entails the task of calculating the new river gradient under certain suppositions as to change of cross section or of silt removal.

Although the first method is valid only for an ideal state, it is, as will be shown later, a suitable one to adopt for the solution of the detritus problem, and by its aid the question of counter measures can be most simply solved.

The arithmetical and graphical treatments entail a knowledge of certain fundamental elements coordinated in such a way as to describe completely the river flow, further, the cross section of the stretch to be considered must be a characteristic one.

Throughout this paper, the following designations are used:— t=time in days, I=mean gradient of water surface, B=width of water level in metres, f=river section in sq. metres, h=height of water surface above datum zero in metres.

$H_m = \frac{f}{B}$ mean depth of water in metres.

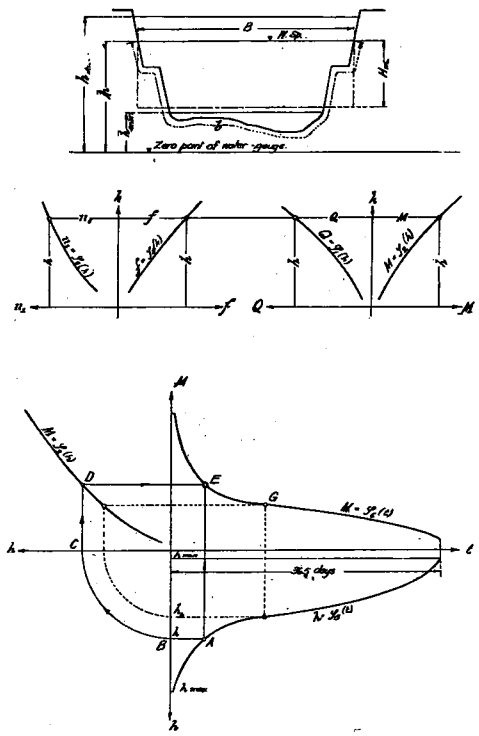
h_b = depth of water to bed-forming water level.

h_{max} = maximum high water level in the year.

h_{min} = minimum low " " "

l = perimeter in m.

Q = volume of discharge in cubic metres per sec.
M = volume of detritus „ „ „
F = weight „ „ „ „ „ per year.
u_s = mean velocity at the bottom at the cross section considered in metres per second.
$Q = \phi_1(h)$ Curve of the water volume, passing the cross-section
$M = \phi_2(h)$ Curve of the detritus volume, passing the cross-section.[1]
$u_s = \phi_3(h)$ Curve of the velocities at the bottom.
$f = \phi_4(h)$ Curve of the wetted cross-sections.
$h = \phi_5(t)$ Curve of the duration of wetting.
$M = \phi_6(t)$ Curve of the duration of detritus volumes.



COMPREHENSIVE REPRESENTATION OF THE STATE OF THE FLOW
FIG 1

[1] On the question of the Detritus volume curve see F. Schaffernak: " Neue Grundlagen für die Berechnung der Geschiebeführung in Flussläufen," 4 Folge der Mitteilungen der Versuchsanstalt für Wasserbau in Wien, 1921, Published by F. Deuticke, Wien.

The curve $M=\phi_6(t)$ may be constructed as shown in Fig. 1, by ascertaining, point by point, with the help of the lines A, B, C, D, E and A-E from the curve of wetting-duration $h=\phi_5(t)$.

The mass of detritus F for the particular year is obtained by finding with a planimeter the area enclosed by the curve of detritus-duration and the axes of co-ordinates. This figure also enables one to find the water level at which the maximum of the detritus has been transported, and for this reason we call that level the river bed-forming water level h_b. It corresponds to the point of inflexion G of the curve of the detritus duration, as this duration-line is the differential of the curve of frequency.

This preparatory work done, we can proceed to find out the measure of the ideal deposit or erosion, as well as the lowering or raising of the river bed for any particular case. The first operation is called "the calculation by detritus mass," the second "calculation by transformation of the river bed."

1. CALCULATION BY DETRITUS MASS.

All problems of this nature start with the same fundamental assumption that no change of the relative water gradient occurs. That assumption is justified in that any actual transformation is prevented by taking counter measures such as dredging, the installation of regulating works, etc.

From the purely theoretical point of view, the condition of maintaining an even gradient is not completely ensured by maintaining the level of the river bottom, as in the stretches between the non-regulated and the regulated sections a transition in the gradient must occur. As these transition stretches are small in comparison with the river stretch influenced, and as it is on the other hand, possible to correct locally any disturbances of the bed, we may, for practical purposes, suppose the gradient to be the same before and after the execution of the counter measures.

We will now treat of the effects of the work intended to influence the levels in the order mentioned above.

(*a*) *Effects of narrowing or widening the river bed.*

In order to be able to apply the solution of this problem to all cases that may present themselves in actual practice, it is necessary first to give a wider meaning to the expression: "narrowing and widening the river bed."

Either of these modifications of the sectional profile may be carried out in various depths of the river section to meet the particular conditions. Therefore, a decision must first be taken as to whether

the work that is generally carried out in a number of sections is to refer to low water level, average level or highest level.

That is to say, it is necessary to decide upon the level that it is intended to regulate. Referring to Fig. 2, if we denote by f_1, f_2, f_3 the superficies of the parts of the cross section of nearly equal depth of water,

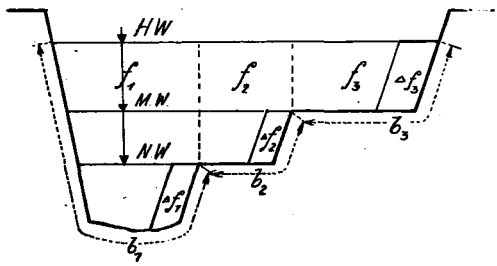


Fig. 2.

Δf_1 Δf_2, Δf_3, the artificial alternations of the section,
b_1, b_2, b_3, the wetted perimeters of the single profile parts.
Δb_1, Δb_2, Δb_3 the alterations of the wetted perimeters of the single profile parts,
I the average fall of the water level,
c the roughness co-efficient according to Kutter,

then for the state 1*, *i.e.*, before the artificial reconstruction the equation :

$$[Q]_1 = c\, I^{\frac{1}{2}} \left[\frac{f_1^{\frac{3}{2}}}{b_1^{\frac{1}{2}}} + \frac{f_2^{\frac{3}{2}}}{b_2^{\frac{1}{2}}} + \frac{f_3^{\frac{3}{2}}}{b_3^{\frac{1}{2}}} \right] \text{ will apply}$$

and for the state 2, *i.e.*, after the artificial reconstruction, the equation :

$$[Q]_2 = c\, I^{\frac{1}{2}} \left[\frac{(f_1 \pm \Delta f_1)^{\frac{3}{2}}}{(b_1 \pm \Delta b_1)^{\frac{1}{2}}} + \frac{(f_2 \pm \Delta f_2)^{\frac{3}{2}}}{(b_2 \pm \Delta b_2)^{\frac{1}{2}}} + \frac{(f_3 \pm \Delta f_3)^{\frac{3}{2}}}{(b_3 \pm \Delta b_3)^{\frac{1}{2}}} \right]$$

will apply.

Hence it follows that where I and the absolute altitude of the water level remain unchanged after a narrowing or widening:

$$[Q]_2 = [Q]_1 \frac{\frac{f_1^{\frac{3}{2}}}{b_1^{\frac{1}{2}}} + \frac{f_2^{\frac{3}{2}}}{b_2^{\frac{1}{2}}} + \frac{f_3^{\frac{3}{2}}}{b_3^{\frac{1}{2}}}}{\frac{[f_1 \pm \Delta f_1]^{\frac{3}{2}}}{[b_1 \pm \Delta b_1]^{\frac{1}{2}}} + \frac{[f_2 \pm \Delta f_2]^{\frac{3}{2}}}{[b_2 \pm \Delta b]_2^{\frac{1}{2}}} + \frac{[f_3 \pm \Delta f_3^{\frac{3}{2}}]}{[b_3 \pm \Delta b_3^{\frac{1}{2}}]}}$$

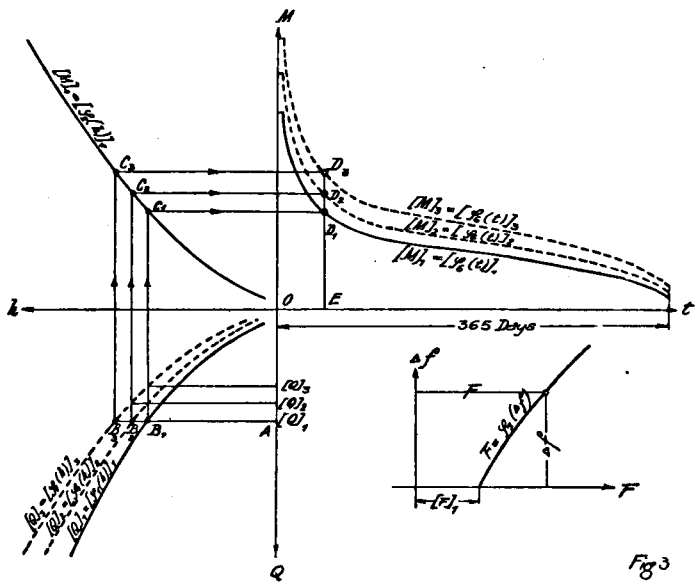
* We shall express the single states 1, 2, etc., by the signs.

It is, therefore, possible to find with sufficient accuracy, for every transformation of the cross section, the changed curve as well as the permanent curve of the mass of detritus for the state 2 $[F]_2$, and finally to find also the connection between the size of the reconstruction of section f and F. The method is shown in Fig. 3.

It consists in calculating from the equation given above, in addition to the known curve of the water volumes

$$[Q]_1 = [\phi_1 (h)]_1$$

the changed curves of the water volumes $[Q_2] = [\phi_1 (h)]_2$, $[Q]_2 = [\phi_1 (h)]_2$, etc.



If we proceed then, point by point, to the new curves of the permanent detritus volumes by drawing in the lines A-B_1-C_1-D_1, A-B_2-C_2-D_2 and E-D_1-D_2, we get the new curves of permanent detritus volumes,

$$F = \phi_1 (\Delta f)$$

We should state that in special circumstances, a narrowing of the low water section might reduce the width of the bottom to such an extent as to prevent the mass of detritus being carried away.

In a special case of that kind the necessary adjustment can easily be made when constructing the curve of the mass of detritus.

Fig. 3 deals with a case of narrowing, and it follows from it that such a change in the cross-sectional profile must lead to an increase in the masses of detritus and consequently to a deepening of the bed of the river. A similar investigation in respect of an enlargement of the cross-sectional profile, on the other hand, will show a reduction of the masses of detritus, and, therefore, a deviation or disturbance in the form of a rising of the bed. Further consideration will show that the extent of the disturbance depends not only on the amount of the change of the cross-sectional profile (Δf) but also on the position of the Δf surfaces.

(c) *Effects of a withdrawal of water by water power works.*

In the present examination it is assumed that of the volume Q flowing through the river, the portion Q_e can be led into the head race of the works without any barrage or weir. This method of

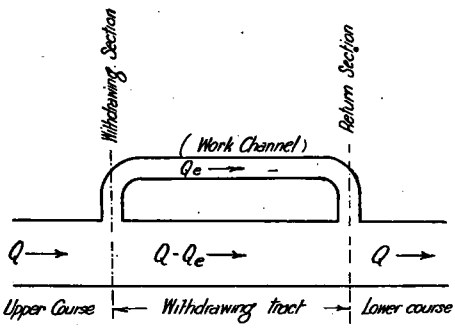


Fig. 4.

conducting the water is called " free conduct " as constrasted with " secured conduct " where the withdrawal of the water is obtained by means of a barrage or weir.

The withdrawal of Q_e into the headrace diminishes the volume of water carried in the upper stretch of the river to $Q—Q_e$, and the addition of Q_e from the tailrace raises the volume of water flowing through the section per unit of time to Q again.

As the amount withdrawn varies according to the water level, it is convenient to represent this relation in a graphical manner by what may be called a curve of water withdrawal, $W=\phi_8(h)$.

Permission to withdraw water is usually given by Government authority and is limited with due regard to navigation, rafting, fishing and other water rights.

The transformation of the curve $(M)_1$ of duration of detritus volumes which is known in the state 1, *i.e.*, before the withdrawing of the water into curve $(M)_2$ for the state 2, *i.e.*, after the withdrawal has taken place, corresponds to the prescribed curve of water withdrawal $W=\phi_3(h)$, (see Fig. 5). Paying due regard to the curve, which is also known, of the water volumes $Q=\phi_1(h)$ and the curve of the detritus volumes $M=\phi_2(h)$ it may be also obtained, point by point, as shown in Fig. 5, with the help of the lines A, B, C, G, H, F and C, D, E, F.

The line A. B, C, G, H, F gives along the ordinate HK the detritus volume that passes through the upper stretch during OK days in

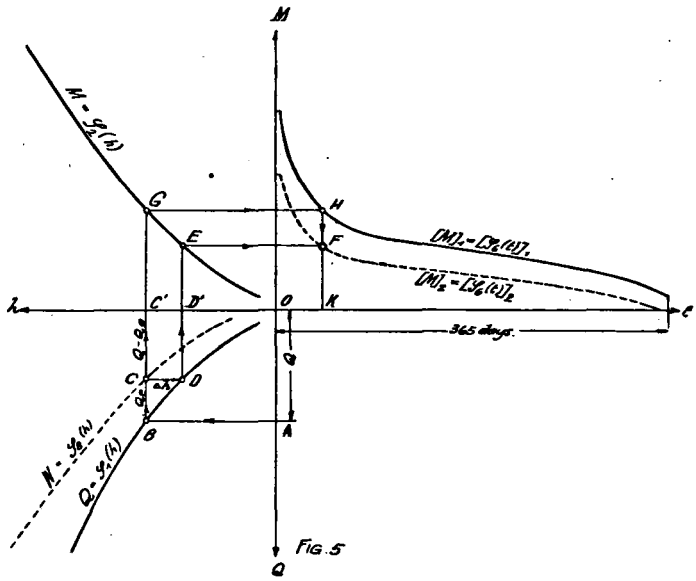


Fig. 5

the year, and which corresponds to a volume of flow of $Q=BC^1$. If now $Q_e=BC$ is withdrawn we get another quantity to transport in the upper stretch, whose flowing volume is now $Q-Q_e=BC^1-BC=CC^1=DD^1$. This, however, is given by the line C, D, E, F in the ordinate KF, as the transport volumes NK and KF correspond to water levels of equal duration of OK days. The difference $KH-KF=FH$ represents therefore the detritus volume, that must be deposited in the upper course at a volume of flow Q in the upper stretch. Thus it follows that the surface, enclosed by the curves of the detritus duration lines in the state 1 and 2 represents

that mass of detritus which in ideal circumstances would be deposited in the upper stretch during the particular year.

The result, therefore, is that a withdrawal of water causes a deposition of detritus, and therefore a raising of the bed in the upper stretch of the main river, which increases as the volume of water so withdrawn. The duration of such withdrawal considerably influences the size of this disturbance.

c. The effects of an equalisation of the water volumes in consequence of the presence of storage installations.

If the storage installation is situated considerably higher up river than the stretch under consideration, the storage will only cause

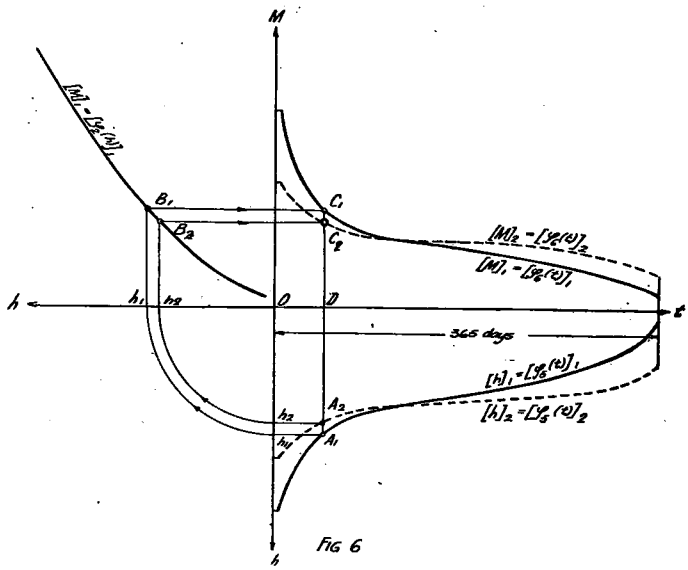


FIG 6

the changed regime of the water flow to change the transport of the detritus. A clearing of sand brought about by the storage of water will produce no tangible effect, owing to the distance of the stretch in question. The solution of this problem will therefore amount to transforming the curve of the detritus duration of the state 1 into that of the state 2, *i.e.*, after the equalisation of the flow.

This transformation may be achieved by the aid of the curves of duration of wetness, $[h]_1$—$[\phi_5^{(t)}]_1$ and $[h]_2$=$[\phi_5^{(t)}]_2$ which is obtained by the original regime and the regime resulting from the equalising effect of the storage installation.

In Fig. 6 the transformation of both the curves of wetting durations

is represented on the basis of the curve which is known, of detritus volume for the cross section $[M]_1=[\phi_2(h)]_1$ which remains equal for both states.

The lines A_1, B_1, C_1 and A_2, B_2, C_2 make it possible to ascertain the detritus volumes DC_1 and DC_2 of the water levels h_1 and h_2, over equal periods before and after the equalisation. The difference of the surfaces of both duration lines gives the required difference of the mass of detritus.

The final result may be summarised thus: an equalisation of water in those river stretches where it can still sensibly affect the water flow, causes an augmentation of the detritus carried and thereby deepens the river bed.

d. Effects of the retaining of detritus by dams.

In this case, unlike that dealt with in section c, the equalising effect of the barrage volume is assumed to be negligible, while, on the other hand, the effect of the clearing away of sand cannot be neglected. Such cases are often found where water power works are built on a large scale. The removal of the sand will affect the river stretch immediately adjoining the barrage or dam more than any other portions. The removal of the sand will depend on the kind of barrage, whether it is fixed or a movable weir. Fixed weirs will remove the sand for a limited period only, because after the dammed space is filled, a continual passage of detritus begins again, and pieces or lumps of detritus are carried over the crown of the weir. Fixed weirs will retain and remove sand only temporarily, although this may be for decades in some places where great barrages or dams have been built.

The effect of movable weirs in retaining sand or gravel is usually underestimated, a circumstance that may have fatal consequences with modern designs. Sufficient attention is not given to the fact that such weirs are open only at higher water levels, for a short period of time only, and when the mass of detritus is of less importance than the huge volume of water.

In dealing with the effects of the disturbance due to removal of sand or gravel, we will assume that the weir is movable, as this is the more general case; we must first enquire the amount or size of the detritus retained in the dam or barrage in one year.

Let us apply the following method.

Let the state 1 again be represented by the curve of detritus volumes $[M]_1=[\phi_2(h)]_1$ and the curve of the duration of the detritus volumes by $[M]_1=[\phi_6(h)]_1$.

In addition, let the absolute damming limit be the water level h_o, then the level h_u may be found from the known curve of the water volumes $[Q]_1 = [\phi_1(h)]_1$ corresponding to the water capacity $Q_{1\,max.}$ of the channel. Then the movable weir will be completely closed at all water levels lower than the water level h_u, and no detritus can reach the " withdrawing " stretch of the river. On the other hand, the weir must be completely opened at all water levels, exceeding the level h_o, and state 1 maintained for the upper stretch of the river. The conditions are expressed graphically in Fig. 7, thus: for state 2 of the cross section at the end of the stowing

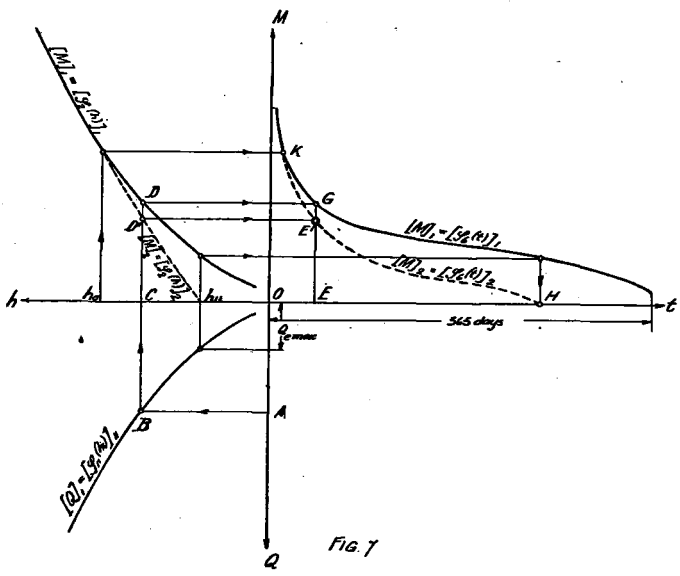


FIG. 7

volume the curve of detritus volumes assumes the form $[M]_2 = [\phi_2(h)]_2$.

This makes it possible to transform the curve of the detritus duration $[M]_1 = [\phi_6(h)]_1$ which is known, into that for state 2, considering that at equal volumes of the flow in states 1 and 2, on account of the change of the curve of detritus volumes from $[M]_1 = [\phi_2(h)]_1$ to $[M]_2 = [\phi_2(h)]_2$, the detritus quantity withdrawn from the river sinks from CD to CD¹. Since both quantities have an equal duration, *viz.*, OE days, it is possible to determine a point E¹ of the detritus duration with the help of the lines A, B, C, D, G, E and D¹ and E¹.

The new duration curve is limited by the points K and H, corresponding to the dammed level h_o and h_u respectively when the weir must be closed. The area closed by both the duration curves gives, upon rectifying the scale, by planimetration the weight of detritus $\Delta = [F]_1 - [F]_2$ retained in the particular year in the dammed volume.

The dammed volume situated up the river effects therefore a partial removal of sand of quantity ΔF and thereby causes a deficit of an equal quantity of the mass of detritus that existed before in the withdrawing stretch. The dragging energy of the water entering the withdrawing stretch is therefore not completely used by the detritus transported there, and therefore the flow of water must carry away material from the bed until the degree of saturation is reached again. The latter requires, however, an annual mass of detritus $[F]_1$, and for this reason the erosion in one year in the withdrawing stretch will amount to $\Delta F = [F]_1 - [F]_2$.

The removal of the sand, therefore, causes erosion in the " withdrawing stretch " and a deepening of the bed of the river.

It follows from this in conjunction with the conclusions of section C, that the influence of a dammed section, in so far as it has any effect in the section considered, has an effect in the same direction in both respects, *i.e.*, both influences cause a deepening of the river bed.

(*e*) *Counter measures against transformation of the river bottom.*

The diverse effects caused by any particular artificial means employed, may be used during the construction as counter measures to reduce the transformation of the river bottom to a minimum. If in this way the tendency to add ground (elevation), caused by withdrawing water, and the tendency to remove it, caused by a narrowing of the river bed are investigated in conjunction with one another, then a correct calculation will make it possible to stabilise the bottom.

The extent to which the narrowing may be carried is limited by the condition that the withdrawal stretch must be able to carry the same mass of detritus as at state 1, the position of the river bottom being unchanged. But, as we found in section 1*a*, $F = \phi_7 (\Delta F)$, we are able to find the required narrowing ΔF for any annual mass of detritus and thus to solve the question of the size of the narrowing.

In a similar way the deepening effect of the withdrawal of sand

and the raising effect of enlarging the cross section can be used one against the other to retain the equilibrium in a river stretch below the dammed volume.

The calculation of the amount of the enlargement is analogous to that described above.

The deepening effect of the removal of sand might possibly be equalised by an artificial addition of detritus or gravel obtained either out of the dammed space or from the river bank. The amount of the gravel required to be added depends on the quantity of sand removed, ΔF calculated in the section 1*d*. It is necessary to mention that in the case of artificial addition of material, especially it if comes out of old gravel layers the composition of such material must be of the right kind, and on the other hand, where material is removed from deposits in dammed spaces, the cessation of the rubbing off of the detritus must be taken into account.

II. CALCULATIONS CONCERNING THE TRANSFORMATION OF THE RIVER BED.

Before the problems can be solved in connection with the transformations of the bed of the river as they actually occur in practice, it is necessary to finish the reply to the question which all these problems have in common.

How does the annual mass of detritus for a given cross section vary with the variation of the fall of the water level from $[1]_1$ to $[1]_2$?

This calculation can be made quite generally, if the relation between the water level and the mean water velocity at the bottom, *i.e.*, $U_s=\phi_3(h)$ is known.

If at state 1, with a fall of level $[1]_1$

$$[U_s]_1=k\,H_m^{\frac{1}{3}}[I]_1^{\frac{1}{2}}$$

then at state 2, where the depth of the water remains the same, H_m, but the fall has changed to $[I]_2$

$$[U_s]_2=k\,H_m^{\frac{1}{3}}[I]_2^{\frac{1}{2}}$$

therefore

$$[U_s]_2=[U_s]_1\frac{[I]_2^{\frac{1}{2}}}{[I]_1^{\frac{1}{2}}}$$

and it is possible to find out from this equation the U_s corresponding to every U_s of states 1, 2, 3, etc., assuming an equal mean water depth, that is, the same water level.

Since $[M]_1=[\phi_2(h)]_1$ and $[M]_1=[\phi_6(t)]_1$ are now also known, we can, assuming that at equal bottom velocity, and unchanged cross section the same quantities of detritus will be transported, calculate the changed curves of detritus durations point by point, with the

help of the line $A\text{-}A_1\text{-}B_1\text{-}C_1$, $A\text{-}A_2\text{-}B_2$, C_2 and $A\text{-}A_3$, $B_3\text{-}C_3$ for states 2, 3, etc.

We obtain the changed masses of detritus $[F]_2$, $[F]_3$, etc., for the new falls of level $[I]_2$, $[I]_3$, etc., by planimetring the surfaces of the curves of duration.

This simple method leads finally to the required relation between the mass of detritus and the fall of the level and of the bottom, a relation $F=\phi_9\ (I)$ that can be best represented graphically as shown in Fig. 8.

We will now proceed to deal with the investigations as to the amount or extent of the transformations that must be expected

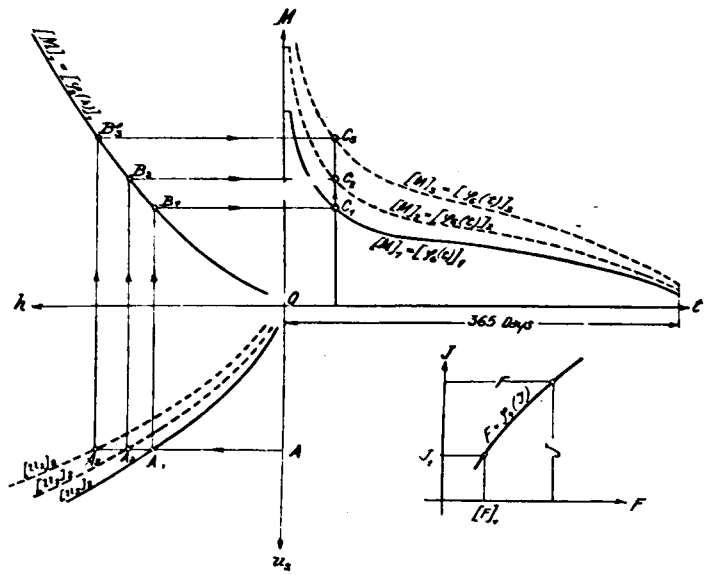


Fig. 8.

to be brought about by the factors enumerated under a, b, c and d on page 2, and which we will discuss in that order.

(*a*) *Transformation caused by narrowing or widening the river bed.*

As has already been explained in paragraph 1e, the narrowing or widening of the river bed can be considered in this case only as a counter measure. In future, the engineer who designs a water power installation will have to provide measures against the injurious effects of withdrawing water, storing water and removing sand in his original designs; any narrowing or widening of the

cross section are likely to be of greatest importance in this connection.

The transformations that have actually occurred in river beds, narrowed or widened for regulation purposes, are evidence of the possibility of substantially influencing the detritus transport by form alterations of the cross section.

We have a very striking example of this in the Isar in Bavaria, which was narrowed by means of new regulation works from the former normal width of 73 m. to 43·8 m. in the period 1862-1879. As reported in the publication "Wasserbau im Königreiche Bayern," deepenings of the bottom down to 4·5 m. were noticeable below

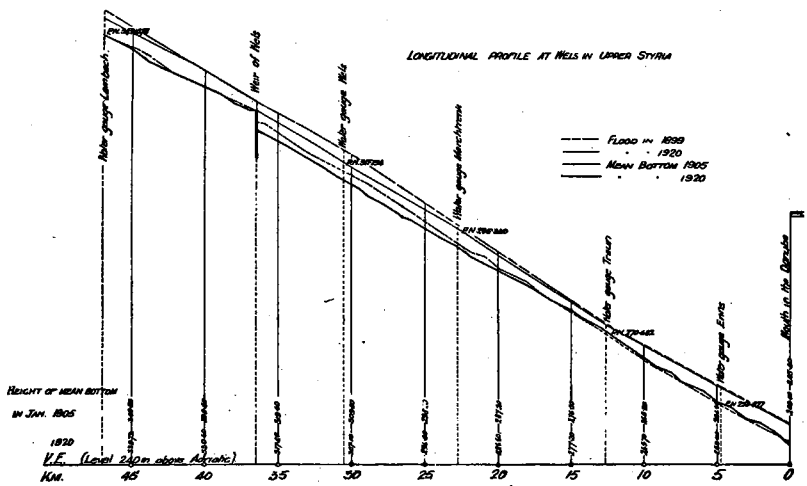


Fig. 9

Munich, and the relative fall was reduced from 2·6 per cent. to 2·08 per cent. Later on the normal width was raised again to 60 m., a measure which became indispensable in consequence of the reduction of the bottom width from 35 m. to 27·9 m.

The river Traun, in Upper Austria, in the territory of the city of Wels, shows this kind of transformation in an especially instructive manner. Here, the deepening, if not entirely, at any rate for the most part, was caused by restricting the section of the high water bed.

The longitudinal section (Fig. 9) shows a reduction of the relative fall from 2·13 per cent. to 2·00 per cent., that occurred in the period 1905-1920, when deepenings down to 2·17 m. were produced below the weir of Wels.

(*b*) *Transformations caused by the withdrawal of water for a water power plant.*

The considerations set out in paragraph 1b have enabled us to ascertain the mass of the detritus ΔF that will be deposited in the river bed in consequence of water being withdrawn freely without a weir.

This process of alluvial deposit will go on until a new state of equilibrium of the river bottom is formed; this will be the case when the mass of detritus transported into the withdrawal stretch can be carried down this river stretch without leaving any behind. This will happen when the relative fall of the river bottom and consequently of the water level is sufficiently raised to be able to carry the mass of detritus $[F]$ from the upper river to the lower river.

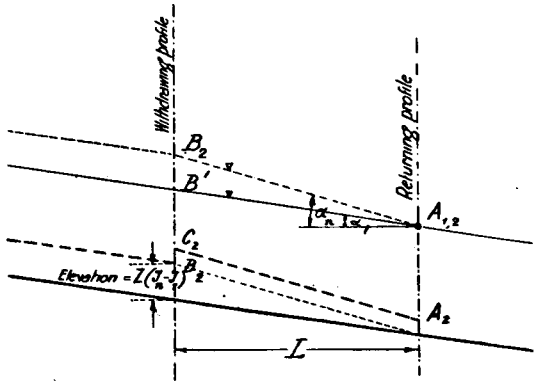


Fig 10.

The solution of the problem will, therefore, amount to ascertaining the alteration of the mass of detritus with changing relative falls of the water level; this preparatory work was indicated in the introduction to section 2.

The graphical representation (Fig. 7) of the relation $F=\phi_9(I)$ enables us to ascertain immediately the fall of the water level for any mass of detritus, if the relation was found when $[M]_1=[\phi_6(t)]_1$ and $[F]$ represents in this figure the curve of duration of detritus volumes or the mass in the withdrawal stretch after the withdrawal of water, but before the transformation of the river bottom.

If the new equilibrium fall, resulting therefrom, $I=tg\alpha_n$ we can immediately ascertain the new position of the bottom.

If we take as the basis of our examination any water level at state 1 (in Fig. 10 the bottom for state 1 is drawn thick and continuous, and the water level fine and continuous), then for state 2, the level

of the new equilibrium state, rising under the fall J_n, or under the angle of incidence α_n, must equal the water level down river which has remained unchanged at the point $A_{1,2}$ of the return profile.

The water level for state 2 (in Fig. 10 indicated by fine dotted line), takes, therefore, the position $A_{1,2}$—B_2, while the river bottom for state 2, in the withdrawal stretch parallel to $A_{1,2}$—B_2, *i.e.*, in the position A_2—C_2 will close up or join at the point B_2 parallel to the bottom line of state 1. The rising amounts, therefore, in the upper part of the river, after the new stable state has been reached, to

$$L\ (tg\alpha_n - tg\alpha_1) = L\ (I_n - I_1)$$

if $I_1 = tg\alpha_1$ represents the original balanced fall of the river.

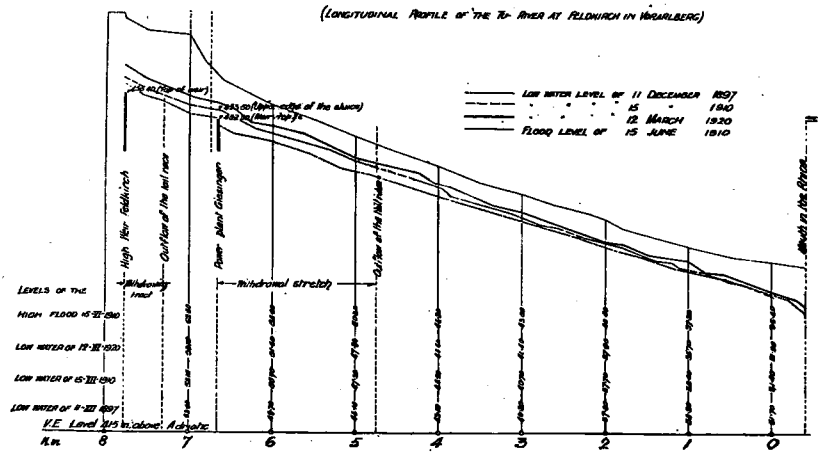


Fig 11

It is seen, therefore, that withdrawal of water causes a permanent elevation of the bottom in the river stretch above the free water catch which also amounts to $L(I_n - I_1)$.

As a further consideration shows, the new position of the bottom in the withdrawal stretches is not permanently stable, but oscillates around a mean position, corresponding to the position of equilibrium at the water level that forms the river bed.

To illustrate the extent of the deformation of the river bottom that may be caused by a considerable withdrawal of water, we would point out the development of the bottom of the river Ill, at Vorarlberg.[1]

[1] See : Ph. Kraph " Regelung der Ill unterhalb Feldkirch und Untersuchungen über den Einfluss des Wasserentzuges auf die Geschiebebewegung " Wochenschrift für den öffentlichen Baudienst 1919, Heft 43.

The water withdrawal for the water power plants of Foldkirch, and also for Giesingen (Fig. 11), situated below amounts permanently to 20 m^3/sec., *i.e.*, nearly 30 per cent. of the mean water flow of the river Ill, and the detritus deposits in the withdrawal stretches (that are almost adjoining) of the two plants have attained a very considerable extent, the more so as these deposits were especially favoured by the abnormally strong gravel transports from tributaries and from the upper part of the river Ill itself.

As shown in the Fig. 11, where the increase of the choking in the single periods can be clearly recognised, the rising amounted in 1922 at the weir of the electricity works at Giesingen to 2·80 m., so that the top timber of this weir has already been completely choked.

(*c*) *Transformations in consequence of the equalisation of water volumes.*

The solution in the case of equalisation is quite similar to that when water is withdrawn. In this case also the curve of duration of detritus volumes for different falls $[I_1]$, $[I]_3$, etc., after the water has been withdrawn, will be transformed, and out of this the relation $F=\phi_9\ (I)$ necessary for the further procedure will be obtained. Since, in the present case also, the new state of equilibrium is only attained when the carrying of the detritus has become continuous and, therefore, the relative fall of the water level has been reduced to such an extent that the detritus of state 1 of the upper part of the river only passes the withdrawal point, it is possible to ascertain the fall $I_n=tan\ \alpha_n$ corresponding to state 1 of the upper current, from the relation mentioned above.

An application of this result to a particular stretch of the river has only a practical importance, if the bottom of that stretch is fixed at the beginning and the end as might be done by artificial beds or is sometimes naturally effected by rock. If this were not the case, the deepening would have to continue in an equal measure, at least theoretically, *ad infinitum*, as the natural disintegration of the detritus is of no importance for shorter stretches and was not taken into consideration in the above statements.

If therefore the practical problem is to ascertain the transformation of a river with solid bed, then, as is shown in Fig. 12, the measure of the deepening after reaching the new state of equilibrium below the solid bed, will be seen by duly applying the considerations made in section 11b to the present case.

$$L\ (tan\ \alpha_1 - tan\ \alpha_n) + a = L\ (I_1 - I_n) + a.$$

The measure $A_1 A_2$, means here, the difference between the water depths $A_2 A_{1,2}$ and $A A^1_{1,2}$, resulting at the equal water flow, but at different relative falls I_n and I_1.

Since, however, the differences of the relative fall will not in actual cases be considerable, the value a in this equation can for practical purposes be taken as O, and therefore the deepening in a river stretch of length L is $L\ (I_1 - I_n)$.

(*d*) *Transformations caused by detritus retained by interposed barrages or dams.*

On the same assumptions as made in chapter 1b, *i.e.*, that only the removal of the sand, but not the equalisation of the water flow will have an appreciable effect, the following must be considered when calculating the transformation.

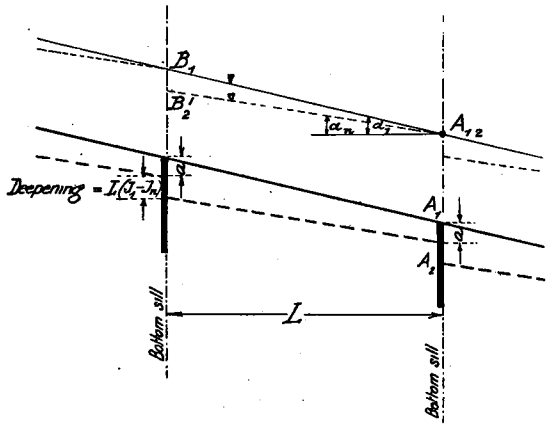


Fig. 12.

If the sand has not completely been removed but only as much as is expressed by ΔF, the adjoining river section has to carry the mass of detritus that has come from up river $[F]_1 - \Delta F = [F]_2$. For this mass $[F]_2$, the equilibrium fall I_n can be found by the method explained under IIc, and thereby also the position of the new bottom between the barrage of the storing volume and the next fixed point of the bottom down river. The procedure is similar to that given in IIc.

If the whole of the sand, however, has been removed, this procedure is no longer applicable, which would also be the case where the removal of sand or gravel ΔF, is relatively considerable, for a new circumstance will appear with the reduction of the fall J to the fall

J_n, and will be decisive for the transformation of the bottom. This is, as suggested by observation and confirmed by experiment, the " self-paving " of the river bottom.

The deepening will go on only until the big pieces contained in the mixed detritus, which gradually collect at the surface of the river bottom, as the smaller detritus is washed away, form a natural protecting cover against further erosion. As experiments in artificial channels have shown, there exists for every mixture of detritus a certain bottom velocity which may be called the " critical " velocity that must not be exceeded if the " pavement " of the river bottom with the biggest gravel pieces contained in the mixture, is to remain stable.[1]

If, therefore, that critical velocity for the detritus mixture of the particular river stretch is $U_{s,k}$ then, as the equation $U_{s,k}=k\,(H_m I_n)^{\alpha}$ is of general application the fall of equilibrium is

$$I_n=\frac{1}{H_m}\left(\frac{U_{sk}}{K}\right)^{\frac{2}{\alpha}}$$

where H_m—if it is intended to go to the extreme position of rest—is the mean water depth that will obtain at the highest flood.

If that flood is Q_{kH} and the corresponding width of the river B, then if c is the co-efficient of roughness according to Kutter

$$Q_{kH}=c\,(H_m I_n)^{0.5}\,H_m B$$

The two equations combined finally give

$$I_k=\frac{cB}{Q_{kH}}\left(\frac{U_{sk}}{K}\right)^{\frac{3}{2\alpha}}$$

where for summary calculations

$$C=30,\ \alpha=0.5 \text{ and } K=20,$$

and we obtain

$$I_n=\frac{30B}{Q_{kH}}\left(\frac{U_{sk}}{20}\right)^{3}$$

At a partial removal of sand, therefore, that result of the two methods mentioned will be nearest to the natural process that gives the smaller I_n.

As an example of the removal of sand, as well as its effect on the adjoining river stretch, we may mention the damming reservoir at Reichenhall in Bavaria and the Saalach river to which its influence extends.

[1] On the determination of the critical velocity see : F. Schaffernak : " New principles for calculating the transport of detritus."

In Fig. 13, the advance of the alluvial deposit in the storage volume and, therefore, the extent of the removal of sand is shown. As will be seen from the cross sections drawn, it amounted for the

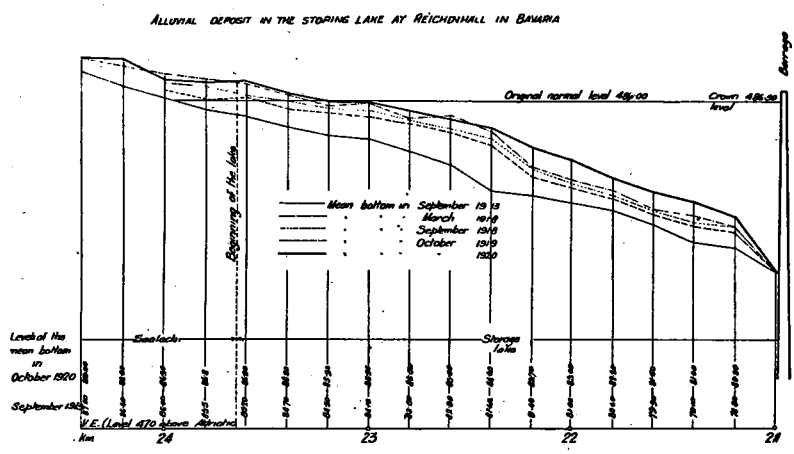


FIG 13

period from September, 1913, until March, 1918, to 956,000 m³, and from March, 1918, until October, 1920, to 629,000 m³.

As a consequence of this ungravelling, there appeared—and is still on the increase—a deepening in the following section of the

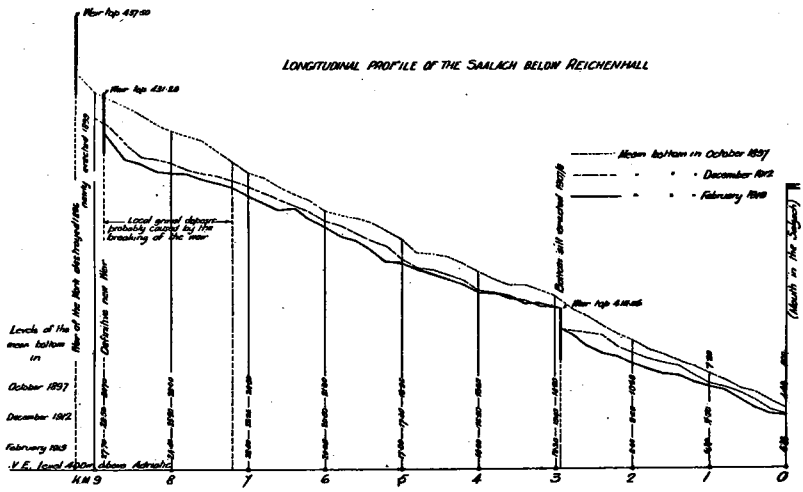


Fig. 14.

Saalach which has a fixed bed as well as by the position of the bed and the water level of the Salzach in the region of the estuary (See Fig. 14).

In the observation period 1897-1919 the maximum deepening of the bottom, partly caused by the narrowing of the river bed, was 3.60 m. The relative fall has diminished in the same period from 2.75 per cent. to 2.40 per cent.

RÉSUMÉ.

L'influence exercée sur le régime des eaux par la construction de grandes Stations Centrales Hydrauliques a amené des variations dans l'état d'équilibre existant dans le fonds des rivières sous la forme d'élévation et d'approfondissement. On rencontre particulièrement les effets suivants :—

(*a*). Un rétrécissement ou un élargissement du lit d'une rivière produit un approfondissement ou une élévation.
(*b*). Une prise d'eau faite sur la rivière principale produit une élévation.
(*c*). Une égalisation des volumes d'eau produit un approfondissement, et
(*d*). l'enlèvement de sable produit un approfondissement du fond de la section adjacente de la rivière.

Comme mesures en vue d'empêcher l'élévation causée par le retrait d'un certain volume d'eau, un rétrécissement peut être appliqué jusqu'à une limite où les deux variations, agissant dans des directions opposées, se compensent mutuellement l'une l'autre.

Les exemples de la nature qui sont mentionnés dans le rapport indiquent le danger d'une nouvelle période de transformation de nos cours d'eau, si les résultats de l'examen de l'influence que la construction des Stations Centrales Hydrauliques exerce sur le régime des rivières continuent à être négligés, alors les effets des mesures adoptées à grands frais pour la régularisation des rivières pourraient devenir fortement négatifs.

Tout Gouvernement qui a soin de l'avenir, devrait en conséquence, insister sur une investigation approfondie de toutes les circonstances matérielles auxquelles nous nous sommes référés lorsque les projets de stations Centrales d'assez grande importance sont préparés.

RIVERS AS FACTORS OF ENERGY

ING. EDUARD SUESS

Water turbines are used for utilising the water power contained in the energy of river currents and the like. Up to now this water power has practically not been utilised at all, although it is far more powerful than any other water power which is at our disposal.

No doubt it would be wrong to try to utilise completely the energy of the current of rivers, but even if we could utilise only 10 per cent. of the water power, we should have many thousands of horse power at our disposal. Such a utilisation would raise the water surface of the river only very slightly, and the depth of the water would be increased by about 5 per cent. only. However, with the present scarcity of coal, the results are of considerable consequence and the interest already taken in water turbines is quite justified.

In order to be fully appreciated the water turbine should be compared with the wind motor, as both have a great deal in common. The specific gravity of water is about 800 times as great as that of air, and therefore the water turbine, at the same speed of the driving medium, will require a cross-sectional surface which is about 800 times smaller than that of the wind motor of the same efficiency. Thus, compared with the wind motor, its diameter will be about

$$\sqrt{800} = 28{\cdot}3$$

times smaller, and its revolutions 28·3 times greater. The advantages represented by these few figures are quite obvious. The wind motors, particularly wind-electric plants, have proved their right of existence, and the water turbine will also prove to be of the greatest economical importance, as many of the difficulties have been considerably mitigated, such as the inconstancy of the driving medium and the great fluctuations in the strength of the current.

Tests to utilise the energy of the current of a river have been made for some considerable time. With the exception of the well-known ship-mills, all other constructions had for their object the utilisation of the energy of the current by means of a propeller-shaped rotary

wheel. The latter was encased in order to increase the effect. Sometimes the casing was enlarged to form a funnel in front of the wheel, in order to produce a suitable " dam " effect.

However none of these constructions produced the desired effect, as they failed in consequence of their very small efficiency.

In order to increase the efficiency, tests were made with a new kind of water turbine (British Patent No. 192396, SUESS), and by this it has been possible actually to increase the efficiency in such a manner, that to-day water turbines can be built with the certainty of a complete economical success. The new result is obtained

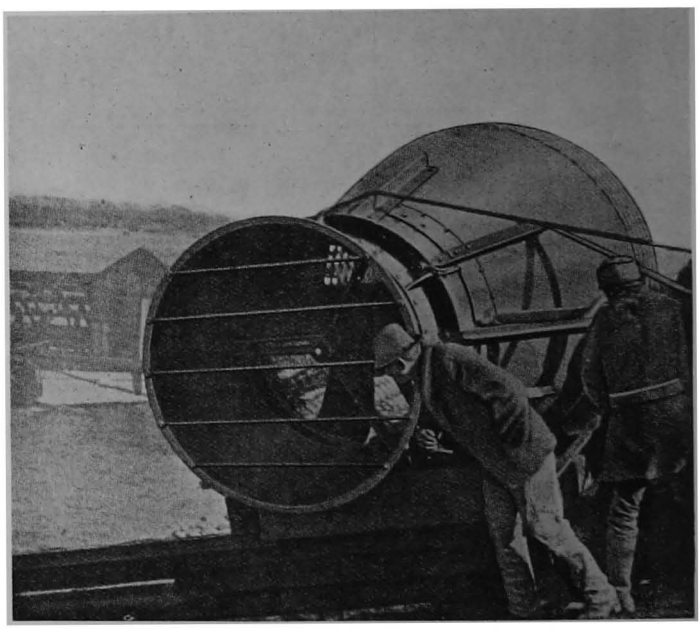


Fig. 1.

by arranging that the turbine (Fig. 1) is moored with the small inlet toward the current, and the water, setting the propeller into rotation, leaves the turbine slowly at the larger outlet of the casing.

Fig. 2 illustrates such a water turbine diagrammatically and in longitudinal section. The supporting cross, located on the admission side, carries the rotary wheel arrangement. The paddles of the wheel are mounted on a drum, which is reduced or tapered off toward the rear end in accordance with the hydraulically favourable shape of a drop. The water turbine is secured to a support,

connected to convenient floats, and its power is delivered by means of a chain-drive, which runs in protective pipes, and is a normal means of transmission.

In order to give an idea of the effect, the dynamic power N, which is to be expected per square metre of the propeller surface (the diameter of the propeller D = 1130 millimetres), has been shown in the diagram (Fig. 3) plotted against the current speed c of the river. As indicated in the diagram, the effect increases very rapidly with the increasing speed of the current.

For instance, if the speed of the current of a river is 3 metres per second and if we require 20 horse power, the diagram will show that

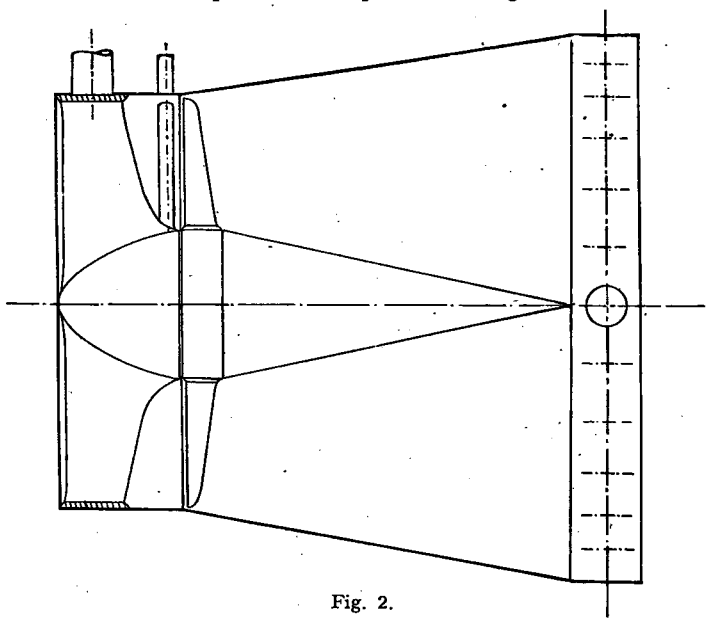


Fig. 2.

an effect of 11·7 horse power is obtained per square metre of the propeller surface. Therefore the necessary propeller surface amounts to

$$F = \frac{20}{11{\cdot}7} = 1{\cdot}7 \text{ square metres}$$

according to a propeller diameter.

$$D = \sqrt{\frac{4 \times 1{\cdot}7}{3{\cdot}14}} = 1{\cdot}47 \text{ or about } 1{\cdot}5 \text{ metres.}$$

In order to judge the economy we will compare it with the power produced by a wind turbine (Fig. 4). This diagram (taken from

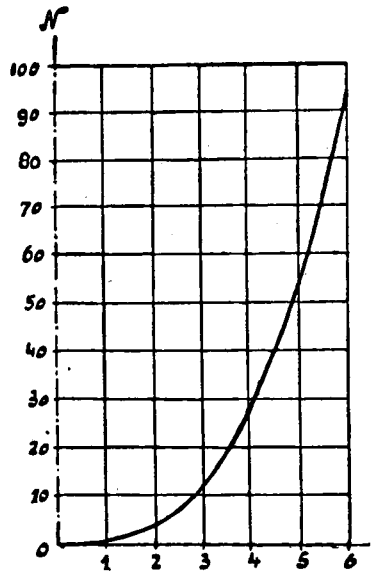


Fig. 3.

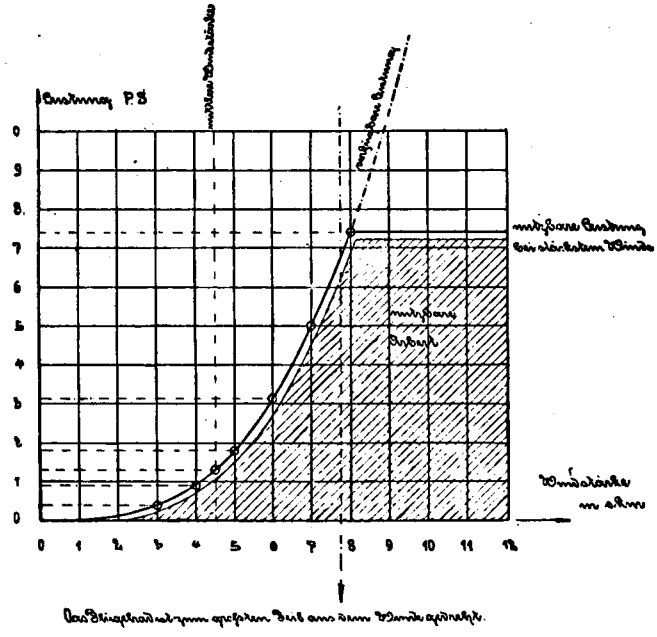


Fig. 4.

the book " STERTZ, Moderne Windturbinen ") is for a wheel diameter D = 6,500 millimetres and the efficiency is plotted against the speed of the wind blowing at the time. For instance if the speed of the wind c = 5 metres per second, the wind turbine will have an efficiency

N = 1·8 horse power.

When comparing these diagrams, the similar behaviour of both power engines will be clearly visible, as the efficiency N rapidly increases. Therefore, the economical efficiency of the water turbine will increase with the greater speed of the current of the river.

It is pointed out that, compared with the power produced by known water turbines, this efficiency may be considered as very moderate at first sight, but it ought not to be forgotten, that the energy of the current of the river is far from being exhausted as a utilisation cross-section of 1·7 square metres, as many such plants may be arranged in the river side by side or the one behind the other, which together yield a very considerable power.

There can be no doubt about the economy of the water turbine of the new design if we consider that, even to-day, an economically working steam engine requires about 1 kg. of coal for one horse power per hour, which means an annual consumption of 8,700 kg.

It would be an excellent thing, and certainly also of great economical value, if by proper exploitation of water turbines by the authorities and interested parties, they could be used on a large scale.

RÉSUMÉ.

Les turbines à courant d'eau ont pour but d'utiliser l'énergie représentée par le courant des fleuves ou rivières, énergie que l'on n'a pas réussi à utiliser systématiquement jusqu'à ce jour, bien qu'elle soit beaucoup plus grande que les autres forces hydrauliques dont nous disposons.

Une comparaison entre la turbine à courant d'eau et la turbine à vent montre que la première est beaucoup plus avantageuse que la seconde ; à vitesses égales du courant de l'agent moteur, le diamètre de la turbine à courant d'eau est plus petit et son nombre de tours plus grand que ceux d'une turbine à vent.

Les turbines à courant d'eau, réalisées jusqu'à ce jour n'ont donné, il est vrai, qu'un rendement médiocre. Ce n'est que par une nouvelle construction des turbines à courant d'eau (brevet anglais No. 192396 Suess) qu'on a réussi à réaliser un rendement suffisant et cela grâce à une forme particulière de l'enveloppe de la turbine et à une disposition nouvelle du rotor dans cette enveloppe.

Quoique la puissance développée par une seule turbine ne soit pas très grande, il faut tenir compte du fait qu'en disposant un nombre suffisant de turbines semblables l'une à côté de l'autre ou en série le long du fleuve on peut produire éventuellement des puissances très considérables.

THE GENERATION OF HYDRO-ELECTRIC POWER IN CANADA

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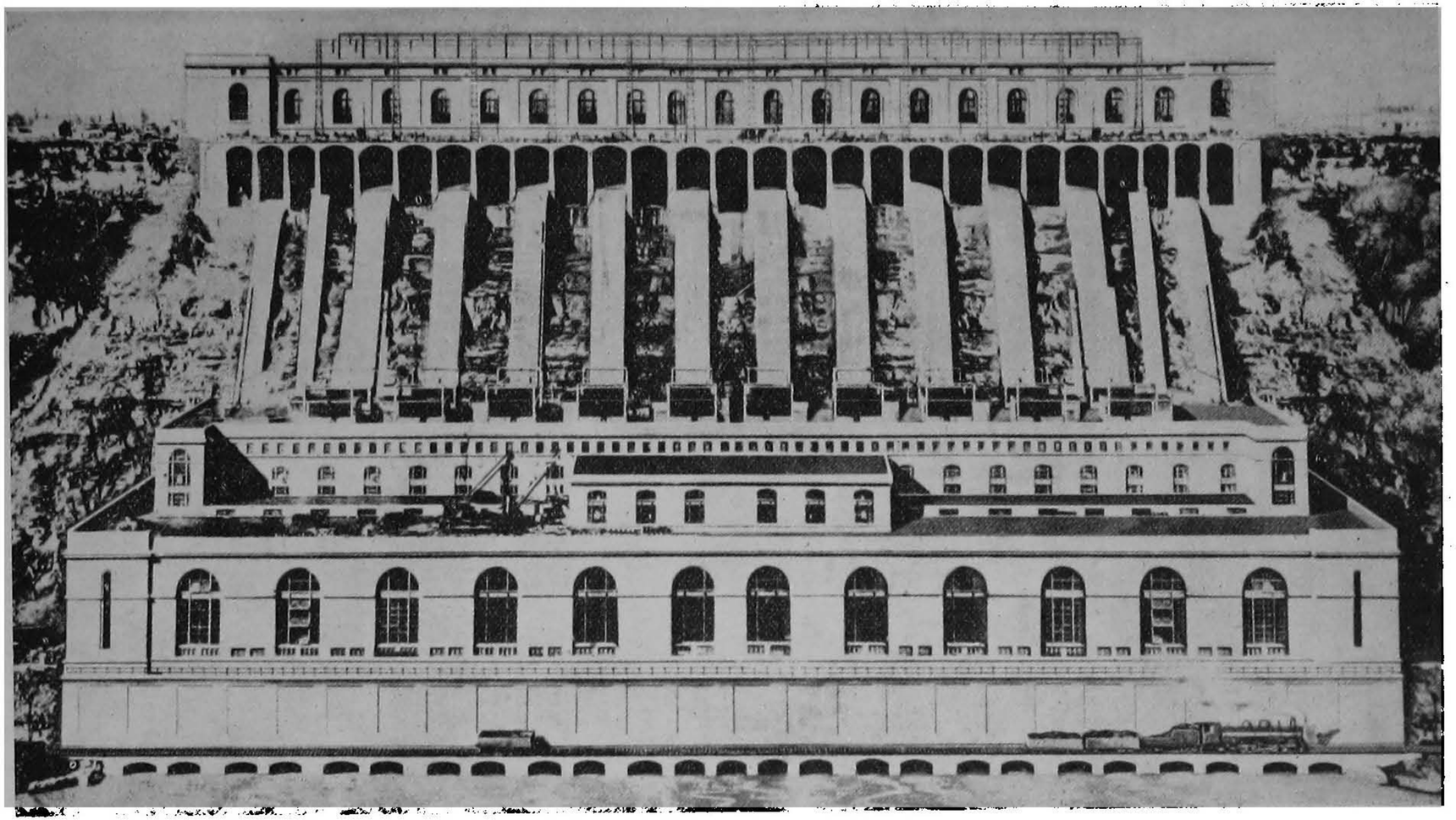


 Frontispiece] A Canadian Power Development of 600,000 E.H.P. Ultimate Installed Capacity.

INTRODUCTORY.

In common with all other countries possessing potential water-power resources, the nature, extent and utility of Canadian water-power is primarily the outgrowth of the purely climatic factors of temperature and precipitation, associated, necessarily, with the topographical frame-work of the North American continent.

Extending as it does from the Atlantic to the Pacific Ocean, and from the temperate zone to beyond the Arctic Circle, Canada embraces all phases of the temperature factor except the tropical and sub-tropical. As regards precipitation, also, the range of variation is great, with an approximate average range of 60 to 80 inches per annum on the Pacific Coast, 40 to 55 inches on the Atlantic Coast, 25 to 35 inches in Central Canada, to as low as 20 to 25 inches on the mid-western plains. Governed by the third factor of the continental topography, Canada has turbulent rivers heading in the high peaks of the Rocky Mountains; huge rivers flowing off the immense central table-land of the mid-west and the Great Lakes basin; and eastward to the Atlantic Coast, a multitude of waterways, large and small, draining the slopes of the Laurentian Hills, and maintained and regulated by countless lake expansions, many of which have areas ranging from 50 to 1,500 square miles.

It is not within the scope of this discussion to enlarge upon the incentive toward water-power development which has existed in Canada by reason of a growing industrial demand and a great variety of natural commodity resources, but granting that such incentive has been, and still is, in existence, it is evident, from the general specification above outlined, that Canada must of necessity possess water-power resources so great in magnitude and so diverse in type as to afford the widest possible scope for engineering accomplishment and initiative, in the matter of their proper and efficient development and utilization. Furthermore, the development and utilization of Canada's water-power resources has been in progress for a great many years, and it would probably be irrelevant and certainly far beyond the reasonable limits of this discussion, to enter into any extended and more or less historical review of the progress of such development in its co-related engineering and industrial phases. It would seem expedient, therefore, to assume a date at which hydro-*electric* power development, in a *modern* sense, had its inception in Canada, and from that point to trace the general progress of the

art up to the present time, stressing only those phases of the evolutionary process, as governed by primary natural limitations and requirements, which have given Canadian practice a more or less distinct identity. " Canadian practice " might, of course, be more appropriately called " American practice," as the progress of the art in Canada and the United States has been in a large measure contemporaneous, due to the similarity of the primary conditions governing its evolution.

The history of modern Canadian hydro-electric practice may be said to have had its genesis in 1905 when three vertical turbines, of Swiss design and manufacture, were placed in operation at Niagara Falls. These units were of 10,000 h.p. capacity each, and were the largest ever installed up to that time. Following closely on this event, there was installed at Shawinigan Falls a 10,000 h.p. horizontal turbine of American design and manufacture; then again at Niagara Falls a group of 10,000 h.p. horizontal turbines of German design and manufacture; and shortly thereafter at the same point, a group of 12,000 h.p. vertical turbines, designed and built in the United States. The then outstanding characteristic of these turbines was their great power, and since that time the element of " size " has furnished the main key-note for Canadian advancement in hydro-electric power production, in respect of such features as differ from contemporaneous practice elsewhere.

Plate C—1 is a view of the German turbines above mentioned. This view is interesting for two reasons; first, on account of the square section of the scroll-case, and second, from the fact that the radial levers of the gate-operating mechanism are clearly in evidence. These turbines were among the first to be equipped with external gate-rigging, a practice which has now become almost universal.

It is not to be inferred from the above statement that hydro-electric development, as an art, would not have progressed in Canada, or elsewhere, but for the large increase in unit power capacity which was inaugurated at Niagara and Shawinigan eighteen years ago. The point is, that, as the direct producer of the saleable commodity, the turbine became the focal point from which radiated all essential considerations bearing on electrical and structural design, to the end that the turbine might perform its vital function of revenue production with a maximum of efficiency. The natural reaction to this condition was to throw into conspicuous relief the shortcomings and imperfections of

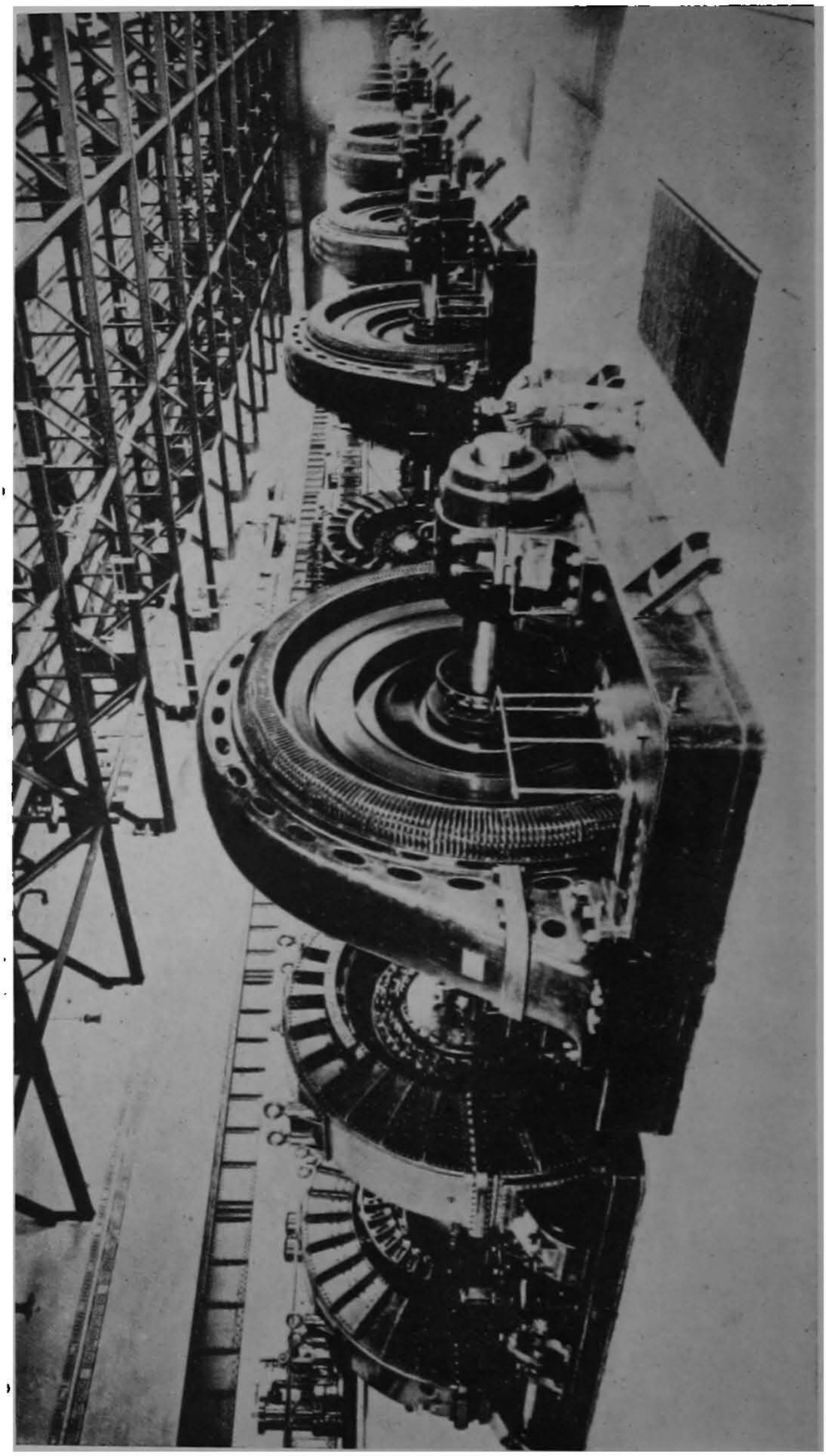


Plate C-1.—Early installation of large capacity turbines.

the turbine mechanism itself, and to force engineering thought into channels leading not only to the refinement and simplification of then existing standards of design, but to the creation of mechanisms having inherently new and improved characteristics. These improvements and innovations having, therefore, been devised, from time to time, to keep pace with the special need arising out of heavy investment in large turbines, it was a simple matter, in most cases, to apply these improvements down, as well as up, in the scale of unit turbine capacity, so that Canadian turbine practice, as a whole, received ultimately the benefit of an advance in the art which originally grew from the demand for turbines of larger unit capacity than had originally been called for elsewhere.

Before enlarging upon the various phases of modern hydro-electric practice to which the above general observations are applicable, it may be well to state that, particularly as regards turbine and electric machinery, it is not the intention to view the situation from the standpoint of the specialist in any one branch of the art, but rather from the standpoint of one who has had sufficient experience in hydro-electric design, construction, installation and operation to weigh intelligently the present status and future trend of the evolutionary process leading to the ultimate of plant efficiency; this latter being a general term including all of the integral elements of stability, simplification, elimination of losses and reduction of unit costs.

The maximum of hydraulic efficiency is realized when the passage of water, from the point of initial intake to the final point of disposal in the tail-race, is accomplished with a minimum of turbulence and distortion. This provision may or may not result in a maximum of unit cost efficiency, and between these two limits lies a world of compromise which precludes any possibility of fixing the precise meaning of " efficiency " by definition. Efficiency, in the broadest sense, results from the proper co-ordination of simplicity and strength in all hydraulic design.

Simplicity in design is of primary importance. The laws of nature function changelessly and with immutable precision by reason, mainly, of their simplicity, and in no branch of engineering is conformity and obedience to the laws and forces of nature a more vital element of design than in power plant construction.

Strength involves all features of design having to do with the stability and security of structures against the action of the

elements, more particularly fire and water, and also shares with simplicity the responsibility for the dependable, precise and unfailing operation of valves, turbines, governors and other mechanical apparatus.

The above generalizations are fundamental, and all the important elements of hydraulic design should conform to them to the greatest possible degree.

It is the intention, if possible, to fix the present status of Canadian practice from this viewpoint.

FEATURES OF PRESENT DAY PRACTICE.

Under this head will be considered various features of Canadian hydro-electric practice, many of which have actually originated in Canada, and do not yet appear to be known, or to have found general acceptance among European designers and builders.

These features fall for the most part under the following headings;—

(1) Waterway Entrance Structures.
(2) Open Waterways.
(3) Long Pipe-lines.
(4) Forebay Structures.
(5) Penstocks.
(6) Penstock Valves.
(7) Governors.
(8) Draft-tubes.
(9) Turbines.
(10) Generators.

In the introductory chapter it was stated that Canada's progress in the hydro-electric art was primarily attributable to certain underlying natural conditions, coupled with a rapidly growing industrial and domestic demand for power. These factors, besides necessitating the development of the " super-turbine " as previously mentioned, also laid upon the power producing corporations a similarly growing obligation to improve service efficiency. One of the outstanding necessities in connection with this latter requirement is to hold the full plant rating continuously available under winter operating conditions. By reason of this fact Canadian practice has attained a certain individuality through the study of the ice problem, as related to successful hydro-electric plant operation under temperatures frequently ranging as low as 40 to 45 degrees (Fahrenheit) below zero.

Dams.—Canadian conditions up to the present time have not given rise to any outstanding features in connection with dam

construction, but in the matter of sluice control, Canadian practice has evidenced a decided reluctance toward the adoption of rolling dams, automatic gates and apparatus of a similar nature which appear to be popular in Europe. Where slow regulation

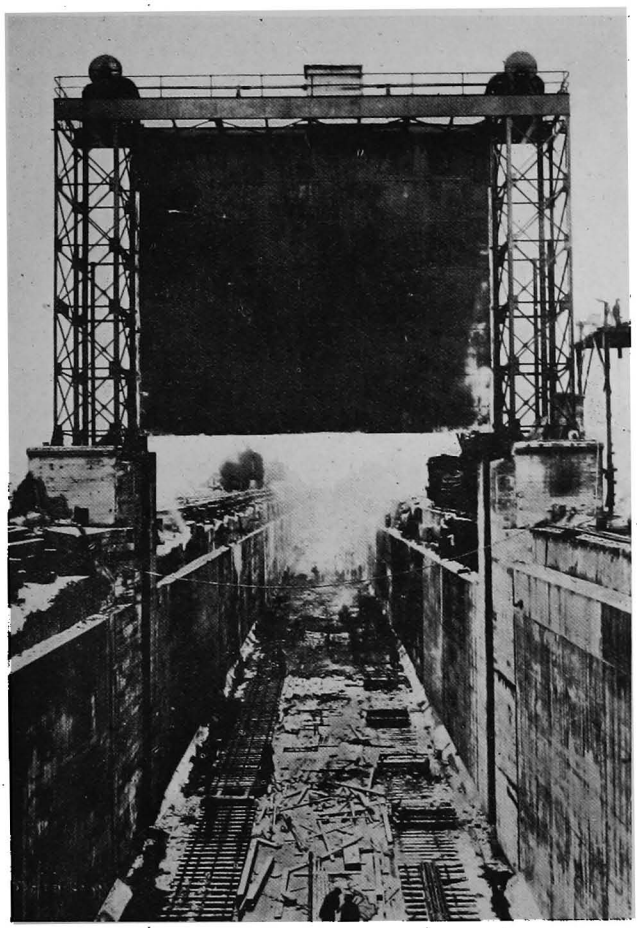


Plate C-2.— Stoney type control gate.

only is required, Canadian practice inclines very largely to the use of the simple stop-gate or stop-log, handled by a mechanically or electrically operated winch. Where frequent and rapid changes in flow conditions are involved, counter-weighted gates of the

Stoney type have an almost universal vogue. In other words, Canadian practice, in this regard, mainly from consideration of winter operating conditions, has leaned toward simplicity and strength, rather than to complexity of design and precise mechanical functioning.

An interesting installation of the Stoney type is shown on Plate C—2. This gate, believed to be the largest of its kind, was designed and built in Canada and entirely controls an ultimate flow of 18,000 second feet in the concrete lined channel in which it is placed. The merit of this single leaf gate is two-fold, in that it obviated a very expensive enlargement in the waterway for the accommodation of piers, while at the same time it saved the head-loss which would have resulted from such enlargement, and from the interposition of the piers.

The structure, as illustrated, has an over-all height of 110 feet and the gate itself weighs approximately 100 tons, being equipped with two hoisting mechanisms and two counter-weights.

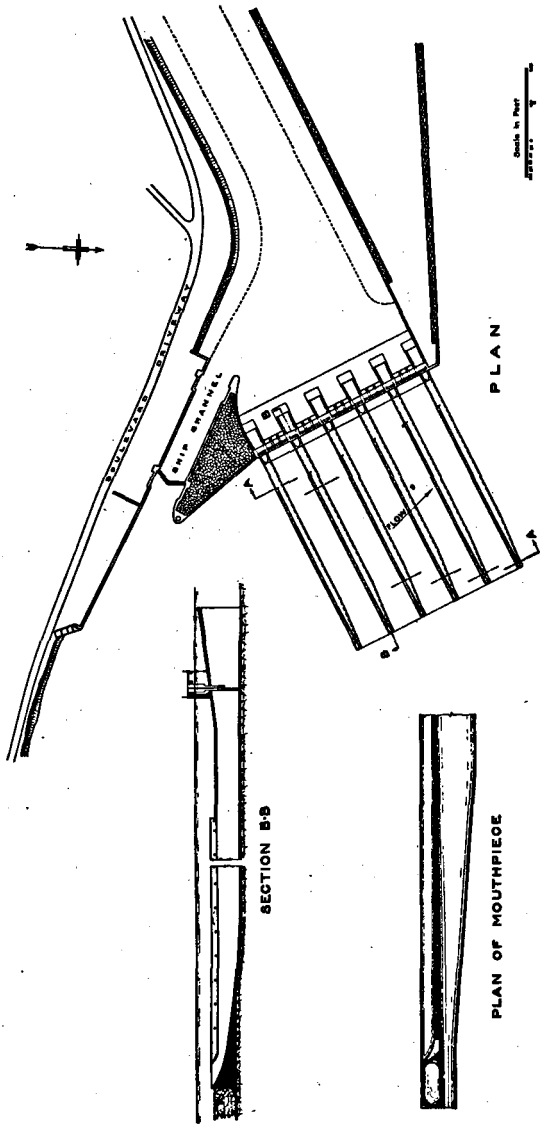
Waterway Entrance Structures.—This term is used to identify structures located at the initial source of the water supply for any hydraulic plant fed through an open canal, pressure tunnel or pressure conduit, and is intended to distinguish such structures from the ordinary forebay and intake structures which are common to all power developments.

In Canadian practice the one controlling factor associated with the design and operation of entrance structures is the protection of the inner system of waterways, whether they be open canals, tunnels or pipe-lines, against the entrance of ice, and, in a secondary degree, of other floating material.

To the above end, the primary general requisite of design for all entrance structures is the fending off of floating matter by an adequate submergence of the entrance passages, coupled with an entrance velocity sufficiently low, not only to prevent vortices, but to be at all times less than the buoyancy impulse of the floating material. The attainment of this objective involves the solution of a complex problem of velocity and draft distribution.

Where the initial source of water supply has an appreciable velocity of its own, any approximation of uniform velocity distribution in the diverted flow through the water passages of the ordinary type of entrance structure is impossible, and any design based on the attainment of such uniformity must inevitably fail. In every such case it will be found that while the average *effective* velocity of entrance may be within the designed limits, there will

PLATE C-3



Waterway entrance structure with gathering tubes.

be regions where the *actual* velocity is so greatly in excess of the assumed average that the structure cannot function according to design, for the two-fold reason that the excessive local velocities destroy the efficacy of the submergence of the entrance passages, and because the resulting turbulence induces hydraulic losses greatly in excess of those calculated from the designed velocity of entrance.

Plate C—3 illustrates the plan of a recent type of entrance structure in which the above elements of design have been very fully developed.

It is evident that the breast-wall portion of this structure is more or less of the conventional type, with rectangular sluice openings controlled by gates, and with deeply submerged curtain-walls.

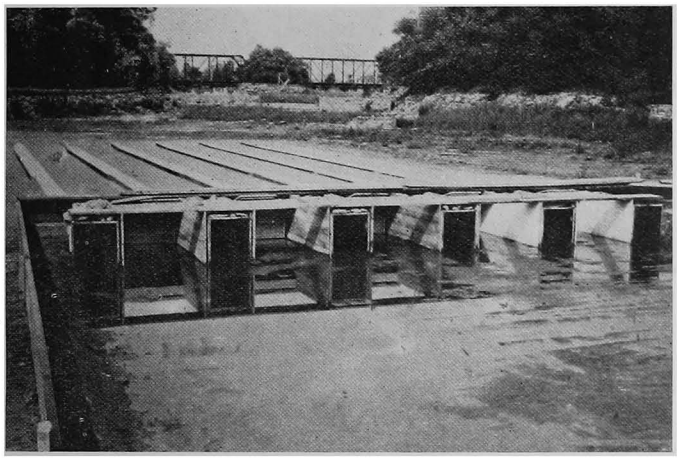
Between each group of three sluice openings, however, will be seen a still more deeply submerged horse-shoe shaped opening through each pier. The transverse and longitudinal sections "A—A" and " B—B " show that each of these openings is connected, within the breast-wall, to a diffuser, and outside to a long, deeply submerged tube. The plan of the mouthpiece of this tube shows a clear opening at the tip, and from this point an additional opening in the form of a longitudinal slot in the top of the tube, of gradually decreasing width, and extending back to within a short distance of the breast-wall.

This tube, known as a " gathering " tube, will deliver 2,500 second feet of water to the mouth of the diffuser with a total head-loss of about four inches. In other words, the six gathering tubes, with the rectangular sluices entirely closed, can deliver a total of 15,000 second feet to the inner waterway. This would, of course, be a very rare operating condition, as a certain amount of rectangular sluice opening would probably be permissible even under the worst conditions of ice formation and movement, so that the above mentioned head-loss, small as it is, will probably never be realized in practice, and the actual loss will be almost negligible.

The design of these gathering tubes was based upon a rational mathematical analysis, and was also confirmed by large scale model tests. The bath-tub shaped opening at the tip of each tube is designed to produce the initial suction impulse necessary for the functioning of the slot opening. The outer end of each tube is tapered in such a way as to give the axial velocity a constant value, after which the diameter of the tube is maintained

uniform, thereby producing an accelerating axial velocity, as additional increments of water are drawn into the shoreward sections. At the same time, the width of the slot decreases shoreward to compensate for the gradually lessening draft capacity of the main stream, and thus maintains the desired rejection ratio, as the tube approaches the shore.

The axial flow in the tube is necessarily induced by a difference of head or head-loss, which initiates and maintains the suction of



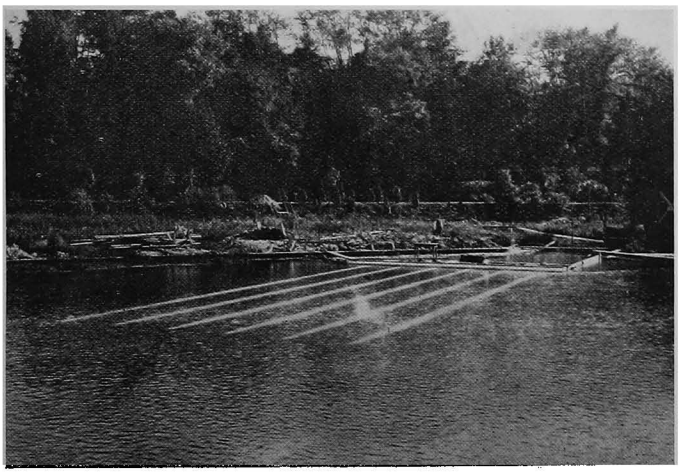


Plate C-4.—Large scale model test of gathering tube intake.

water through the slot. This head is the resultant of three components; namely, the initial loss in the priming tip; the cumulative induced losses in the tube, at any point, due to distortion of the stream lines in the slot entrance; and the cumulative losses, at any point, due to friction and velocity head-loss in the bore of the tube itself.

One most obvious merit of this gathering tube is, of course, its deep submergence, but the more significant factor of the design is the scientific distribution of draft from the source of supply. Instead of drawing 15,000 second feet of water from a narrow zone contiguous to the breast-wall, as is customary with structures of this kind, the draft zone is extended, in the case illustrated, over an area of 300,000 square feet, or nearly seven acres. Moreover, this draft, as previously mentioned, is mathematically adjusted to the draft capacity of the source of supply; in other words, the greater quantity of water is drawn through the outer extremities of the tubes, where the supplying flow is a maximum, and lesser quantities are drawn through the slots as this flow gradually decreases shoreward.

On Plate C—4 is shown a view of the tested model of this structure. This model was constructed to a 20 to 1 scale, and quantities of water up to 100 second feet were used in the experiments. It was indicated by these experiments that a quantity of water corresponding to 25,000 second feet, as applied to the full scale structure, could be drawn through the tubes, with the sluice openings entirely closed, without materially altering the stream lines of the source of supply, and that floating matter would pass entirely over the tube area without any appreciable reduction of buoyancy, and with little or no diminution in forward impulse.

Having these facts in mind, it may reasonably be anticipated that an intake of this type will deliver water free of floating debris, even though the surface transportivity of the source of supply may have an extremely low value. Under the extreme condition of a zero value of surface transportivity, floating material would naturally trap over the draft zone, but it could be periodically removed, if necessary, by mechanical means, before its buoyancy impulse had been overcome by suction.

Plate C—5 shows a view of this structure from the shore side The gathering tubes have not yet been built, but the view shows clearly the rectangular sluice openings and the mouth of one of the gathering tube diffusers.

Open Waterways.—The discussion under this head is to be limited to open waterways, because Canadian practice at the present time offers no distinctive features, from the structural standpoint, in connection with pressure tunnels, and also because the higher and purely hydraulic characteristics of closed pressure conduits will be discussed later under the head of long pipe-lines.

While the fundamental consideration bearing on the design of an open waterway, of any considerable length, is an economic balance between capital cost and the annual value of lost power, each constitutes an unique problem in itself by reason of the many purely local factors involved, such as right-of-way values, alignment and topography.

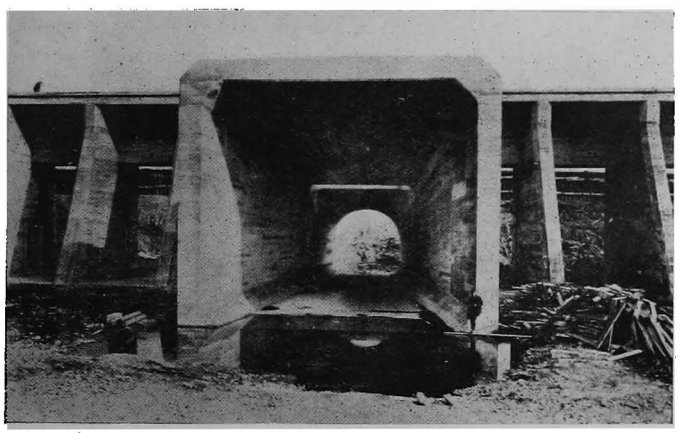


Plate C-5.—Intake structure with gathering tubes.

In Canadian practice, however, particularly in cases where the system load requires that full plant rating be continuously and instantaneously available, one outstanding factor enters into the consideration of all open waterway design; namely, the maintenance, under extreme low temperature conditions, of a delivery of water sufficient at all times to carry the revenue producing capacity of the turbines up to the limit of their rating. In the general case, a waterway which meets this specification embraces the other elements of efficiency, because the general equation of capital investment against the value of lost power will have been satisfied.

It is, therefore, necessary to consider the effect of the ice problem

on another important element of hydraulic design. In this case, however, the discussion turns mainly on stationary ice cover, rather than ice in motion, because, with the assumption of an adequately designed entrance structure, the problem of moving ice becomes of minor importance, being limited to the comparatively small quantity originating within the area of the waterway itself.

The formation of ice on a waterway of the type under discussion is influenced by variable combinations of air temperature, water temperature, wind, and the relationship which exists, for any fixed volume of flow, between marginal and mid-section velocities. The latter factor is more or less a controllable one, inherent in the design, the others being of climatic origin and, therefore, uncontrollable.

When ice *formation* on such a waterway is an accomplished fact, the subsequent occurrence of ice *trouble* is governed primarily by the degree of uniformity of mean velocity, and the relationship between width and depth for any fixed area of wetted section.

Where water flows in a regular channel with an appreciable velocity, ice formation always originates in the low velocity portions of the cross-section near the shores. Having secured the shore line for an abutment, this marginal ice builds out, bridge-like, from both shores towards the centre of the stream, the rate of progress being mainly governed by the climatic factors above mentioned. While these marginal ice sheets build outward, they also thicken, and if the climatic factors are such as to cause them to meet in the middle of the stream, the under surface of the sheet is roughly parabolic in form, having a minimum thickness at mid-stream, and a maximum thickness at the haunches abutting the shores.

In climates where there are sustained periods of low temperature, as in many parts of Canada, a complete ice cover may be formed in this way and persist for considerable periods, but if the temperature rises sufficiently, the ice sheet at mid-section disappears through the joint action of temperature and erosion, and open water will show. This thread of open water will widen out, or get narrower, or close altogether, in harmony with the variation in the climatic factors. Meanwhile, the haunch ice holds intact and tends gradually to thicken through the agency of ordinary frost action, and also by reason of accretions of slush and frazil which adhere to the lower surface of the ice sheet, as

a result of the low transportivity of the shoreward current filaments.

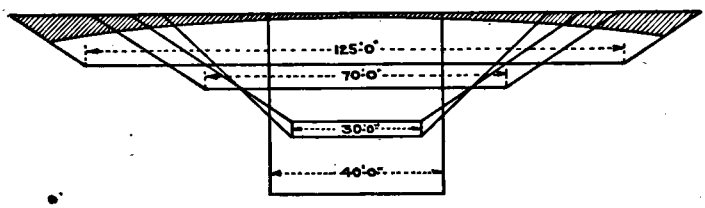
It is therefore evident that in a waterway where the width is great in proportion to the depth, and where the side slopes are flat, the tendency to encourage ice formation is a maximum.

As above mentioned, another primary requisite in reducing the ice hazard in an open waterway is to keep the water flowing, throughout its length, at as uniform a velocity, and with as little disturbance in the gradient and alignment of the current filaments, as possible.

This means that all sudden natural expansions and contractions of the cross-section should be obviated to the greatest extent practicable, and that such obstructions to flow and interruptions in gradient as are caused by bridge piers, regulating sluices, drop weirs, etc., should be reduced to a minimum.

The above precautions will not only tend to reduce the thickness

PLATE C-6



BOTTOM WIDTH	DEPTH FROM UPPER ICE SURFACE	SIDE SLOPES	TOTAL AREA	ICE AREA	NET WATER AREA	PERCENT OF TOTAL AREA OBSTRUCTED BY ICE
125·0	11·87	1·5 To 1	1687·5	433·5	1254·0	25.7
70·0	17·50	"	"	241·8	1445·7	14.3
30·0	25·00	"	"	183·9	1503·6	10·9
30·0	26.70	1 To 1	"	137·6	1549·9	8·2
40·0	42.19	VERTICAL	"	45·4	1642·1	2·8

Diagrammatic representation of width and depth ratio.

of sheet ice cover, but will fulfill the far more important function of reducing the liability of frazil and anchor ice formation at critical temperatures, as the turbulence induced by such structures will cause frazil to form in amounts which will be dependent upon the length and frequency of periods of critical temperature, and which might, during some winter seasons, be frequent enough, and of sufficient duration, to form a hanging dam under the solid ice sheet, of such extent as to seriously restrict the effective discharge section.

The problem of width and depth relationship is simply explained by reference to the diagram shown on Plate C—6.

On this diagram are shown a number of typical canal cross-sections all of *equal area* below water or ice level. The discussion of this diagram is based upon the primary assumption that the disparity between marginal and mid-section velocity is a minimum in waterways of deep, narrow section, and a maximum in waterways of wide, shallow section; also, upon acceptance of the secondary proposition that the parabolic form of the lower surface of the ice sheet becomes more pronounced as the disparity between mid-section and marginal velocity increases.

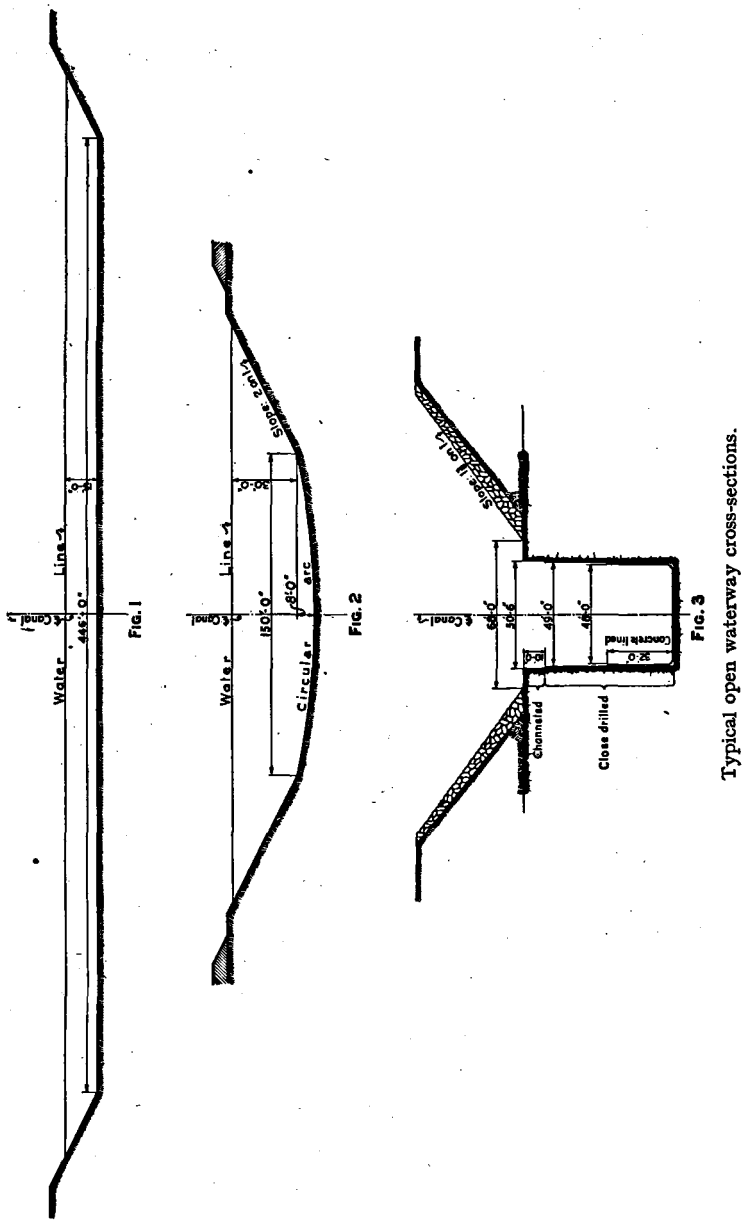
On the basis of the above proposition, a conventional wide, shallow section of the well-known text-book type has been assumed, and a parabolic ice sheet sketched in as above described. The other sections have been derived simply by reducing the width, steepening the slopes, and fixing the respective bottom elevations in such a way that all are of *equal area* below the assumed water or ice line.

Inasmuch as the ice sheet offers a material obstruction to flow through the combined agency of contracted discharge area and surface friction, the significance of the diagram on Plate C—6 is at once evident.

These theoretical sections are drawn to scale, and it was, therefore, possible to make a rough computation, shown on Plate C—6, indicating the relative extent to which the assumed ice sheet contracts the effective discharge area in such case. It is evident that the wide, shallow section offers a maximum of obstruction, and that the deep, rectangular section offers the least.

Assuming that the theory upon which the above conclusions are based is reasonably sound, it follows that the most efficient cross-section for an open waterway should have such a maximum of depth, and minimum of width, as is consistent with the character of the over-burden and underlying solid material through which the waterway is to be excavated. This conclusion is furthermore reinforced by two other considerations which are usually involved, the first being that considerable heat is retained in the larger and deeper body of water which usually constitutes the source of initial supply, and this heat will be retained longer in the waterway itself if the section is narrow and deep instead of wide and shallow; the second consideration is that in a wide, shallow section, there is danger of the temperature of

PLATE C-7



Typical open waterway cross-sections.

the bottom material being at times lower than the water which flows over it, thus offering encouragement to the formation of anchor-ice. On the other hand, if the waterway is deep enough, a converse condition obtains, whereby the underlying strata will always be warmer than the flowing water, and its ice resisting properties will derive the additional benefit of convection, and variation in density.

Therefore, as regards the type of waterway under discussion, it would appear, from the standpoint of the ice hazard, that the primary factors influencing the design should be:—

(*a*)—To provide as uniform and smooth a surface gradient from intake to forebay as topographical conditions will permit.

(*b*)—To make the depth of the waterway as great in proportion to its width as the natural slope and scouring propensities of the overburden, and underlying solid material, if any, will allow.

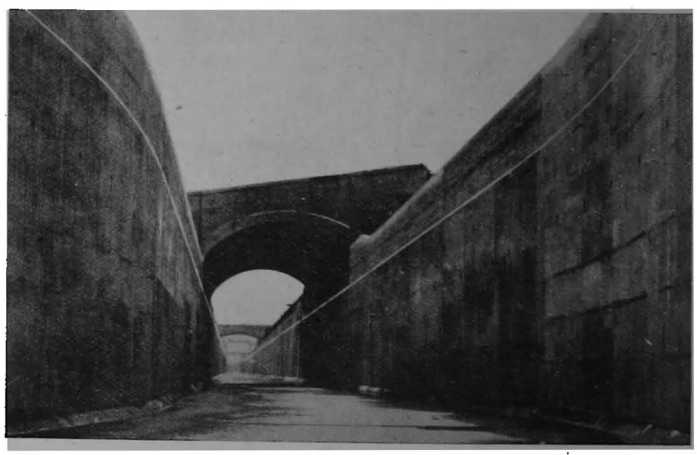


Plate C-8.—Concrete-lined power canal.
Mean water indicated by white line.

More particularly where the channel of the waterway is in earth and the range of permissible velocities thereby limited, an additional manifestation of ice trouble must frequently be considered in the design, having to do with the effect of weekly load-factor on ice cover.

If a power plant, fed through an open waterway, ordinarily operates during the working days of the week under fairly uniform loading, a sustained period of extreme low temperature may

cause solid ice cover to form throughout the length of the waterway, transforming it for the time being into a closed conduit subject to surge pressure.

If the above period of uniform plant loading terminates with a more or less sudden week-end shut-down, the induced surge pressures will rupture the ice sheet, and spurting water will flood the surface of the ice and saturate any snow which may have fallen, or drifted in, in the meantime. Subsequent to this occurrence, if the extreme weather continues, and the shut-down covers a period of, say, 36 hours, this surface water and slush will have time to freeze solid and become part of the original ice sheet, having nearly the same specific gravity. Consequently, when load is again pulled on, this thickened ice sheet will fall with the surface gradient and further contract the effective dis-

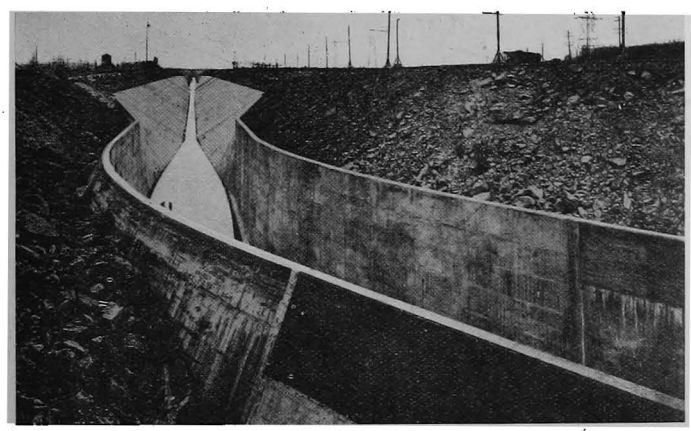


Plate C-9.—Curve construction and tradezoidal canal section over soft ground.

charge area by an amount roughly corresponding to the increment of thickening. Furthermore, in a wide, shallow section the sheet will adhere to the shores and sag in the middle, and if it takes a freezing set in this position it forms an inverted arch, which will greatly intensify the surge pressure, and flooding action, during the next ensuing shut-down period. In a deep, rectangular section the sag factor does not enter into the problem, because the ice sheet shears vertically at the shore lines, and rises and falls bodily with the surface gradient.

It might be assumed from the above description that the sagging ice sheet on a wide, shallow section could alternately flood and

freeze until the water supply was shut off completely. This cannot happen where there is any reasonable volume of flow, because there is always a critical point, governed by fortuitous combinations of air and water temperature, at which the tendency of the sheet to thicken is counteracted by the erosive action of the free water, which increases with its velocity, and scours away the lower surface of the ice sheet. This action is necessarily much more rapid and pronounced in a deep, narrow section than in a wide, shallow one, because in the former instance the marginal, as well as the mid-section velocities, are high, and also because the water temperature is usually higher, as previously explained.

This concludes the argument in connection with the formation and resulting phenomena of ice cover, and the consequent significance of the width and depth relationship, and uniformity of flow, as factors in design.

On Plate C—7 are illustrated several waterway cross-sections illustrative of the above argument.

Figure 2 represents the actual section, in earth, of a Canadian power canal, and Figure 1 shows the shape of a conventional cross-section of the same area of wetted section.

Figure 3 shows the actual section of the same power canal where the wetted perimeter is wholly in rock.

The above actual and comparative cross-sections show clearly that the width and depth relationship was pushed to the extreme limit of safety and feasibility, as governed by the angle of repose of the slopes in the case of the earth section, and by construction limitations as regards the section in rock.

Plates C—8 and C—9 are also actual views of the same power canal, and exemplify the development of the theory of velocity uniformity, and of width and depth relationship. On Plate C—8 the points to note are (a) the entire absence of any obstruction to stream-line flow, or flow acceleration, (b) the effect of the smooth vertical walls in reducing the disparity between marginal and mid-section velocities to a minimum, and (c) the relationship between the width and depth of the wetted section.

Plate C—9 indicates the means devised to overcome an unavoidable topographical feature in the form of a deep transverse ravine, the bottom of which was lower than the bottom elevation of the canal. Here, again, cognizance was taken of the width and depth relationship by tilting the side slopes up on a 1-3/8:1 ratio and crowding them together till the base width of the trapezoid was only 10 feet. Uniformity of flow and flow acceleration were also provided for, to the greatest extent possible, by determining

experimentally the most efficient angles of enlargement and contraction respectively, at each end of the trapezoidal section, this latter feature being more clearly shown on Plate C—10. The direction of flow in this view is toward the background.

Another interesting feature of recent Canadian practice in connection with open waterways has to do with the design of bends. The theory of this design is more conjectural than mathematically precise, and is briefly to this effect; (a) that the loss induced by the deflection of the stream-lines will be a minimum if the agency producing the disturbance, namely, the curve itself, is made as short as possible, and (b) that the turbulence induced by the

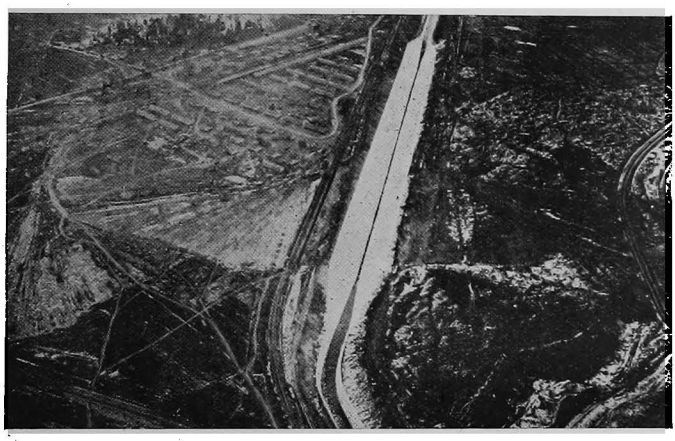


Plate C-10.—Aeroplane view of trapezoidal canal section with curve and transitions.

change in direction of flow will be reduced and more or less localised if extra lateral space is provided at the seat of disturbance, so that whirls and eddies may be quickly dissipated, instead of being forced forward into the straight section of the waterway. The first requirement is met simply by making the radius of the curve as short as possible, and the second by making the curve equi-radial.

A curve of this type is to be seen in the foreground of the views on Plates C—9 and C—10. This curve has a radius of 300 feet, and the radius of curvature is the same on both sides, thus gradually increasing the extra width between walls up to a maximum of about five feet at the middle point of the curve. This expedient has been tested in actual operation and appears to function as anticipated.

Other features of Canadian practice under this head, including such problems as the fixing of economic mean velocity, bottom slope, and surface gradient for non-uniform flow, would require a detailed mathematical analysis for intelligent demonstration, and are therefore not susceptible of the descriptive and general method of treatment adopted throughout this discussion.

Long Pipe-lines.—As related to Canadian practice, it so happens, as in the case of large turbines, that several distinctive features of pipe-line engineering originated at Niagara Falls. Otherwise, Canadian pipe-line installations, in general, offer no unique or special features from the structural standpoint, with the possible exception of those shown on Plates C—11, C—12 and C—13.

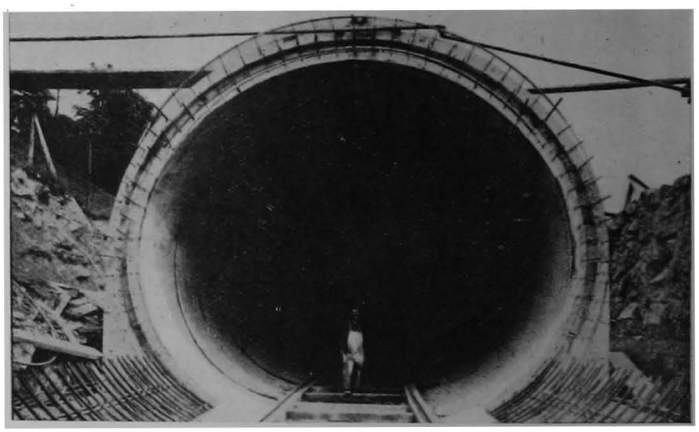


Plate C-11.—Reinforced concrete pipe of oblate section.

Plate C—11 is a view of a 6,600 foot reinforced concrete conduit, having an area equal to an 18 foot diameter circle. The distinguishing feature of this structure is the oblate cross-section, which shows plainly in the picture, and is derived from an ingenious application of the stress characteristics of the "hydrostatic chord," as applied to pipes of large diameter under comparatively low heads; that is, where a large part of the stress in the enveloping membrane is due to the hydrostatic pressure of the fluid contents of the pipe only, as would be the case with a large pipe subjected to a total static head of not more than three times its own diameter.

If a section of this pipe can be imagined as being constructed of some flexible but inextensible material, and stood on end, it is

obvious that it would assume a circular shape when filled with water, and also that all portions of the envelope would be in pure tension. If, however, this section of pipe were then bulk-headed and laid on its side, the condition of pure tension would not obtain until a certain amount of the water had been released to compensate for the resultant deformation. In other words, if a hole were pierced in the top of the pipe, and a piezometer tube attached, the pressure which resisted deformation would be released, the water would rise in the tube, and the pipe section would bulge laterally until a condition of static equilibrium once more obtained, with the envelope again in pure tension. If the

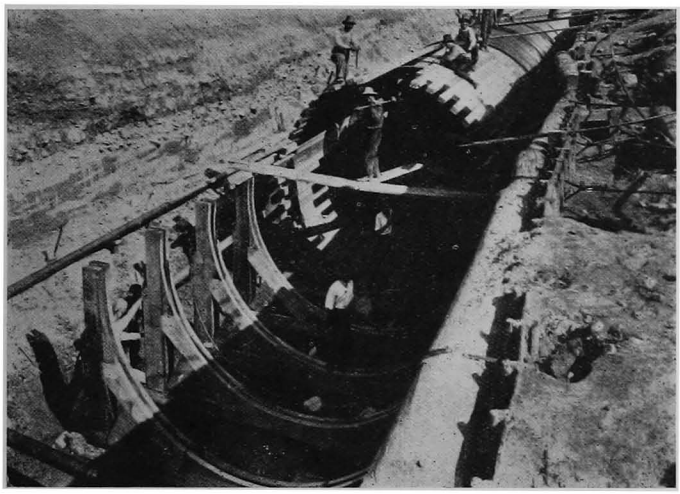
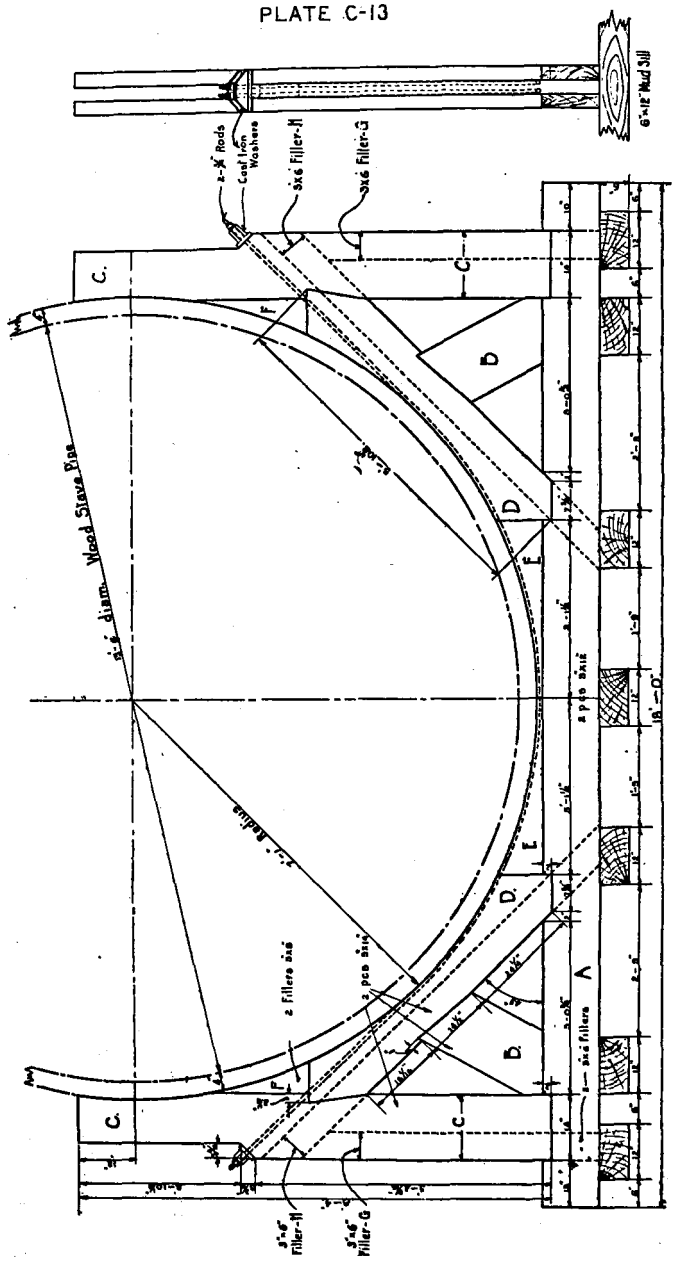


Plate C-12.—Large wood stave pipe construction.

flexible membrane can now be imagined as assuming a state of permanent and practically rigid fixation in this latter position, the basic principle of the design shown on Plate C—11 will be readily understood. In other words, taking into account the low external head on this pipe, it was found that the envelope would not be in pure tension if a circular section were adopted, and that heavy reinforcement would in such case be necessary actually to prevent the pipe from assuming an oblate form. On the other hand, by adopting the oblate section, a natural law of fluid pressure was taken advantage of instead of being violated, with the result that a very large saving in capital cost was realized by building a

PLATE C-13



Detail of saddle construction for wood stave pipe.

pipe designed for tension only, as compared with the cost of a circular section of equivalent strength and serviceability.

Plate C—12 shows a view of wood stave pipe construction. Apart from its large diameter, 13½ feet, the matter of interest is the design of the wooden saddles, as shown in detail on Plate C—13. The feature of this design is the steel tie-rod, which is so placed that the total weight of the full pipe resists any tendency of the saddle to spread.

Where the development of power involves the use of a closed pressure conduit of any considerable length, certain phenomena become manifest which frequently constitute a serious menace to safe and practicable operation. The continuous rejection and pulling on of load increments, under such a condition, causes recurrent surges throughout the length of the conduit, which, if not damped out or relieved, will sometimes multiply and become super-imposed to such an extent as to cause pressures very greatly in excess of that due to the static head. This condition, in conjunction with the conversion of static pressure into velocity head for acceleration purposes, when a large increment of load is pulled on, will impose a duty in the governors which they are not designed to perform, and where long closed conduits are connected to over-gated turbines, which is a far from unusual occurrence, an aggravated condition may obtain which is entirely beyond the regulating range of the governor.

Here, also, it happens that the advent of the " super-turbine " was the primary cause of bringing the above described phenomena into prominence in connection with modern hydraulic design. The reason for this was that the continuously increasing amounts of water to be handled gave rise to serious problems of pipe design, having to do primarily with the heavy capital cost involved in the construction of pipe-lines of constantly increasing diameter, while at the same time adhering to the then accepted limits of feasible peak-draft velocity. This condition naturally led to an intensive study of flow phenomena in closed conduits, the progress of the art under this head being marked by the use of the primitive vent-pipe, the more modern stand-pipe, the bursting plate, and various mechanical devices, all aimed at the one possible means of solution; namely, the extending of the limit of feasible peak-draft velocity.

The discussion hereunder has to do with the controlling elements of this problem, and a description of the means of its final solution.

The power-discharge curve for the ordinary turbine will show a maximum production per second foot at the point of best efficiency, and the first differential of this curve will show a rapidly decreasing rate of production per second foot from that point to full gate. Consequently, every horse-power pulled on in excess of best efficiency capacity will require a rapidly increasing amount of water to produce it. If, therefore, the turbine is operating at or beyond the point of maximum efficiency, when the system demands a large increment of load, there will be a falling off in power production per unit of water supplied, and coincident therewith, a loss of effective head, due to the absorption of such velocity head as is necessary to accelerate the water-column. During the period when the water-column is accelerating, it is therefore evident that a condition might obtain where the power output is actually falling off while the water input is increasing, the result being that the governor may open the gates full-stroke in response to the falling speed, at which point its controlling function will cease, until either the fly-wheel effect of the system holds the unit, with dropping frequency, for the space necessary for the governor gradually to resume control on rising speed, or until the generator drops the load and the turbine jumps to run-away speed at full gate, with possible disastrous consequences.

In so far as the control of surge pressure is concerned, it is evident that if no practical limitations be placed upon it, in the matter of diameter and height, the ordinary stand-pipe would be an ideal corrective agency. It is clear, however, that in the case of a large capacity high head installation, unrestricted scope in design is wholly impracticable from the standpoint of both cost and space limitation. On the other hand, a simple stand-pipe, designed and located within reasonable cost and space limitations, may at times actually make more acute the conditions it is designed to correct or alleviate. This is due to the fact that the simple stand-pipe can only passively absorb surge pressure, with its recurrent phases, and for this reason often acts as an agency for super-imposing, one upon the other, pressure waves generated by successive changes in load.

Another obvious expedient under this head is to limit the range of velocity change in the conduit by means of a synchronous relief-valve or by-pass, actuated by the governor mechanism. Such a contrivance can be adjusted to prevent the occurrence of disruptive pressures in the conduit, and also to supplement the influence of the system fly-wheel effect, in holding the unit within the

regulating range of the governor when the unit is pulling on or rejecting load, but only by reason of the fact that the condition under discussion has not necessarily to do with the maximum conduit velocity at any one time, but with the *range of change* in conduit velocity over a short period of time, and with the absorption and building up of head energy induced by these changes, within their low and high limits.

The synchronous by-pass or relief-valve, therefore, has a useful function, but in the case of a large high head installation, its usefulness would be largely discounted by its cumbersome dimensions, its waste of water, and an added mechanical complexity which should be avoided whenever possible as a matter of principle.

The discussion under this head has now reached a stage where it is possible to define the specifications of an ideal surge control agency:—

(*a*)—It should have the effectiveness of a simple stand-pipe of very large dimensions, without its cost and space requirements.

(*b*)—It should be capable on the one hand of preventing, or counteracting the effect of any undue absorption of head energy when load is pulled on, and on the other hand, of preventing or counteracting the effect of any serious recurrent surge pressures arising from load rejections, whether isolated or successive.

(*c*)—The water surface should be sufficiently active to prevent freezing in ordinary low temperatures, and dimensions should be such as to allow feasible and effective frost protection against extraordinarily low temperatures.

(*d*)—It should operate without wasting water.

(*e*)—It should be mechanically simple with a minimum of moving parts and adjustments.

(*f*)—It should be entirely dissociated from the governor mechanism, leaving the governor free to perform its own peculiar and highly important function, which is to control the speed of the generator, and not the vagaries of the water-column.

This specification has been met with a large degree of effectiveness by the Johnson differential surge-tank, one of the most wholly original and useful contrivances recently developed in the field of hydraulic engineering.

It has been stated above that the incentive which initiated the

development of modern pipe-line engineering in Canada was the necessity of extending the limit of feasible peak-draft velocity. This problem, in the first place, involved a realization of the fact that if the old standards of design were adhered to, pipe-line and stand-pipe construction would soon reach a dimensional limit which would be fixed almost wholly by cost considerations. Furthermore, where large modern turbines are connected to long pipe-lines, the element of mass becomes a major factor in design, as related to the effect of the inertia and momentum of a heavily energised water-column on speed control.

As the two factors, inertia and momentum, are a direct function of velocity, length of pipe, and gross head, it follows that there are possible combinations of these factors, especially if they involve a very low ratio of gross head to length of pipe, where the older methods of design may be entirely inadequate even at prohibitive cost. The unique feature of the differential surge-tank lies not in the fact that it can merely improve and cheapen conditions, which might be met by other means, with an adequate degree of effectiveness, but that it can insure efficient speed control even under the extreme conditions above mentioned. The reason for this will now be explained, after first briefly describing the main structural features.

The structural features of the differential surge-tank are extremely simple, and consist of three essential elements; namely, an ordinary tank of diameter and height varying with the conditions to be met; a simple stand-pipe, or " riser," having about the same diameter as, and connected direct to, the pressure conduit, and also projecting through the bottom of the tank to a height definitely fixed by design; and finally, one or more "ports" or openings, precisely located and proportioned, forming a water connection between the internal riser and the bottom of the surrounding tank.

In the case of an ordinary simple tank, the taking on of an additional increment of load will cause the contents of the tank to fall bodily, through a distance which measures the head necessary to accelerate the water-column and meet the demand of the turbines for more water. Conversely, following a rejection of load, the water-column in the simple tank moves bodily upward through a distance which measures the balancing conversion of active energy or velocity head, into potential energy or static head.

The characteristic accompaniment of this cycle of operations is

the assumption of a pendulum-like oscillation, synchronous with the period of the pipe-line, and controlled, so far as the inherent capabilities of the simple tank are concerned, solely by friction. It is evident, therefore, that the simple tank has one attribute only which can be utilized for the flow control of a long pipe-line; namely, storage capacity, which in turn is a function of diameter and height, and, therefore, of capital cost. On the other hand, the differential surge-tank possesses an additional characteristic, distinct from storage capacity, which enables it to function with very much greater effectiveness than a simple tank of similar dimensions or equal cost.

In order to describe concisely and clearly the principle of operation of the differential surge-tank, the following hypothetical cycle of plant operation will be assumed:—

(*a*)—Turbines operating on constant gate-opening, with resultant balanced conditions in the system.

(*b*)—A sudden demand for a large increment of power.

(*c*)—Reversion to balanced conditions, after the above demand has been met and maintained.

(*d*)—A sudden rejection of load.

Under condition (*a*) the respective levels in riser and outer tank must necessarily be the same, with no characteristic different from a simple tank.

Under condition (*b*) there occurs an immediate and rapid drop in the riser water level to an elevation *below* the hydraulic gradient corresponding to the then existing conduit velocity, thus almost instantaneously communicating to the main conduit the velocity acceleration impulse required for the delivery of an additional supply of water. Coincident with this action in the riser, but at a different and much slower rate, there occurs a drop in the level of the water in the outer tank, which naturally results from the passage of water through the ports into the riser, under the impulse of the lower water level therein. The outer tank, therefore, has the two-fold function of supplying stored water during the speeding-up interval in the main conduit, and of helping to maintain the head on the wheels while the riser water-column is furnishing a maximum of accelerating impulse to the velocity in the main conduit.

Under condition (*c*) balanced conditions are again assumed, with riser and tank levels equalized at the new hydraulic gradient.

Under condition (*d*) there conversely occurs an immediate and rapid upward surge in the riser water-column to an elevation

above the hydraulic gradient corresponding to the then existing conduit velocity, thus immediately communicating a decelerating and damping impulse to the conduit water velocity and to the induced surge pressure. At the same time there occurs a flow from the riser through the ports, to storage in the outer tank, which is necessarily governed in rate and quantity by the difference in levels. This joint functioning on the part of the riser and tank continues until the levels finally equalize on the new running gradient.

The above description of operating regimen should serve to make clear the differential action from which this type of tank takes its name; that is, the function of the active and sensitive water-column in the riser in imparting an appropriate accelerating or decelerating impulse to the conduit water-column, as differentiated from the separate but simultaneous function of the outer tank in making good any short period deficiency in water supply on the one hand, or in storing rejected water on the other. The separating of these two functions, by means of flow back and forth through the ports, has the further effect of destroying the synchronism between the conduit and tank water-columns. Its effectiveness in this connection is so marked that the most extreme and dangerous operating condition possible, where a simple tank is used, cannot obtain; namely, a condition of synchronism between successive load changes on the turbines and the harmonic period of the pipe-line.

The crucial factor of design, in order that the differential surge-tank may have the characteristics above described, is to fix the area of the ports, and the proportions of the outer tank, so that, upon a change of load, the new elevation immediately assumed by the riser water-column shall be maintained throughout the entire period of change in velocity of conduit flow, while at the same time the rate of depletion or replenishment of tank storage, as the case may be, shall be such that the equalization of tank and riser levels will coincide with the resumption of a stable running gradient in the conduit system.

Contrary to the case of the simple tank, the above principle of design is susceptible of such exact mathematical analysis that predicted performance is usually realized in operation within a margin of two per cent. maximum error in any part of the cycle, so that, if required, the differential tank may be designed for " dead-beat " action. In the majority of cases, however, this characteristic is not of sufficient importance to justify the extra

cost involved, but where the pipe-line is very long and the velocity and friction gradient high, the non-synchronous functioning of this type of tank nevertheless makes it possible, well within the cost limits of a simple tank of adequate dimensions, to design for the " dead-beat " or absolutely non-oscillatory condition, where the range of variation in tank levels is never beyond either the maximum or minimum running gradients of the conduit system, as governed by the characteristics of the connected load.

The initial consideration involved in the design of one of these tanks is the range of load change over which it is intended to function. This in turn involves primary consideration of the nature and characteristics of the system load, but in a scarcely

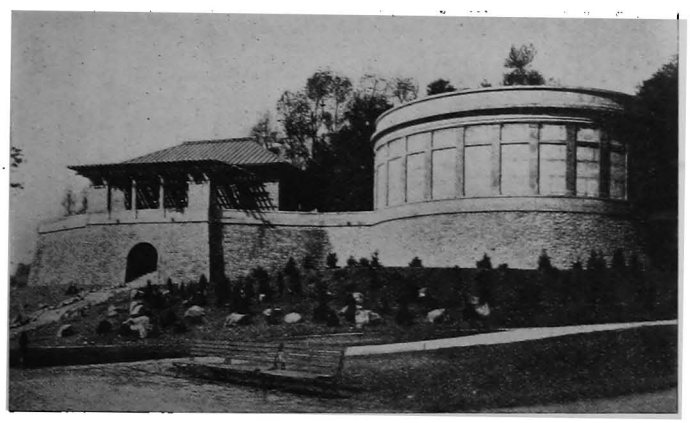
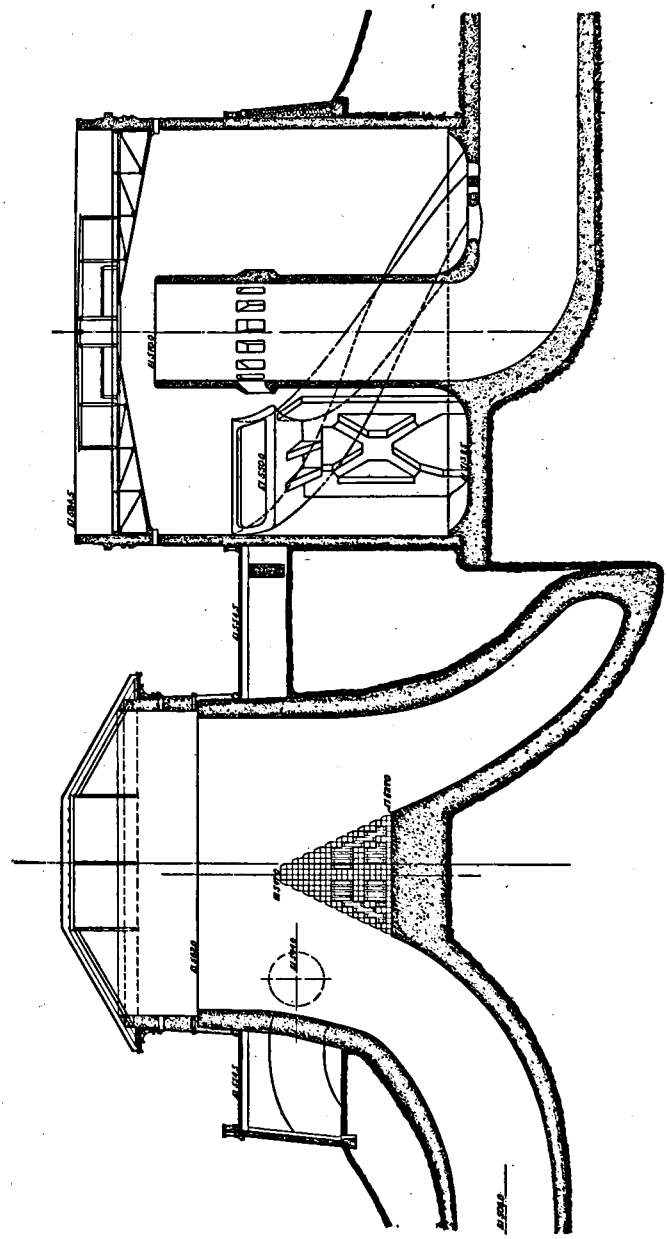


Plate C-14.—Exterior view of simple and differential surge-tank.

less important degree, the co-related factors of length of unregulated pipe-line, and the fly-wheel effect, whether inherent or externally applied, of the machine installation. There is wide scope for experienced judgment in this connection, and though quite possible, it is not usual to design the tank for perfect functioning under the full range of emergency or accidental load variation, but rather for a range in the neighbourhood of 40 to 60 per cent. of full load pulled on instantaneously, but making it safe, at the same time, for full load rejected. This latter condition is made possible by the fact that the only abnormal result of a full load rejection is the overflowing of the internal riser, which spills into the outer tank. The volume and impact of this overflow furthermore acts as a direct deterrent to the conduit

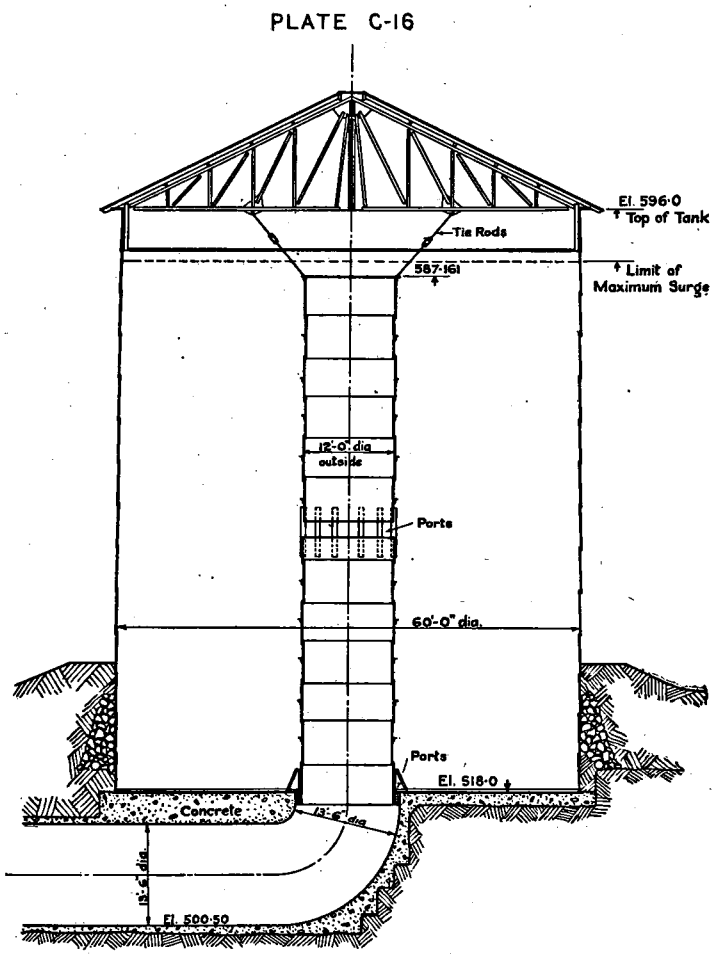
PLATE C-15



Cross-sections of simple and differential surge-tanks.

surge, and thus reduces the amount of water required to be absorbed by tank storage.

Plate C—14 is a view of two surge-tanks forming part of a large Canadian installation. These tanks are connected each to a



Cross-section of surge-tanks of non-spilling type.

conduit of identical length and cross-section. The structure on the left is a simple tank, and that on the right is the first differential tank ever designed and built. The conduit connected to the simple tank is of rivetted plate steel construction, while the differential

tank is connected to the reinforced concrete conduit shown on Plate C—11.

Plate C—15 is a cross-section through these tanks which clearly shows their distinctive features. It will be seen that the simple tank, on the left, has no function whatever beyond the relieving of surge pressure and the passive acceptance of water rejected by the turbines, to be passed to waste, if necessary, over the crest of a weir into a spiral discharge tunnel. In the other section the elements of the differential surge-tank may be clearly seen, consisting, as indicated, of an outer storage tank, an inner regulating riser, and two sets of connecting ports; one set of overflow ports near the top of the riser, and the other set located between the top of the conduit and the floor of the tank. There is also shown an overflow weir which is not essential to the design. It would probably have been cheaper to have made the tank high enough to impound all rejected water, but certain conditions, quite unrelated to the hydraulic design, made it necessary to restrict the height of the structure at the time it was built. As a matter of fact, a third tank subsequently built in connection with the same installation, was of the non-spilling type. This tank is of steel construction and is shown in section on Plate C—16. It requires no further explanation beyond calling attention to the fact that the elevation reached by the rejected water, for full load instantaneously thrown off, is indicated on the drawing.

Two interesting features in connection with the tanks shown on Plates C—14 and C—15 are worth mentioning.

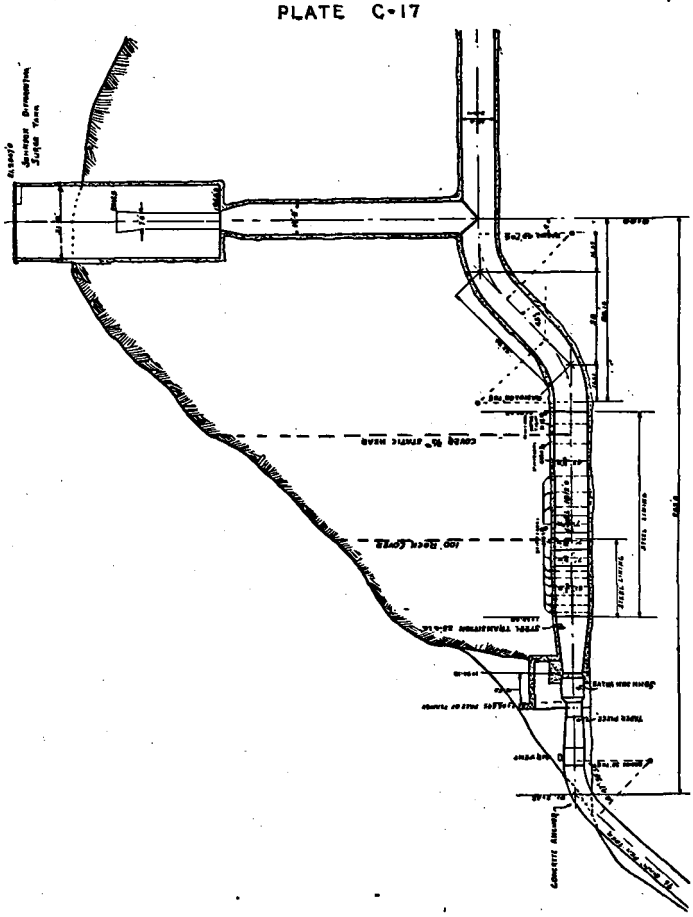
As previously mentioned, the conduits connected to each of these tanks are alike in length and cross-section. The maximum allowable peak-draft velocity in the conduit connected to the simple tank is 15 feet per second, and its maximum power capacity is 59,000 E.H.P. On the other hand, the conduit connected to the differential tank can be operated up to a peak-draft velocity of 26 feet per second under perfect conditions of turbine governing, and its resultant power capacity is 97,000 E.H.P., an excess of 38,000 E.H.P. over the other conduit, which condition is jointly due to the solution, by means of the differential tank, of the problem of extending the limit of safe and operable peak-draft velocity, and to the superior hydraulic characteristics of the concrete conduit. If the simple tank were replaced by a differential tank, the maximum power capacity of the steel conduit would be increased to 70,000 E.H.P., or a net gain of 11,000 E.H.P., for which the differential tank is responsible, and a margin of

27,000 E.H.P. due to inherent hydraulic characteristics of the concrete conduit.

The other interesting point is of a purely structural nature.

The differential surge-tank shown in section on Plate C—15 is built of reinforced concrete, and on account of its large diameter, a certain amount of deformation was anticipated under water pressure. This deformation would naturally take the form of an increase in the diameter of the barrel of the tank, thus introducing an extremely complex problem of stress determination and distribution of reinforcement, as related to any rigid connection between the barrel and the base of the tank. This problem was finally

PLATE C-17



Differential surge-tank in rock.

solved by the unique method of doing away entirely with any such rigid connection, and providing instead a free sliding contact between the base of the tank and the annular area of the barrel. This method of solution is shown in part on the above-mentioned cross-section and apparently consists of a low curb of diameter slightly less than the inner diameter of the barrel. The real point of the procedure, however, consisted in providing a smooth finished surface on the annular section of the base under the barrel of the tank, and simply building the barrel on it, after first applying a grout wash. There was thus provided a free sliding contact upon which the tank could swell and contract under pressure, and water-tightness was secured solely through the agency of the weight of the tank.

This tank has been in absolutely uninterrupted service for twelve years, and has been perfectly water-tight from the first day of its operation.

An interesting application of the differential tank is shown on Plate C—17, where the greater portion of the tank and riser consists of a shaft excavated in solid rock and lined with concrete. This surge-tank regulates two steel conduits 35,000 feet long, and is connected to three units, each of 35,000 E.H.P. capacity, operating under a net head of 857 feet. It is designed to give good regulation for an instantaneous load increase of any amount up to 50 per cent. of full load, and to take full load rejection with a small percentage of spill.

Forebay Structures.—The general problem under this head is to a large extent analogous with that of entrance structures, in that it primarily involves the adequate protection of the penstock intakes from entrance of, or obstruction by ice and other floating material, and also because the gravity of the problem is proportional to the percentage of flow diverted from the initial source of supply. The fact also that the forebay structures, which are assumed to include the racks, constitute the last line of defence before the water enters the wheels, adds materially to their importance from the standpoint of design.

Whether the distance from the forebay to the initial source of water supply be long or short, it is nearly always necessary to reduce the velocity in the feeding waterway before it passes through the racks, thus introducing at once the problems of enlargement loss and draft distribution. Unless the velocity in the feeding waterway is very low, the above conditions manifest themselves in the form of reverse currents and eddies along the

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margins of the enlargement, because the momentum of the entering stream has a tendency to keep the flow in straight lines instead of diverging with the cross-section, and frequently also tends to form localized vortices in front of the racks or curtain-walls, through defective draft distribution. Besides dissipating otherwise convertible energy, the above conditions have the far more serious effect, previously mentioned, of forming areas where floating material, including ice, will be trapped, or where suction will overcome its buoyancy impulse, and draw it into the racks or penstocks before it can be harmlessly disposed of through ice-weirs or chutes.

Plate C—18 shows a view of the forebay and gate-house of a

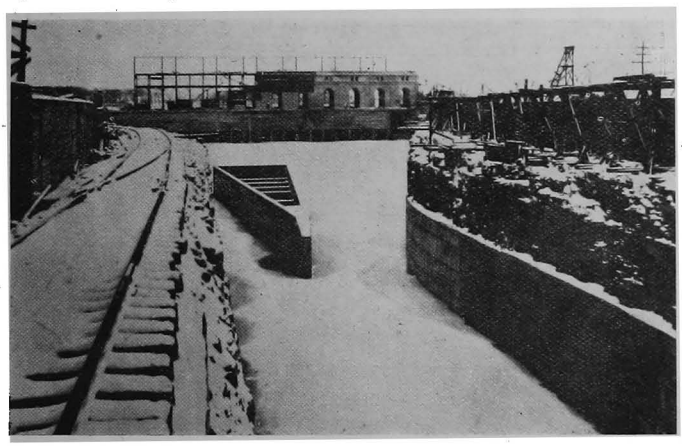
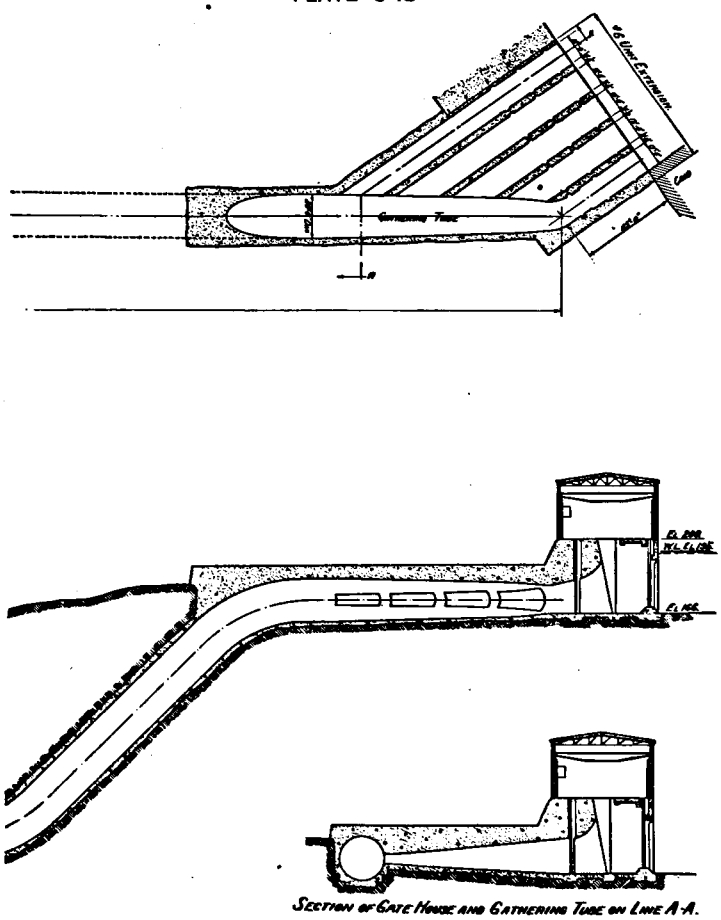


Plate C-18.—Forebay diffuser.

large Canadian installation recently placed in operation. Under ultimate peak-draft conditions, the velocity at the throat of this forebay will be about 12 feet per second, and as the most efficient angle of enlargement could not be adopted on account of the prior requirement of main unit spacing, it was evident that the high momentum of the entering stream would produce very undesirable conditions in the forebay, in the form of defective draft distribution, vortex action, and general turbulence. This condition was remedied by inserting a wedge-shaped diffuser in the throat of the forebay, as shown in the foreground of the above-mentioned illustration. The length, shape and critical dimensions of this structure were fixed by experiment, the factor of first importance being the determination of the most efficient angle of flare in the

passages on each side of the diffuser, the flare angle of the forebay walls being definitely fixed. The height was so adjusted that the top would be slightly submerged at maximum hydraulic gradient, in order that there would at no time be any available anchorage to encourage ice formation.

PLATE C-19



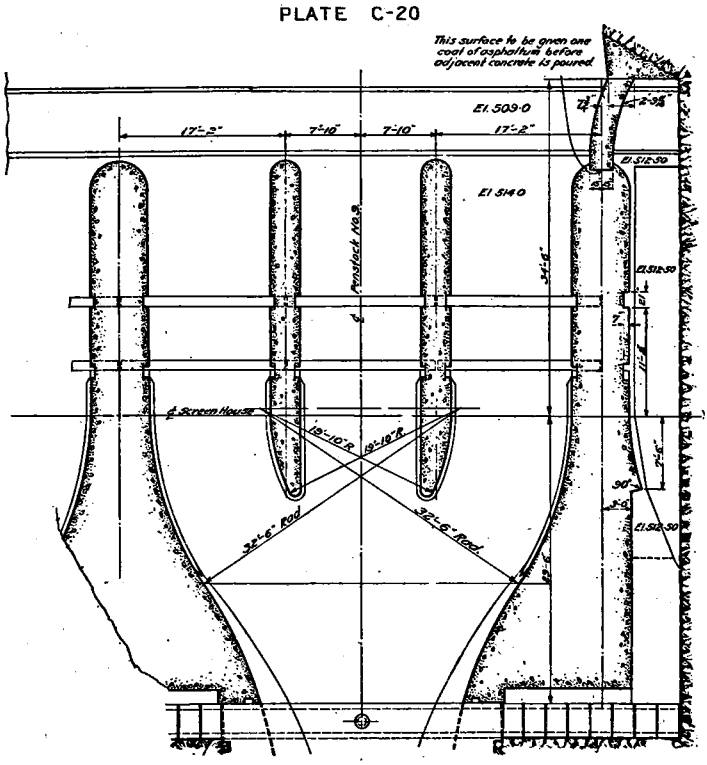
Forebay intake with gathering tube.

The performance of this structure, at loads somewhat in excess of one-half ultimate capacity, has been satisfactory, and indicates that a uniform draft distribution will obtain under all conditions of flow, with the incidental result that nine-tenths of a foot of

velocity head will be regained, or about 1,500 E.H.P. of otherwise wasted energy made available under peak-draft conditions.

In another large Canadian plant, a substantially similar problem was solved by the interesting and original method illustrated on Plate C—19. In this case, as will be seen, the remedy was applied after the water had passed through the racks, instead of in the forebay itself. Two conditions made this procedure expedient;

PLATE C-20



Plan of gate-house substructure.

namely, the irregular shape of the forebay, and the importance, in view of the large quantity of water involved, of transmitting the flow from the forebay into a 20 foot diameter tunnel with a practicable minimum of loss. This latter requirement, in turn, called for uniform draft distribution through the racks, and smooth acceleration from that point to the circular tunnel section.

The above result was obtained by means of a design precisely similar in principle to that previously described under "Entrance

Structures." As the illustration indicates, this structure consists of a " gathering " tube heading directly into the tunnel, and branching off from it, at an angle of about 35 degrees, are five passages of varying length and cross-section, which emerge abreast at a like number of sluice openings in the gate-house.

The shortest passage enters the gathering tube through an elliptical opening analogous to the " priming tip " in the design previously described, and similarly also, the remaining four passages enter the tube through longitudinal slots of gradually decreasing width, as the illustration shows, and so proportioned as to deliver to the gathering tube a constant increment of flow per unit of axial length. The cross-section of the gathering tube was fixed upon the assumption that the discharge at any point was proportional to the square of the velocity, the dimensional result being a gradually increasing area in the direction of flow, and the hydraulic result, a smooth acceleration of flow up to the junction with the constant tunnel section.

This intake was recently tested under operating conditions, and the degree of uniform draft distribution actually realized was as follows:—

No. 1 or priming sluice	...	20% of total flow
No. 2 sluice	... ...	21% ,,
No. 3 ,,	... ...	22% ,,
No. 4 ,,	... ...	20% ,,
No. 5 ,, (the longest)		17% ,,

The deficiency in respect of No. 5 sluice was considered to be due to a ledge of unexcavated rock immediately in front of it. Such being the case, the above results show such a close agreement betwen predicted and actual performance, as to constitute a distinct advance in the art.

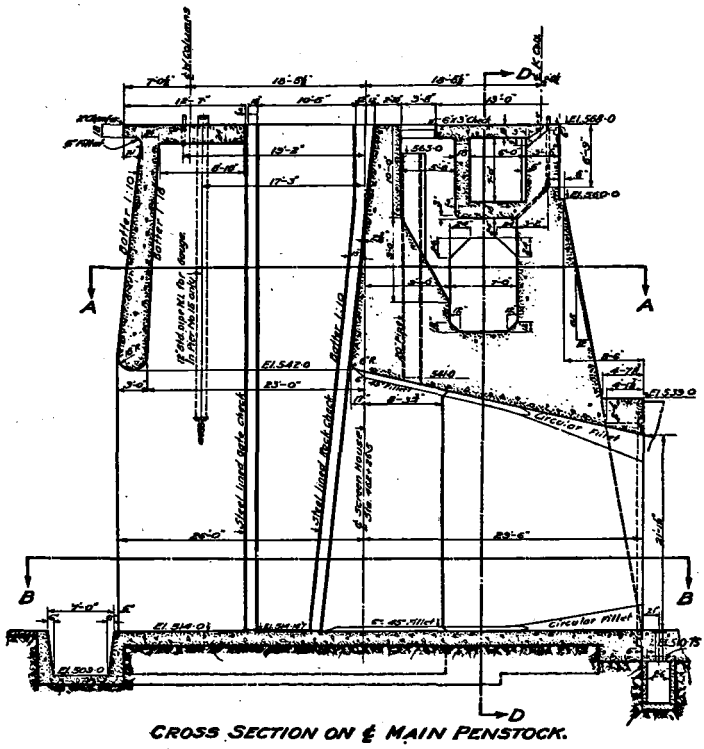
The primary considerations in gate-house design are, first, the fixing of sill elevations so as to make surface draft a minimum, and to permit a properly proportioned and symmetrical acceleration of intake velocity for the full range of forebay gradients; and second, completely to house in the racks and provide such a curtain-wall seal as will insure frost protection to the above-water portions of the rack structure, and at the same time protect the penstock openings from surface ice and other floating material.

Plates C—20 and C—21 show a plan and section of a gate-house designed in accordance with these principles. The features of this design are the carefully transitioned intake passages, the deep curtain-wall seal, deep submergence of racks, and a considerable length of rack above water level.

All of these features combine to deliver water to the penstocks with a minimum of loss and disturbance and to maintain unimpaired service under winter operating conditions.

The deep curtain-wall seal serves the double purpose of fending off floating material and of protecting the racks from the cold. The superstructure is also built so as to allow any necessary inside temperature to be maintained. The deep submergence of the

PLATE C-21



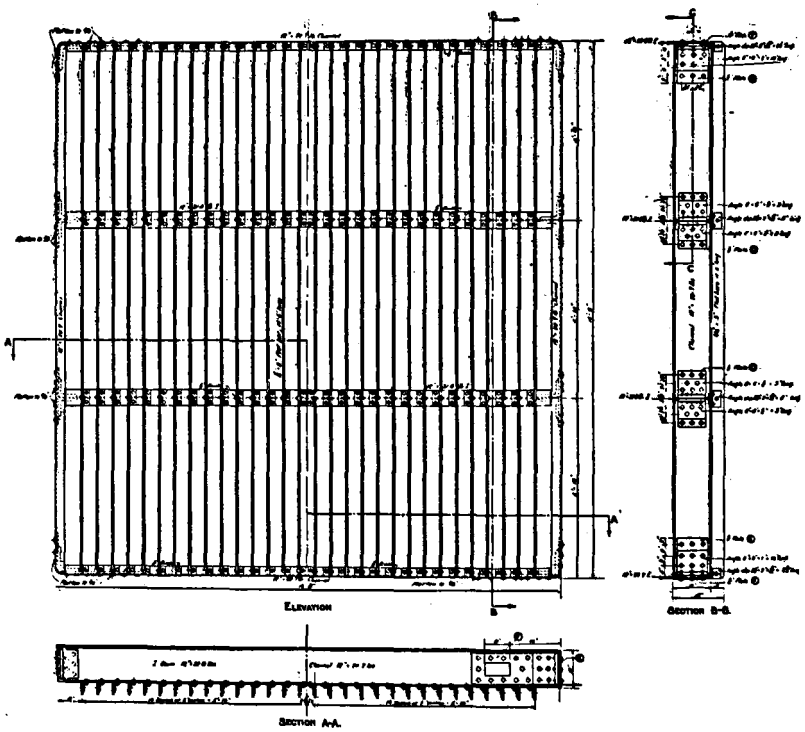
Cross-section of gate-house substructure.

racks gives the bottom sections the protection of the lower strata of water, where the reciprocal effect of density and convection tends to maintain temperatures above freezing point. Similarly, when the interior of the superstructure is heated, the long section of rack above water protects the upper submerged sections through the agency of conduction. Conversely, if the exposed sections of rack are not warmer than the water, a condition may

obtain where the racks will absorb heat from the water, with the result that anchor-ice will form on the rack-bars at critical temperatures.

An interesting feature of the design illustrated is that no portion of the rack structure is permanently fixed under water, as the sections are entirely self-supporting between the intake piers, and all metal structures are removable with the exception of the

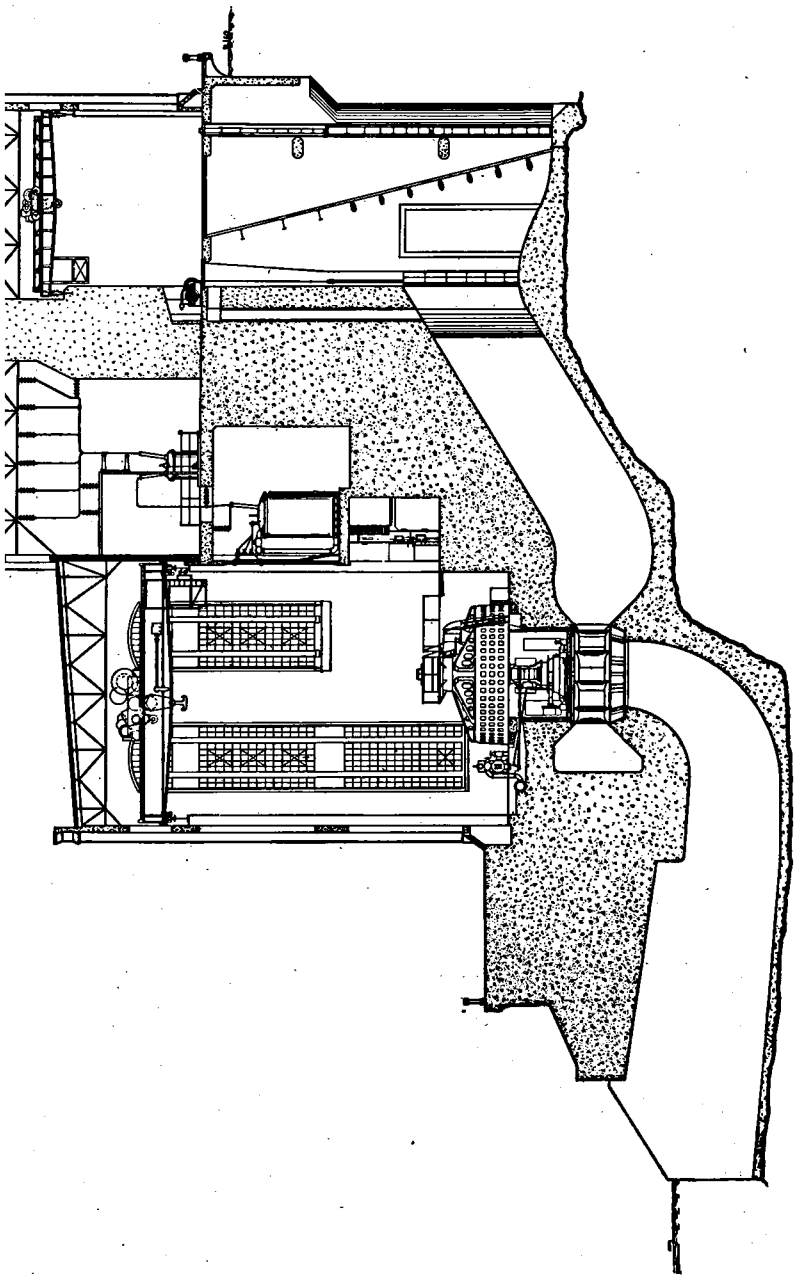
PLATE C-22



Self-supporting rack section.

channels lining the grooves. Plate C—22 shows the construction of one of these rack sections, which is designed to withstand a pressure corresponding to a static head of 10 feet. For this reason there is little likelihood of the rack structure failing as a result of being clogged with ice or debris.

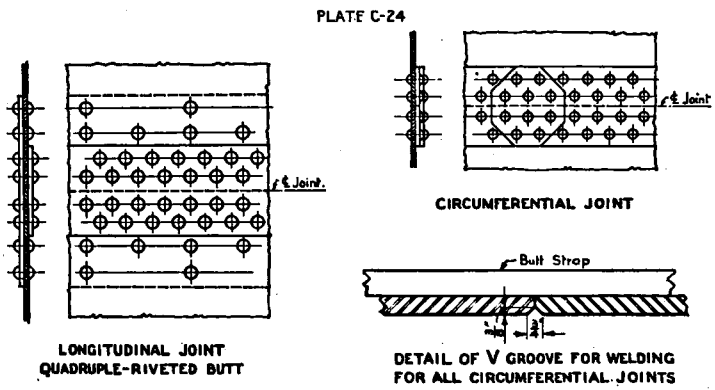
PLATE C-23



Typical concrete penstock construction.

Penstocks.—Nothing of an outstanding nature has developed in Canadian practice under this head, the various types of plate steel, wood stave, reinforced concrete, lock-bar and welded steel penstocks being installed more or less in harmony with the governing factors of static head, length, gradient, size of installation, and climatic conditions. The influence of these factors, in their various combinations, upon the design and type of installation does not require to be enlarged upon at any length for the reason mentioned at the outset.

When extreme low temperature is a factor, it is common practice to house in or bury the penstocks, or to use wood stave pipe, where the other factors permit, on account of its cold resistant properties. As an alternative to the very doubtful expedient of burying steel pipe, the better method of encasing it in concrete



Detail of riveted and welded penstock joint.

is often employed, and where the distance is short from head-gate to turbine, solid concrete alone is used with the joint object of frost protection and permanence. Plate C—23 illustrates this type of design as applied to one of the earlier " super-turbine " installations in Canada, consisting of nine horizontal units each of 20,000 E.H.P. capacity, under an operating head of 83 feet. It will also be noted that the entire substructure assembly, including not only the penstock, but the dam, scroll-case and draft-tube, is monolithic.

Plate C—24 illustrates a minor feature of penstock design, of Canadian origin, which is of some interest. The penstock to which this detail was applied is 400 feet long, 16 feet in diameter, and is connected to a 58,000 E.H.P. unit operating under a normal head of 300 feet. Instead of the ordinary lap-joint for

the girth seams, a single external strap butt-joint was used to secure the best possible alignment of flow.

The other special feature of this construction was the electric welding of all joints in the interior of the pipe. The drawing reproduced on Plate C—24 shows how the edges of the butting plates are chamfered, thus forming a V-shaped recess to receive the weld. Plate C—25 shows a view of the finished interior construction of this penstock.

Six of these penstocks have been placed in service, and upon filling, none of them showed any signs of leakage beyond a small amount of sweating, usually around rivet-heads.

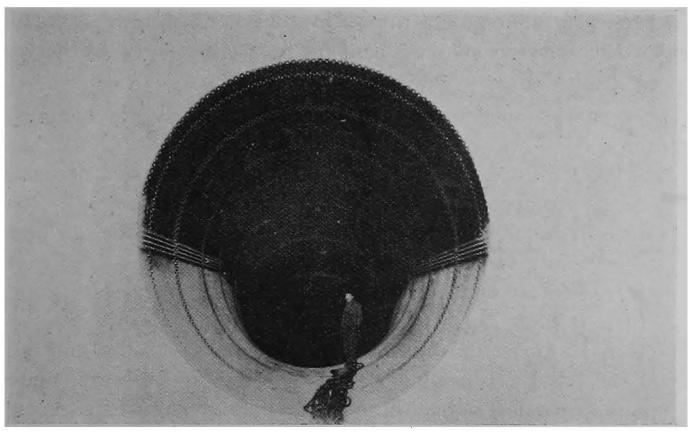


Plate C-25.—Penstock with welded joints.

Under the circumstances, it does not appear that any further development in penstock design and construction, of a revolutionary nature, is to be anticipated in the future.

Penstock Valves.—As a result of the growth in the size and unit capacity of the turbine, the safe and expeditious control of static pressure finally became the most vital of all the ancillary problems of plant design; simply by reason of the fact that the faulty or uncertain control of a proportionately heavy penstock water-column would otherwise introduce an element of personal and investment risk, so serious as to largely discount the value of expensively acquired operating efficiency.

The ordinary gate-valve offers an entirely inadequate solution for the problem where high heads are involved, and even for comparatively low heads, in cases where the penstock is beyond six feet

in diameter. Similarly, the butterfly valve, while it has a much wider range of application than the gate-valve, becomes a source of serious operating risk as related to the higher order of unit capacities now becoming prevalent in Canadian practice.

The above limitations have naturally developed to a large extent through the almost unavoidable necessity of placing the penstock valve adjacent to the turbine in the larger modern installation, thus subjecting the valve to the pressure of the full static head. This necessity arises primarily from the fact that a valve, at or near the entrance of a large penstock, cannot protect the plant against a sudden or uncontrolled release of the potential energy of the static water-column, such as might occur in the event of a wheel-case failure, or a failure in governor control. A further advantage arises from the saving in time which would otherwise be lost in draining and filling the wheel-case.

The general specification for a large penstock valve may be written as follows:—

(*a*)—It must be capable of being built in any size necessary to accommodate any conduit, however large.

(*b*)—It must be capable of being designed to operate under any static head, however high.

(*c*)—It must open and close rapidly.

(*d*)—It must be tight under all conditions of service.

(*e*)—Its operation must at all times be safe, sure and positive; in opening under any static pressure, and in closing under the most serious of plant emergencies.

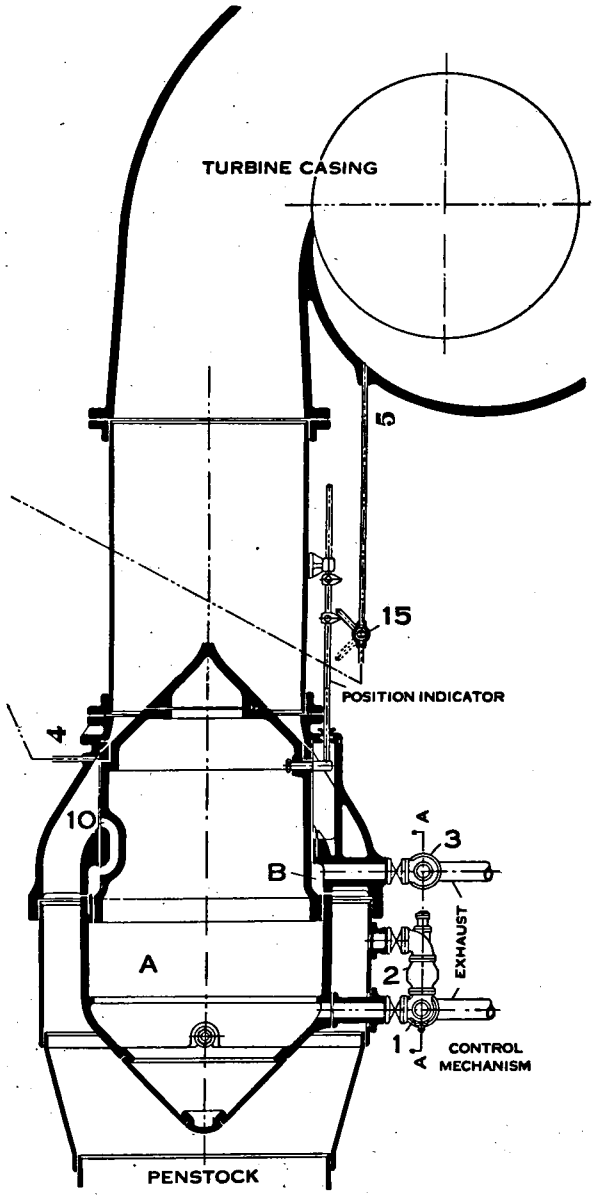
(*f*)—Where very large penstocks are involved, there should also be an automatic closing device.

Obviously, the above specification eliminates the older types of valves, but it has nevertheless been met to a substantial degree, in Canadian practice, by the use of the Johnson automatic plunger valve.

This valve, like the differential surge-tank, is a distinct hydraulic speciality based on simple and inherently sound fundamental principles, and its development has proceeded along lines that should ultimately lead to its exclusive use for the purpose under discussion, if a proper proportion of its comparatively high cost is allocated to the safety insurance which its use makes available to an unusual degree, even under the most onerous conditions of service.

The structural features and operating principle of the Johnson valve are shown diagrammatically on Plate C—26.

PLATE C-26



Diagrammatic sketch of Johnson valve.

The valve consists of two main elements, one being an outer shell or casing, the larger end of which is connected to the penstock, and the smaller end to the turbine casing. Within this outer shell is a smaller torpedo-shaped structure, the rear end of which, marked " A," is rigidly attached to the casing, while the forward section, or plunger, telescopes it and can move back and forth within it on a sliding fit. The annular space between the inner and outer element is the main water passage of the valve. It is, therefore, clear from the diagram that the passage of water through the annular space is entirely controlled by the position of the moveable section of the plunger, which shows fully closed in the diagram.

Of the several types of control devices used in connection with these valves, that shown on Plate C—26 is in most common use on large installations, and illustrates a principle of operation common to all.

This control is effected by means of three small plunger valves, marked 1, 2 and 3 on the diagram, each of which is actuated by a pilot piston, which in turn is operated by penstock pressure.

As indicated on the diagram, valve 1 (set vertically) is connected direct to the interior of the plunger body, by means of a pipe traversing the main water passage.

Valve 2 (set horizontally) connects the main water passage with the inner chamber " A."

Valve 3 (set vertically) is connected direct to the annular chamber, marked " B " on the diagram, which is formed by the difference in diameter between the main body of the plunger and the enlarged rear flange.

The pipes shown leading away from valves 1 and 3 discharge to atmosphere.

The valve now being in closed position with no pressure in the turbine casing, it is clear from the diagram, that in order to keep the plunger seated there must be penstock pressure in the chamber " A." Consequently, valve 2 must be open, and exhaust valve 1 must be closed.

To move the plunger off its seat, it is evident, in the first place, that the penstock pressure in chamber " A " must be exhausted to atmosphere, which process is affected by closing valve 2 and opening exhaust valve 1, but as there is no pressure in the turbine casing it is necessary to provide, by other means, the impulse necessary to move the plunger back against the atmospheric pressure in chamber " A." This impulse is supplied direct by

the penstock pressure, which builds up in the annular chamber " B " as soon as valve 3 is closed, through the agency of the priming port 10 and the leakage through the fit.

It is also evident that when the valve has been slightly opened, the initial differential impulse is augmented by the reaction of the free spouting jet on the plunger nose-piece, unless the turbine casing has been previously primed.

In practice, the opening and closing operations are performed by the manipulation of a single reversible hand lever connected to the pilot pistons by a three-way plug valve. When the lever is on the neutral point all three operating valves are normally

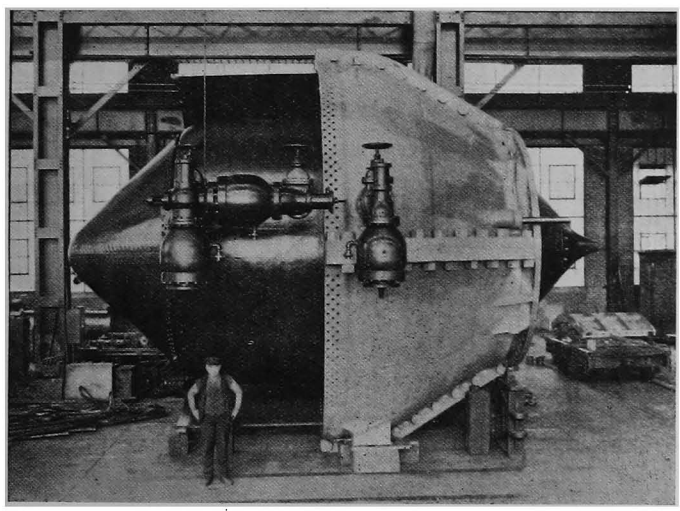


Plate C-27.—Shop assembly of Johnson valve.

closed. When the lever is thrown over to the opening position, valve 1 opens immediately, and exhausts the internal chamber to atmosphere, upon which the differential pressure in the annular chamber begins to function and the plunger moves to the open position. The operating lever is then restored to neutral position with all operating valves closed. To close the valve, the operating lever is swung in the opposite direction, thus simultaneously opening valves 2 and 3, with the result that penstock pressure is restored in the inner chamber " A," and the annular chamber " B " is exhausted to atmosphere, so that the plunger must move to the closed position.

In order to obviate any serious pressure rise in the penstock,

and to prevent shock in seating, a small pipe is provided at the point 4, which is connected to the control valves; therefore, when the plunger is within about half an inch of closing, the high velocity in the throat causes a reduction of pressure at that point, which reacts on the pilot pistons of valves 2 and 3 and closes them. The result is that the plunger must travel the remaining distance to its seat at a greatly reduced speed, which is directly proportional to the rate at which the water trapped in the annular chamber can escape by leaking through the sliding fit.

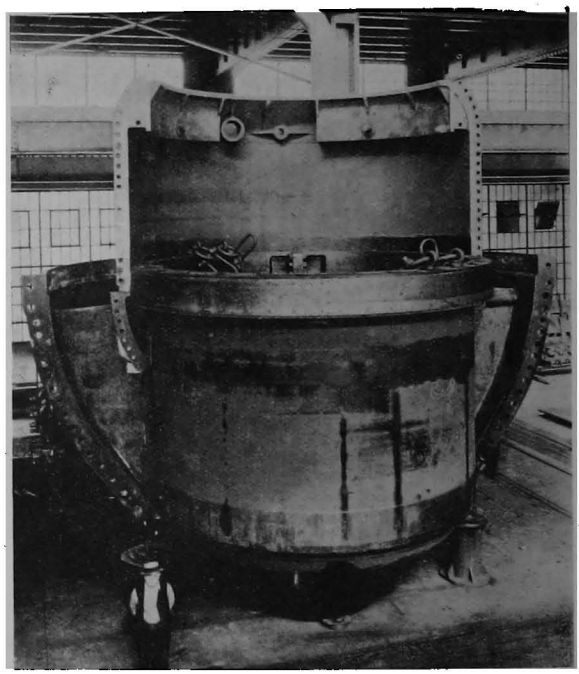


Plate C-28.– Shop view of 20 foot Johnson valve.

The pipe connection at point 4 serves also the purpose of priming the turbine casing during the opening cycle. When the control lever is thrown over to the opening position, and valve 1 opens the inner chamber to atmosphere, the plunger cracks open until the jet velocity causes a sufficient drop in pressure to close valve 1, upon which the plunger immediately moves back to its seat. It opens up again immediately, however, as the control lever is still in the opening position, so that a reciprocating oscillation of

the plunger is automatically set up which continues until the turbine casing is primed, after which the plunger moves to its final position.

Plate C—26 also shows the necessary connection for the automatic closing of the valve in the event of a break in the turbine casing or any accident which would result in losing control of the penstock water-column. This result is achieved by the simple expedient of connecting valves 2 and 3 to the turbine casing by means of the pipe indicated at point 5. This connection, as regards the closing stroke, functions in precisely the same manner as the throat connection at point 4.

At point 15 is a valve which controls the automatic closing connection, through the agency of a pair of dogs on the indicator arm. When the plunger is seated this valve is closed, so that the throat connection can function for the priming operation. When the plunger moves open the dog on the indicator arm throws valve 15 open so that the automatic closing feature may function if required.

Plate C—27 is a shop assembly view of a 16 foot Johnson valve now installed in a Canadian plant under a 300 foot head, which clearly shows the control mechanism, the control valves numbering 1, 2 and 3 from the left, according to the previous diagram. The vertical valve on the left is the exhaust from the inner chamber, which is also in view on the left. The horizontal valve in the centre is the penstock pressure connection, while the other vertical valve is the exhaust from the annular plunger chamber. At the extreme right is seen the nose-piece of the moving plunger projecting beyond the cast steel housing.

Plate C—28 is a view of a 20 foot Johnson valve built in Canada, which is at such a stage of assembly as to show very clearly the main annular water passage and the annular plunger chamber.

The tightness of the Johnson valve is due to the wide angle at which the seat rings meet when in the closed position. There is no dragging of unlubricated surfaces tangentially over each other under heavy pressure, while at the same time the sealing surfaces meet with great pressure intensity, due to the small area of contact, the result necessarily being an extremely tight closure.

Plate C—29 is a view of the first Johnson valve ever built. This valve has been operating continuously in a Canadian plant since 1911. It is still in perfect condition, and has had no repairs or maintenance whatever in the interval, beyond an occasional coat of paint.

Governors.—The development of the art of speed regulation and control in Canada has been materially influenced and simplified by three factors which are complementary to, but not integral with the governor mechanism itself; namely the modern methods of controlling the inertia and momentum of long water-columns;

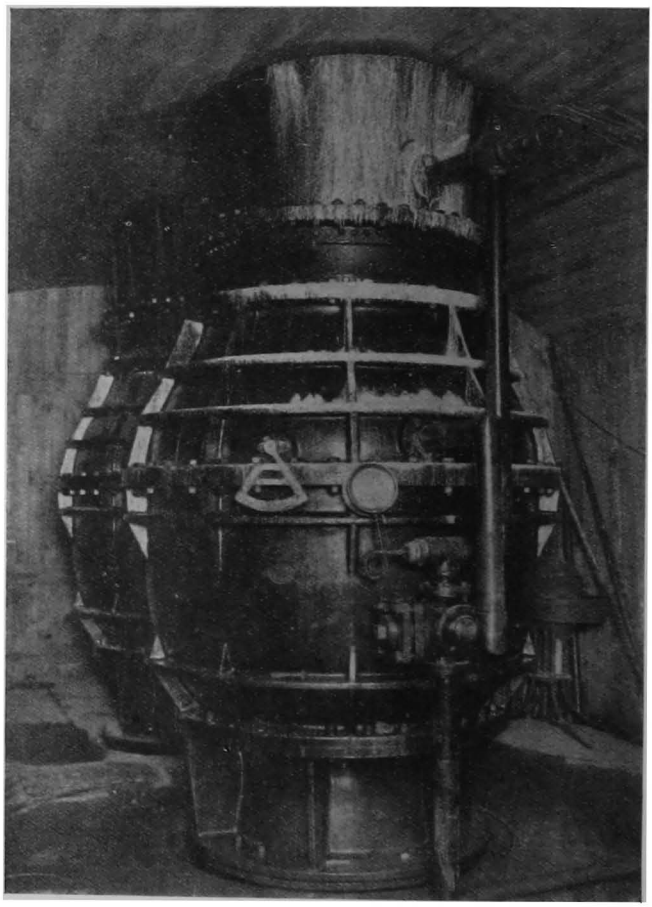


Plate C-29.—First Johnson valve installed in 1911.

the inherent fly-wheel effect of large generators, combined with automatic voltage regulation; and the system fly-wheel effect of the large transmission net-works which absorb the output of the majority of large Canadian installations.

As to the turbine governor itself, the so-called double compen-

sation principle is the accepted basic element of design, together with the utilization of the inherent speed-drop characteristic to maintain stable conditions of synchronism and load distribution on unit groups in parallel, within such normal range of demand as may be fixed by the characteristics of the connected load.

Briefly described, the double compensation principle of speed control, as applied in Canadian practice, involves first the provision of a quick-acting direct primary impulse on the turbine gates, which causes an immediate change in their position in response to the initial impulse arising from a change in load, and the consequent tendency toward a change in speed. This primary impulse is effected through a mechanical connection between the centrifugal governor head and a pilot-valve, which in turn releases sufficient governor fluid to enable the servomotors to move the gates. At the same time, there is applied to this initial movement of the gates a primary compensation in the form of a restoring mechanism, which, immediately following the commencement of gate movement, reacts directly upon the pilot valve, closing its ports, and checking further movement of the gates. As the restoring mechanism is mechanically actuated by the gates themselves, the cycle of primary impulse and primary compensation is entirely self-contained and reciprocal for any one change of speed.

Following the above primary cycle, and coincident with it within a very short interval, a retarded secondary compensation begins to function, usually through the agency of a spring controlled oil dash-pot. This secondary compensation takes control of the gates, and at a greatly reduced rate adjusts them in such a way that normal speed is restored within a small percentage, varying with the magnitude of the load change. This secondary compensation, besides counteracting the hunting tendency induced by the primary impulse on the gates, and which is sometimes only partially offset by the primary compensation, has the further important function of effecting the final gate adjustment in harmony with the amount of absorption or building up of head energy in the penstock, turbine and draft-tube water-column, as induced by load changes, and as related to the normal effective head on the turbine. Therefore, while the primary compensation, in restricting the gate motion, nevertheless allows a considerable amount of initial variation in speed, the secondary compensation overcomes this speed variation at a slower rate, and finally restores the balance between gate opening and load demand, the

extent to which the secondary compensation functions being measured jointly by the magnitude of the load change involved, and by the inertia of the water-column.

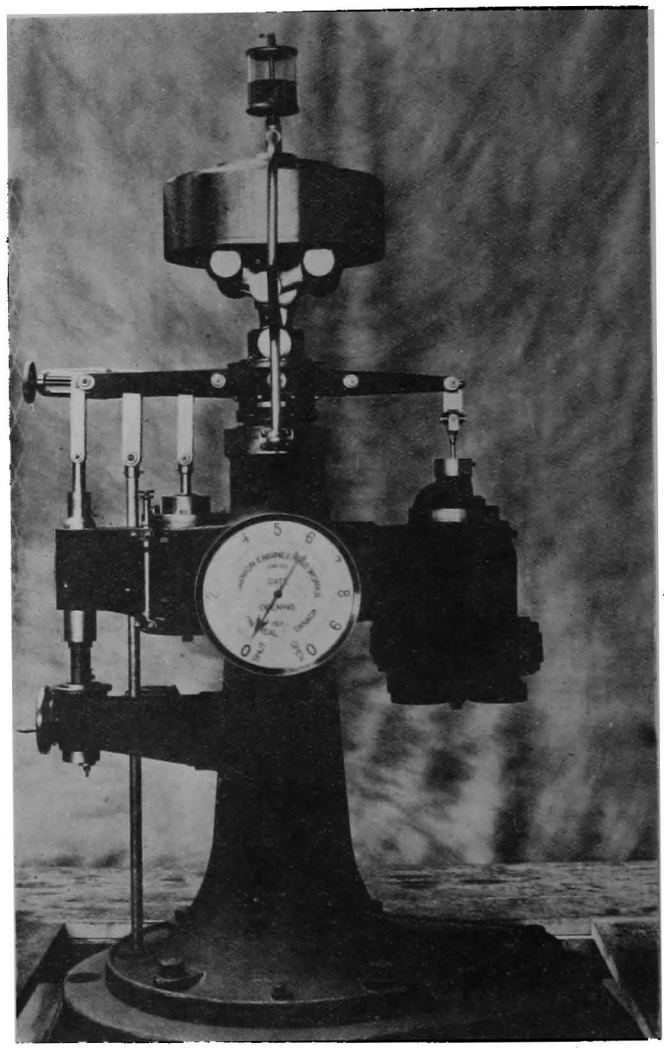


Plate C-30.—Belt-driven turbine governor.

Plate C—30 illustrates a governor of the type above described. At the top of the column is a shrouded centrifugal element to which a double floating lever is connected. One end of this lever

is shown connected direct to the pilot-valve, but the pressure pipes leading therefrom to the main governor valve are not in the picture. To the left the restoring rod may be seen passing through the base of the column, and to the right of the restoring rod is the dash-pot connection. Both of these are connected to a secondary floating lever which is suspended at the end of the main lever as shown. To the left of this point of suspension is a spring connection which has an adjustable point of attachment to the secondary lever, in order to regulate the movement imparted to the dash-pot by the restoring rod.

The fly-ball drive spindle passes up inside the column and is connected to the main shaft by either a belt or a gear drive.

As the primary requirements of governor operation are precision and reliability, the natural trend of development has been in the direction of simplicity in principle, the reduction of lost motion by the use of a minimum of moving parts, and precise shop work. Arising out of these requirements, there have been several recent innovations in design, among the most interesting of which is the shaft fly-ball drive, the centrifugal element being mounted direct on the main turbine shaft, thus obviating the complication and uncertainty of a belt or gear drive.

Plate C—31 shows a view of one unit of a small Canadian installation equipped with a governor of this type. In the foreground may be seen the essential parts of the centrifugal element, which is mounted on the main shaft within the cylindrical housing, as shown in the view. This view also clearly shows the mechanical connection between the centrifugal element and the pilot-valve.

Another recent improvement of great value is the substitution of automatic plunger valves for gate-valves in connection with the control of the governor fluid. This substitution is particularly useful when changing over from governor to hand control. With the older type of control the opening and closing of four to six gate-valves involved not only an expenditure of time that could be ill-spared in an emergency, but a serious hazard due to ignorance or carelessness on the part of the operator. The new type of control, on the other hand, enables the operator to simultaneously close all governor control valves and open all hand control valves, or vice versa, with a single movement of one control lever. This operation can, therefore, be performed so quickly that there is little or no chance of losing control of the unit, and no chance whatever of varying the proper sequence of procedure.

Remote switchboard control has also developed to such a stage that there is considerable latitude as to the location of the actuator, which is sometimes placed on the machine-room floor, in some cases on the switchboard gallery, and in others directly over the servomotors.

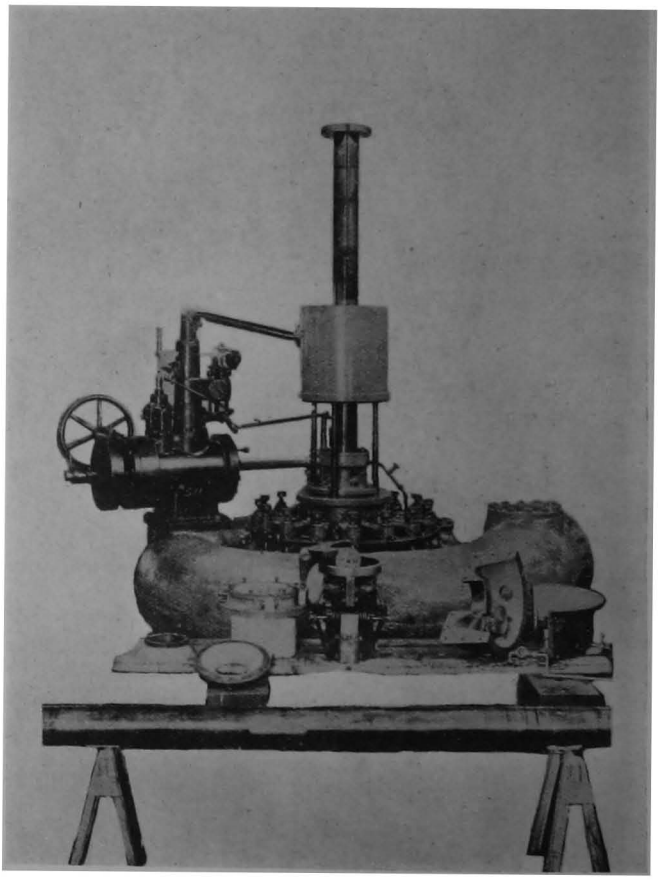


Plate C-31.—Turbine with shaft fly-ball governor.

Plate C—31 illustrates the latter type of installation. On the other hand, the actuator illustrated on Plate 30 is located on the machine-room floor, 40 feet above the servomotors.

As exemplified in the types of governor above described, the double compensation principle, combined with the restoring mechanism, and the load-limiting attachment where necessary,

appears to meet all requirements of turbine speed control adequately and safely, and efficient regulation is assured within safe operating limits for all gate movements up to the full stroke of the servomotors.

While the preceding statement is true throughout the full range of hydro-electric plant operation and interconnection, it is not always true where hydro-electric and steam-electric plants are operating in parallel. In many such cases there is a tendency toward unequal distribution of load by reason of the comparatively short time element in governing, and the frequently greater fly-wheel energy, of steam-electric units.

Draft-tubes.—Recent advances in the art under this head, in Canada, are largely attributable to the vogue of the "super-turbine." As the unit capacity of turbine installations increased, it was found that the unstable regimen of the water-column in the then existing types of draft-tubes so magnified the effects of vortex action and intermittent vacuum as to cause troublesome and often dangerous operating conditions. These conditions manifested themselves variously in the form of pulsations communicated to the penstock water-column, and in periodic vibratory and resonance effects in the power house superstructure which seriously interfered with operating procedure.

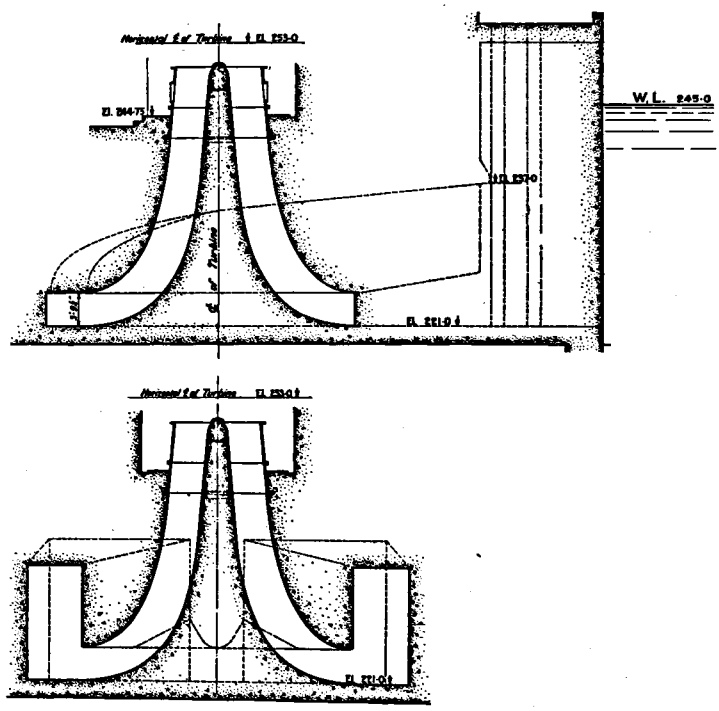
Considerable attention has, therefore, been given, within the last four or five years, to this phase of hydraulic design, and due to an efficient combination of theoretic and experimental research on the part of American turbine manufacturers and their customers, a very gratifying measure of success has been achieved.

The fundamental truth established by these investigations was that there could be no rational basis upon which the performance of various types of draft-tubes might be compared, unless a fixed relationship existed between the specific speed of the runner and its elevation above static tail-water level. In other words, the absolute velocity of the runner discharge has a definite inverse relationship to the elevation of the runner above tail-water, which must be recognized in connection with performance comparisons. With this condition taken cognizance of, or eliminated, a rational analysis of the results of recent important laboratory tests may be attempted with some assurance of reaching correct conclusions.

Of the earlier types of draft-tube, the vertical diffuser was the most efficient, in that it permitted the regaining of an appreciable part of the velocity head of axial flow if properly designed, and if the tail-race were deep enough. However, as the specific speed

of the runner increased, the necessary corresponding increase in length of vertical tube and depth of tail-race finally reached a point where capital cost became a controlling factor. This situation was met by an expedient which gave birth to the widely used elbow type draft-tube; namely, the turning upward and outward of the lower section of a vertical diffuser, the result being a hybrid structure of which the upper section was a true draft-tube, and the lower a tail-race, with the junction between the two effected

PLATE C-32



Moody type spreading draft-tube.

through a quarter turn of such inherent hydraulic characteristics as to largely destroy the respective functions of the other two elements of the structure.

The elbow type draft-tube had a practically exclusive vogue until the specific speed and capacity of the turbine runner had further increased to such an extent that the energy losses in the draft-tube became a matter of serious concern, not alone from the standpoint of efficiency, but by reason of the power and intensity of the

disturbances through which these losses became manifest. This condition was, of course, due to the fact that the tangential or " whirl " component of flow was increasing with the specific speed, and causing a proportionately greater interference with the axial component of flow, as the two traversed the quarter turn into the horizontal or tail-race section of the tube. The result was not only largely to neutralize the benefit of regained axial velocity head in the vertical or diffuser section of the tube, but to restrict the effective waterway area of the tail-race section with vortices and periodic reversals of flow.

The search for a remedy for the above situation led to the development of the so-called " mushroom " type of elbow draft-tube, together with a number of other more or less abnormal variations of the original elbow type, the whole embracing an evolutionary process which found its first rational expression in the White hydraucone.

The White hydraucone is essentially a vertical diffuser so modified as to make it applicable, within feasible dimensional limits, to installations of large unit capacity. This modification is effected by substituting, for the abnormal length of tube and depth of tail-race otherwise required to meet the demand of a constantly increasing specific speed, a horizontal baffle or diaphragm, normal to the axis of the tube, and elevated a short distance above the invert of the tail-race. The falling water-column impinges on this diaphragm, spills over and around its edges into an expanded lower chamber, from whence the water runs to waste. The function of the diaphragm is to assist the diffuser section in maintaining the integrity of the water-column, or " hydraucone," and to regain velocity head, acting, in an elementary sense, in the same manner as one of the buckets on an impulse wheel. The function of the lower chamber is to carry the " spill " to waste with the assistance of the residual absolute velocity.

The " hydraucone " was a distinct improvement over the elbow type tube, but inasmuch as the discharge from a reaction turbine runner is not purely axial, as in the case of the nozzle of an impulse turbine, the functioning of the " hydraucone," as a velocity head regainer, suffered to an appreciable degree the same disability as the elbow tube, in that it was unable efficiently to reclaim the energy of whirling flow, owing to its inability to control the turbulence of the draft-tube water-column. Nevertheless, the White hydraucone marked the emergence of draft-tube design from a stagnant period during which unsound theory and ill-

conceived expediency prevailed, the draft-tube being considered a thing apart from the turbine, except as a convenient means of piping off the runner discharge as quickly and cheaply as possible.

Apart from the incentive arising from a desire for essential rightness of design, a distinctly commercial element has been in a large measure responsible for recent advances in the art of draft-tube design; namely, the fact that the large capacity turbines of the present day permit an appreciable increment of useful power to be reclaimed as the result of a gain of only a fraction of 1 per cent. in overall efficiency.

Based, therefore, on this double incentive, the object of recent experimental research has been to regain as much as possible,

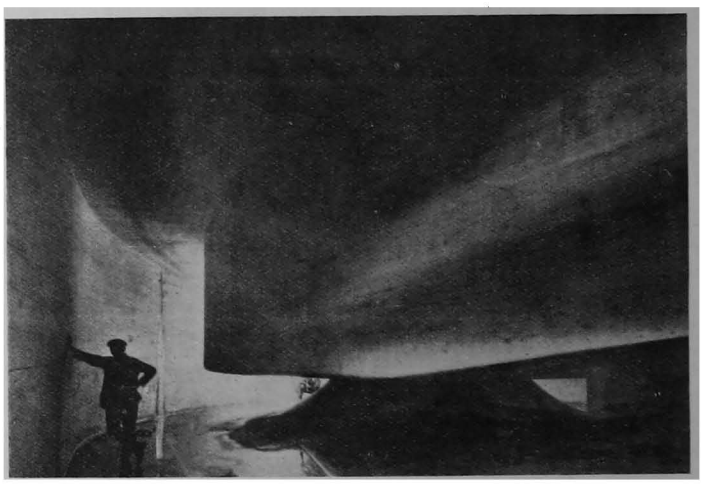


Plate C-33.—Spreading draft-tube with high concentric cone.

not only of the axial, but of the tangential component of the velocity head of the runner discharge, and to devise means of training the combined axial and whirling flow, through properly shaped water passages, so as to eliminate vibration and transmitted pulsation to the greatest extent possible.

The research work so far accomplished by the principal turbine builders in the United States has demonstrated the faulty basis of conception and relative inadequacy of all forms of the elbow type tube, and, beginning with the " hydraucone," has developed a series of types, more or less co-related, which have given satisfactory results in commercial operation.

Of the later types of draft-tube so developed, that known as the

Moody Spreading Draft-tube has found somewhat general acceptance in Canadian practice. The most recent type of Moody tube is illustrated on Plate C—32, the drawing being sufficiently clear to obviate the necessity of a detailed explanation.

This tube was conceived in theory, and experimentally developed, on the basis of the following facts and assumptions:—

(*a*)—That the inverse relationship between the specific speed of the runner and its elevation above tail-water is an essential factor in design, and as such must be fixed.

(*b*)—That the draft-tube is as much a part of the turbine mechanism as any of the other water passages.

(*c*)—That in any reaction turbine, tangential or whirling flow is always present in the runner discharge at part-gate and over-gate.

(*d*)—That in reaction turbines of the higher order of specific speeds there is whirling flow at all gate-openings.

The above conditions are more or less a recapitulation of the previous discussion, and recent exhaustive tests have confirmed, respectively, the fact of their existence or their justification. The tangible result, as shown on Plate C—32, is a tube where the annular contour of the runner discharge is preserved intact from the runner to the tail-race invert, by training the combined tangential and axial flow, directly from the point of origin, through a gradually expanding and carefully transitioned sequence of annular areas, until a point is reached where the residual velocity head is required for the disposal of the spent water. Inasmuch as the central cone solidly fills the region of maximum turbulence, it seems reasonable to assume, even without experimental confirmation, that it must be effective in preventing cavitation, and the formation of vortices, with their resultant vibratory effects. Serving this purpose, it also naturally follows that it must effect a useful conversion of hitherto wasted whirl energy in the central zone, realizing thereby a gain in efficiency as well as a betterment in operating conditions.

On Plate C—33 is shown a partial view of the latest type of spreading draft-tube installed in a Canadian plant, as part of a 58,000 E.H.P. turbine. The view shows one side of the discharge passage leading to the tail-race, and a portion of the lower circumference of the diffuser section surrounding the central cone.

The spreading draft-tube has a very essential function in connection with low head turbines of high specific speed, as it improves efficiency throughout the full range of gate-opening. Used with

high head turbines of low specific speed, it is of considerable value as related to part gate efficiencies and overload capacity. In the case of high head turbines of very large capacity it is of material benefit, apart altogether from considerations of efficiency, in largely eliminating the operating hazard which would otherwise

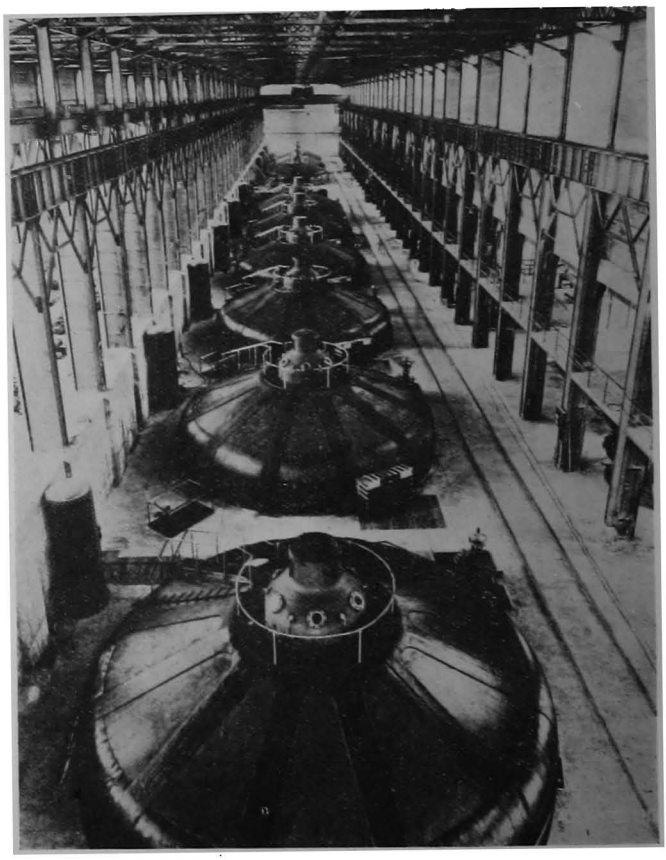


Plate C-34.—Large low head vertical installation.

obtain through the powerful reactions produced by disturbances in the heavy water-column of the draft-tube.

Turbines.—By reason of the limitations imposed in the opening chapter, the scope of the discussion under this head will be limited to the consideration of reaction turbines, as the development of heads in excess of 500 feet has not been sufficiently

extensive in Canada, up to the present time, to produce any unusual or distinctive features.

Head conditions requiring the use of impulse turbines are confined almost exclusively to the Pacific coast region, where there are important developments using the widely known Pelton type runner under heads ranging from 400 to 1,820 feet, and in unit capacities as high as 13,000 E.H.P.

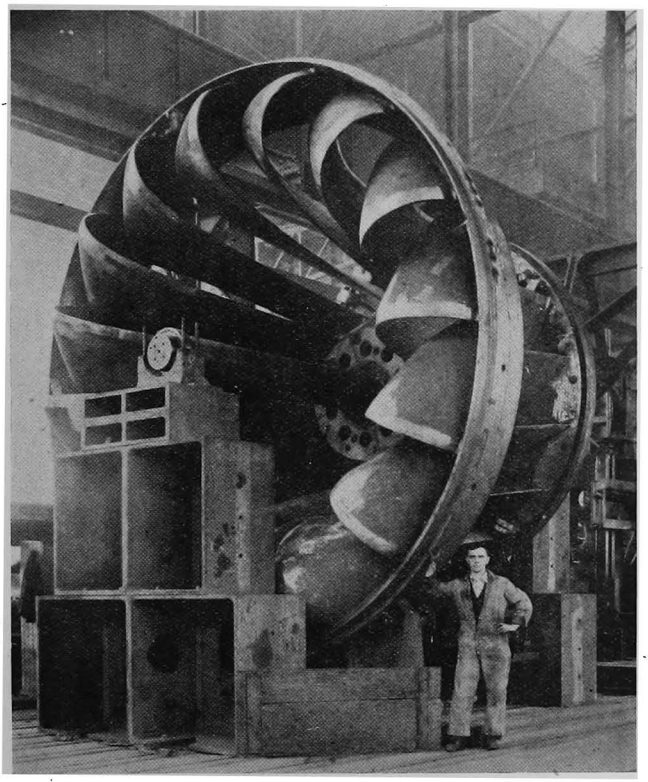


Plate C-35.—Large low head runner of 11,400 E.H.P. capacity.

While some interesting variations in impulse runner design are now under investigation and test, nothing has as yet transpired to challenge the supremacy of the Pelton type turbine in the high head field, either in Canada or the United States.

In the reaction turbine field, the primary outstanding feature of Canadian practice has been the adoption of the single runner vertical setting for Francis type turbines. While the original

incentive toward this type of setting was undoubtedly due to the large unit capacities involved, its popularity subsequently led to its application through a wide range of unit capacities and speeds, until in Canada to-day this type of setting may be regarded as standard practice, with the horizontal double or multi-runner setting an obsolete type, used only in relatively unimportant installations or in connection with the extension of old plants, where the original commitments rendered any radical change in design impracticable or unduly expensive. An extreme case, where the vertical single runner setting was amply justified by operating conditions alone, is illustrated on Plate C—34, which is a view of a large plant in central Canada, having a total installation of 195,000 E.H.P. in units each of 10,800 to 11,400 E.H.P. capacity, operating at 56 R.P.M. under a normal head of 30 feet. The immense size of the runner is evident from the shop view shown on Plate C—35. This runner has a lower band diameter of 17½ feet and a finished weight of 175,000 pounds.

Including the feature above mentioned, it may be stated that since the 10,000 H.P. prototype of the modern super-turbine was installed at Niagara eighteen years ago, the subsequent advances in turbine design have been directed toward the improvement of efficiency in the broad sense previously defined, including strength, simplicity, and economy in the use of water. In this connection the spreading draft-tube may be looked upon as a development more or less complementary to the use of the single runner vertical setting, and may be bracketed with it as a joint primary agency in improving the operating efficiency of large reaction turbines.

In large capacity turbines the question of the stiffness and stability of the scroll-case becomes a matter of importance, depending upon diameter and pressure conditions. As between cast-steel and steel plate scroll-case construction there is no definite field of application, beyond a preference for cast-steel in the larger capacities where the static head is in excess of about 200 feet, as the steel plate construction, under such conditions, is subject to deformation and requires the support of a heavy mass of concrete in the power house substructure, while a cast-steel scroll-case, similarly placed, actually contributes to the stability of the power house foundations.

In the matter of cost, there is usually no material difference between the two types, if due consideration is given to equivalent hydraulic characteristics and to the great saving in time and labor which is realized in the field assembly of the cast-steel, as

compared with the steel plate casing. Furthermore, the steel plate casing is not susceptible of a pressure test before final installation, so that perfect workmanship and careful inspection constitute the only assurance that the requirements of the design have been met, and that leakage or other defects will not develop under operating conditions.

Plate C—36 shows a shop view of a plate steel scroll-case being built in a Canadian shop for a large installation now under construction in eastern Canada. This casing has an inlet diameter of 20 feet, and the completed turbine will be one of twelve having a capacity of 40,000 E.H.P. under a 100 foot head.

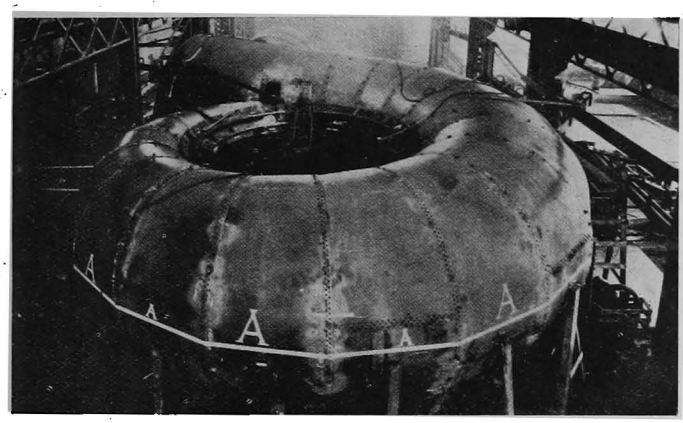
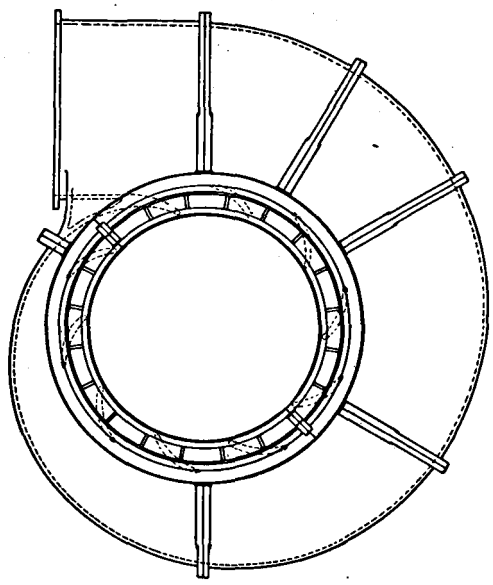


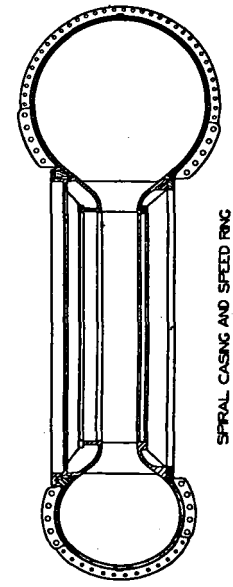
Plate C-36.—Steel plate scroll-case under construction.

Plate C—37 illustrates a condition which has given trouble in connection with the design of very large cast-steel casings.

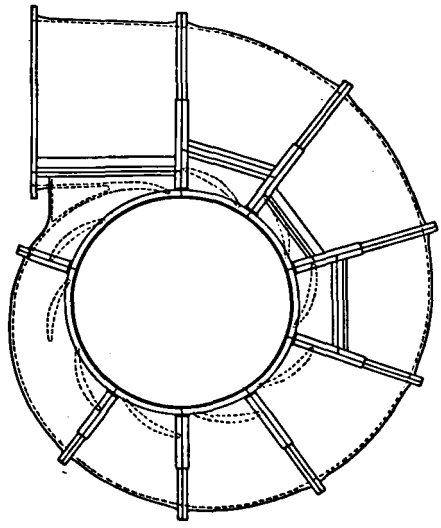
The figure to the right is an outline of the ordinary type of scroll-case casting with flanged radial sections making a bolted connection with the circumferential flanges of a separately cast speed-ring. It will be seen that the bolt circles of the radial flanges necessarily terminate at the edges of the horizontal flanges of the speed-ring, with the result that the tendency of the casing section to open up under internal pressure causes a cantilever stress in the unsupported section of the radial joint adjacent to the upper and lower speed-ring flanges. In large casings designed for high heads this stress is frequently so great under pressure test as to stress the bolts beyond the elastic limit, and to deform the flanges and bolt-holes, with a resultant serious leakage.

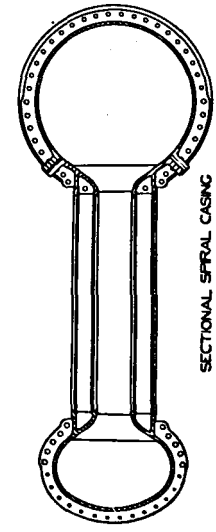
PLATE C-37





SPIRAL CASING AND SPEED RING





SECTIONAL SPIRAL CASING

Comparison of new and old designs of large scroll-cases.

The corresponding figure to the left on Plate C—37 illustrates the means devised to remedy the conditions above described.

In this type of casing, known as the Taylor sectional spiral casing, each radial section is split transversely, and the speed-ring stay-vanes are cast integral with the small inner section. The transverse joints are staggered, and so located as to permit of heavy flanges and effective bolt spacing, not only in the transverse flanges, but in radial flanges throughout their full length, as the drawing shows.

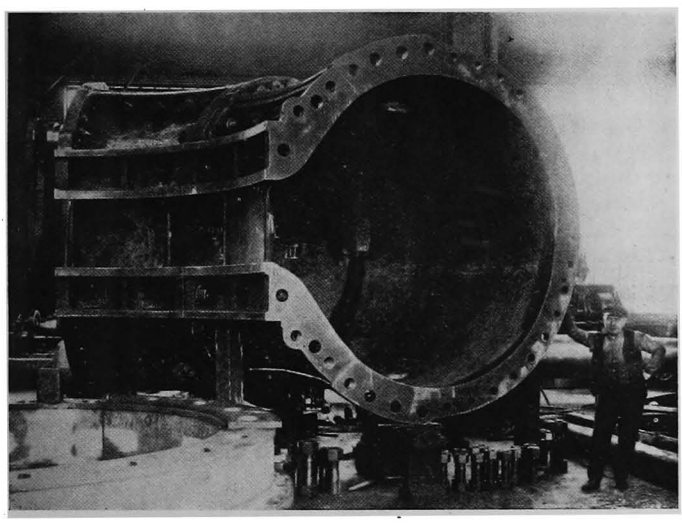


Plate C-38.—Two radial sections of sectional scroll-case.

Plate C—38 is a shop view of two radial sections bolted together, which clearly shows the integral stay-vanes, the transverse joint, and the bolt spacing of the radial flange. Plate C—39 shows a completely assembled scroll-case of this type ready for the shop pressure test. This casing was the first of the sectional type ever built, and was for a turbine of 58,000 E.H.P. capacity later installed in a plant in central Canada, under a 300 foot head. This casing successfully met a pressure test of 260 pounds per square inch, on the first trial, with no indication of leakage or deformation.

The showing made by the sectional scroll-case under shop pressure test would seem to indicate that no undue risk would be involved in setting very large casings of this type, under heavy operating pressures, entirely in the open, with only such a

quantity of surrounding concrete as might be necessary to secure a stable anchorage and freedom from vibration.

Another useful feature incorporated in modern Canadian practice is the Rogers offset lever operating mechanism, as illustrated on Plate C—40.

For efficient speed regulation, any change in speed should correspond to a definite change in load throughout the full loading range of the unit, and most governors are so designed that any such change in speed also gives rise to a correspondingly fixed displacement of the servomotor piston. The piston displacement, however, cannot produce a continuously proportional gate movement at all stages of load, as the angular movement of the gates must of necessity be governed by the load on the turbine at the

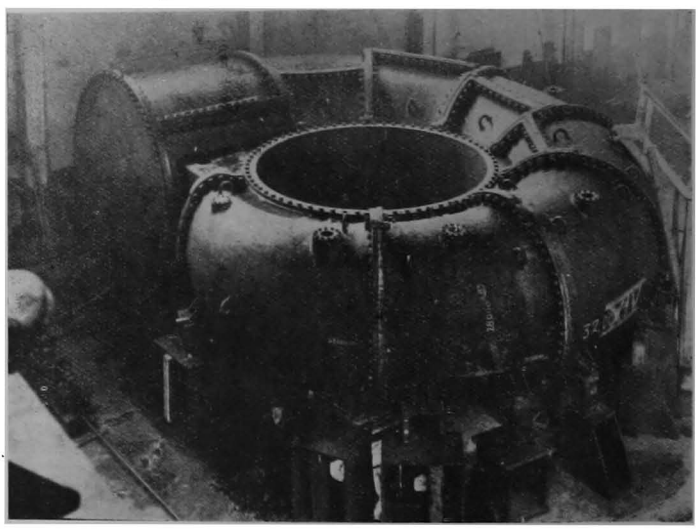


Plate C-39.– Assembled sectional scroll-case under 260-pound pressure test. Three million pounds on head-cover.

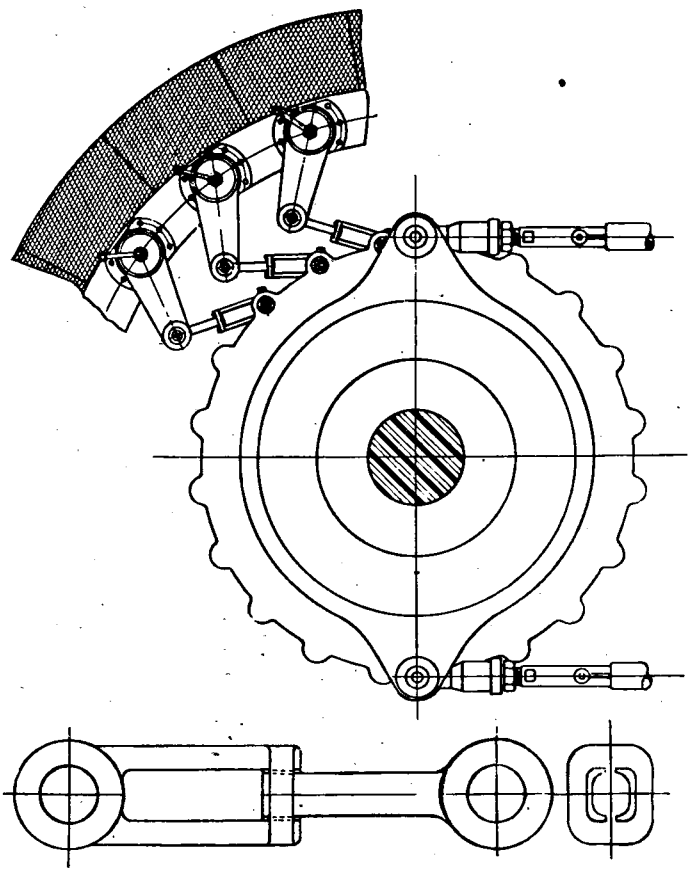
time of such movement, and is therefore a function of the shape of the efficiency curve. The advantage claimed for the offset lever mechanism is that it meets the above requirements more efficiently than the ordinary radial lever type.

As the operating ring moves counter-clockwise to close the gates, it is evident that the angular movement of the gates will decrease, for a given piston displacement, as the gates close. This characteristic is advantageous at small gate-openings, as it reduces the amplitude of the piston and pilot-valve oscillation which obtains

under such gate-openings by reason of unstable hydraulic conditions.

A further advantage of this type of operating mechanism is that the maximum torque on the gates is exercised when they are in the closed position and thus subjected to the maximum hydraulic

PLATE C-40



Offset lever mechanism and breaking-link.

load, thus reducing the governor capacity which would otherwise be required.

With an efficiency curve of the shape usually traced by the larger turbines used in Canada, the offset lever mechanism preserves a

more consistent relationship between piston travel and angular gate movement, up to the point of maximum efficiency, than the radial lever type. Beyond this point the radial lever mechanism has somewhat the advantage. This feature in favor of the radial lever type is largely discounted, however, where economy in the use of water is a material factor in operation.

Plate C—40 also illustrates the type of breaking link used with the offset lever mechanism. As clearly shown in the illustration, this link will fail in shear, thus giving consistent protection to the gates and gate-shanks independent of whether they encounter an obstruction on the opening or closing stroke, or whether the link as a whole is consequently in tension or compression at the time of failure.

In high head turbines of large capacity, the great circumferential dimensions introduce a leakage factor which materially affects efficiency where the ordinary type of seal ring and gate shank is used, and more particularly when the clearances have become enlarged through ordinary wear, or the action of silty water. This condition has been met by the use of the so-called "labyrinth seal" and by the "Overn disc," both of these devices having been recently incorporated in the design of large Canadian built turbines.

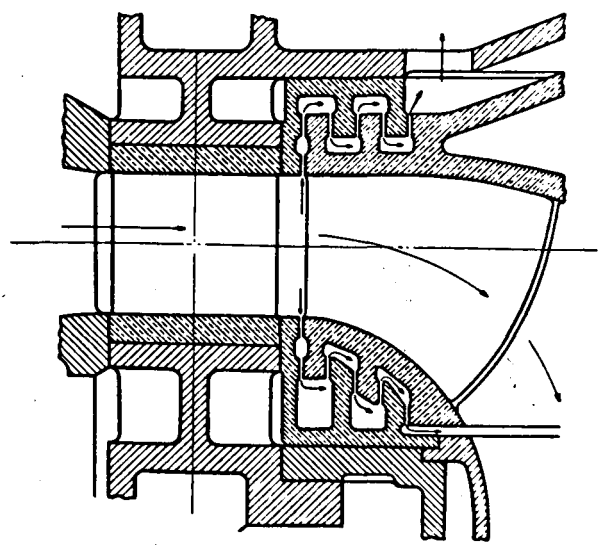


Plate C-41. Diagrammatic illustration of labyrinth seal.

Instead of the ordinary simple seal consisting of a straight annular passage past the crown of the runner into the space under the head cover, and a similar passage past the runner-band into the draft-tube, the labyrinth seal consists of a series of alternately expanded and contracted passages which destroy the velocity head, and reduce the head on the final free jet to a fraction of its original value. The diagram shown on Plate C—41 indicates the shape and disposition of the expanded and contracted passages, as well as the direction of flow of the leakage.

The Overn disc consists simply of two annular rings cast integral with the gate-shank, one at each end of the gate proper. These

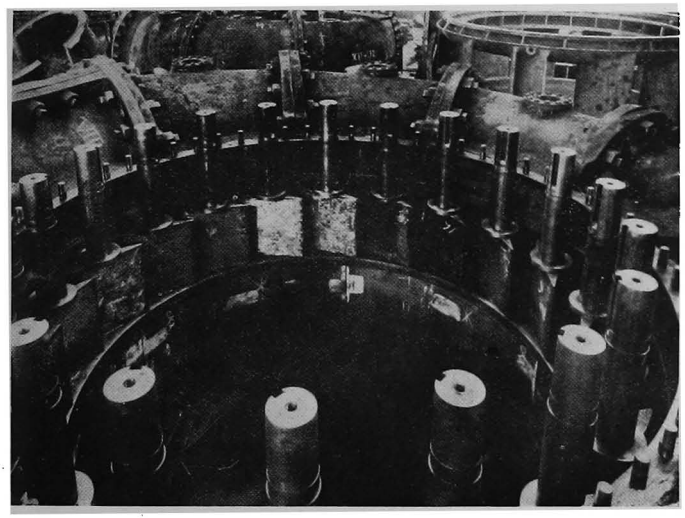


Plate C-42 Gate assembly showing Overn disc.

discs are machined, and are so located as to set flush with the upper and lower distributor plates. Therefore, while they do not in any way obstruct the flow through the gates into the runner, they materially reduce the leakage through the gate-shank stuffing boxes at all times, and also through the upper and lower gate clearances when the gates are closed. This device also provides a very strong mechanical connection between the shanks and the gate itself. The view on Plate C—42 clearly illustrates the function of the Overn disc and the manner of its installation, being a complete gate assembly with the upper discs in view at the point of junction of the shanks and vanes.

As in the case of the power development as a whole, the basis of high efficiency in a turbine is the provision of water passages of ample section, with abrupt changes in direction of flow eliminated wherever possible, and where such changes are unavoidable, careful proportioning and transitioning. Secondary, but none the less significant factors are the elimination of leakage and other minor refinements as above described, together with accurate shop work. As related to present Canadian practice, a gain of one per cent. in the efficiency of a turbine of 40,000 E.H.P. capacity, as a result of the proper consideration of the above factors in the design, would produce sufficient extra power to supply the requirements of an average community of 2,000 population.

Plate C—43 shows a cross-sectional view of a 58,000 E.H.P.

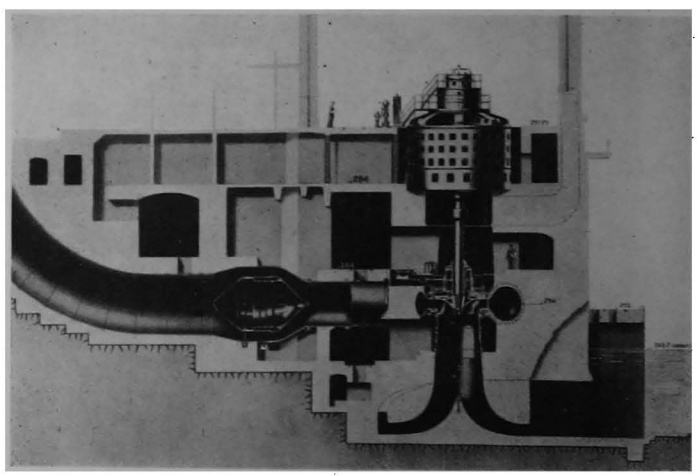
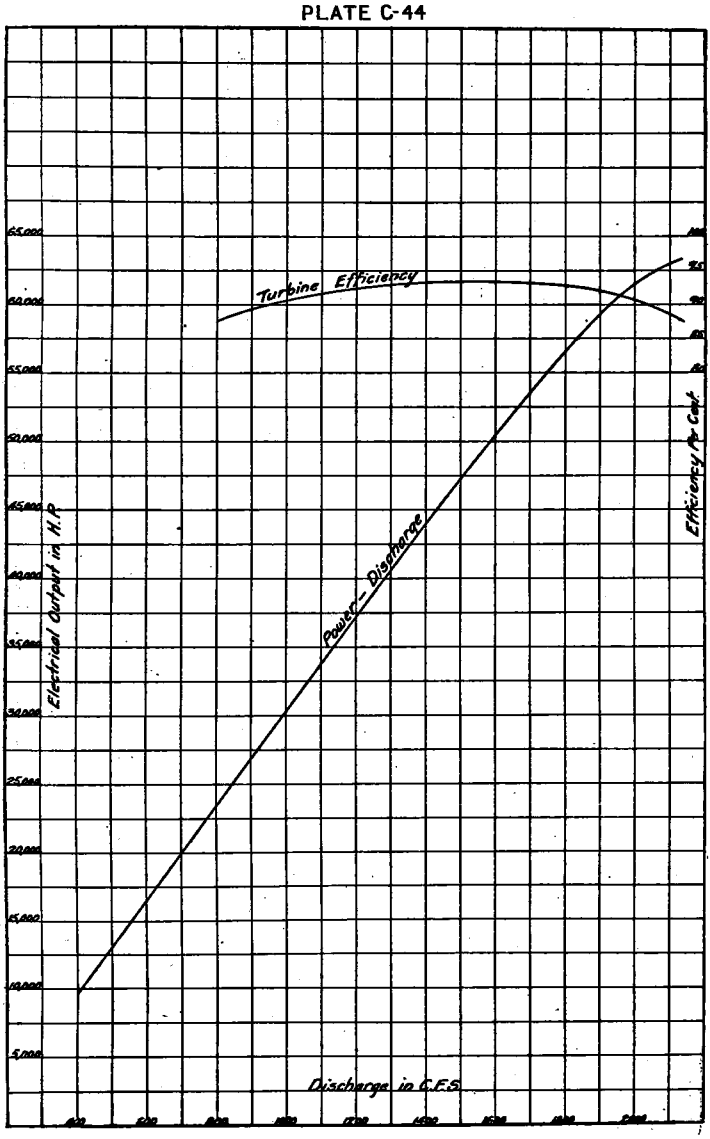


Plate C-43. Cross-section of 58,000 H.P. unit.

unit installed in an operating plant in Central Canada, in which the above specified principles of design are to a large extent incorporated. In this view will be noted the carefully designed annular water passage of the Johnson valve at the entrance to the scroll-case, the well-proportioned and transitioned passages through the scroll-case, speed-ring, and draft-tube, and the elimination of one right-angled change in the direction of flow through the use of the vertical setting.

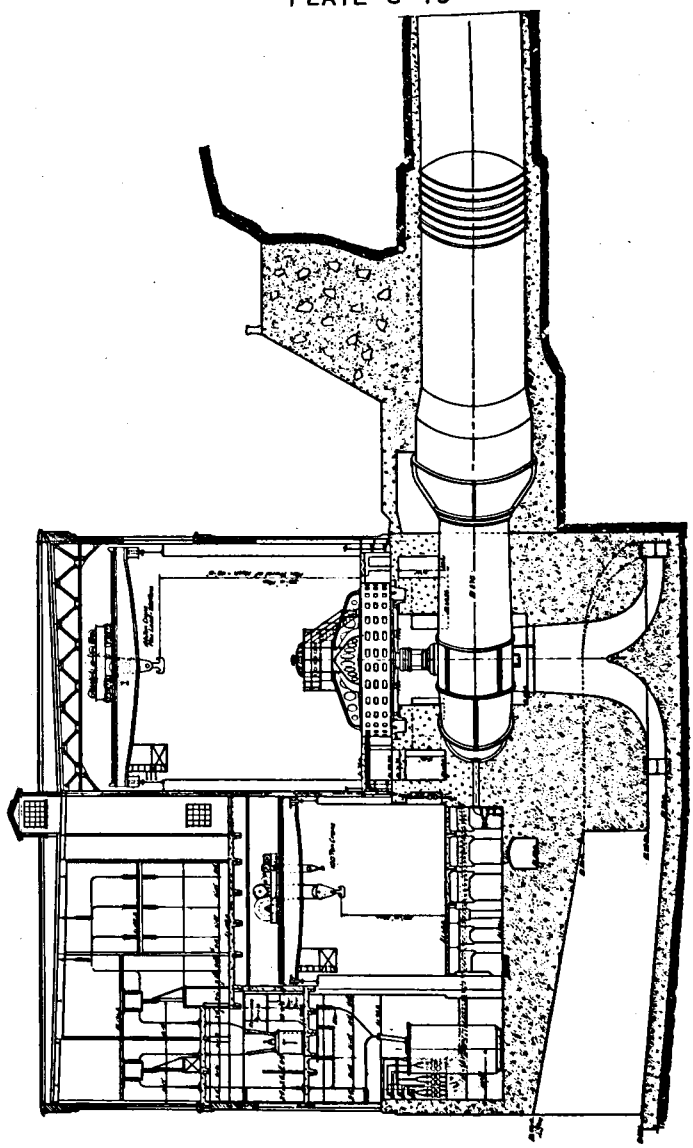
The advantage arising from a proper utilization and co-relation of these factors is exemplified in the efficiency-power-discharge curve for the above-mentioned unit, as shown on Plate C—44.

PLATE C-44



Turbine efficiency and power-discharge curve.

PLATE C-45



Cross-section of 41,000 H.P. unit.

The matters of interest in connection with these curves are as follows:—

(1)—The maximum turbine efficiency is 93½%.

(2)—The turbine efficiency at full gate is nearly 88%.

(3)—The output at full gate is 63,500 E.H.P. under a 305 foot head.

(4)—The turbine has a capacity range of 30,000 to 62,500 E.H.P. at efficiencies of 90% or over, and a capacity range of 38,000 to 60,000 E.H.P. at efficiencies of 92% or over.

(5)—The maximum overall efficiency at the switchboard, as determined during the period of the above tests, is 91%.

It is believed that the above results constitute the high record for a turbine of any type or capacity, up to the present time.

It will be noted, also, that this turbine was equipped with the original low cone type of spreading draft-tube.

A more recent installation, of the same general type, is shown on Plate C—45, which is a cross-sectional view of a 41,000 E.H.P. unit recently built and installed in Central Canada.

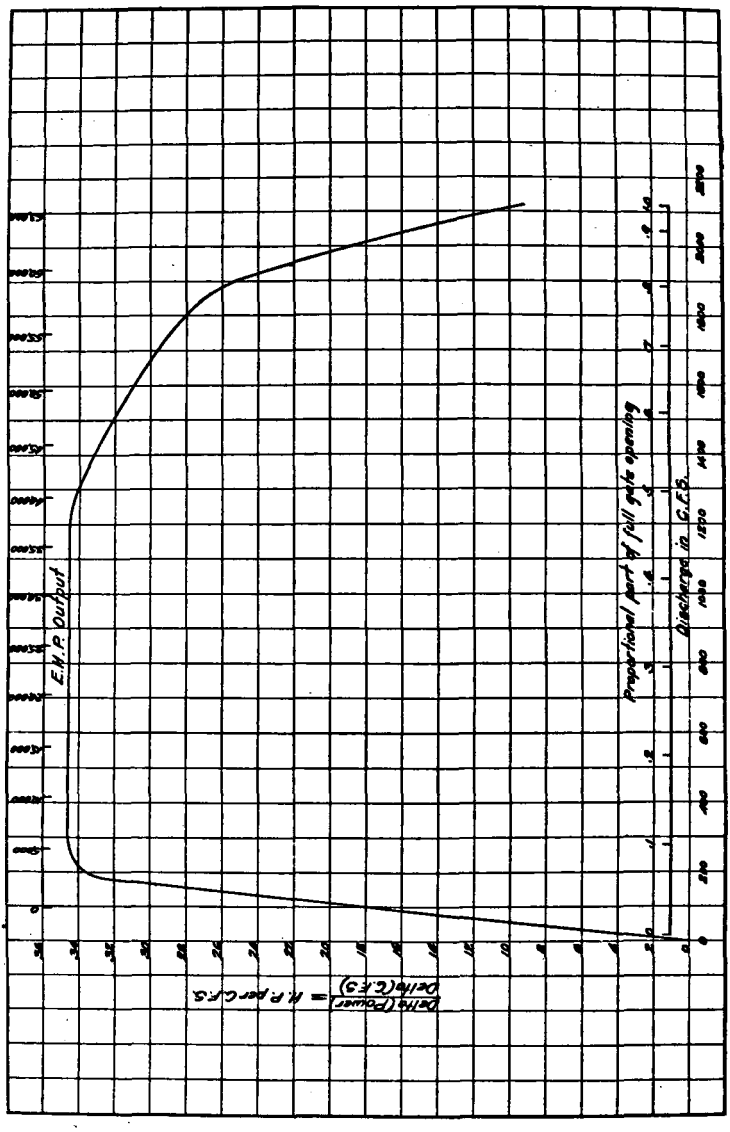
On Plate C—46 is shown an interesting curve representing the first derivative of the power-discharge curve on Plate C—44.

As its name implies, this curve is derived by plotting the amounts of horse-power produced per second foot of water, in various regions of gate-opening, by a very small additional opening of the gates. In other words, it shows, not the gain, but the rate of gain in power for an increasing rate of water input.

It will be seen that as the gate opening approaches the point of maximum efficiency, the corresponding rate of gain in power per unit of water input is 34.5 E.H.P., while actually at the point of maximum efficiency, with a water input of 1,500 second feet, the gain in power for one additional second foot supplied is about 32 E.H.P. On the other hand, in the vicinity of full gate, where the turbine is taking water to the limit of its capacity, the gain in power for one additional second foot supplied is only 9 E.H.P.

The two extremes above cited serve to illustrate the significance of previous statements made under the head of flow in long pipe-lines, and also to confirm the truth of the following statement; that under high heads, where the gross potentiality per second foot of water is correspondingly great, it is in the best interests of economy, as well as safety, to operate normally at the point

PLATE C-46



First derivative of power-discharge curve.

of best efficiency, and to employ the excess capacity of an over-gated turbine for emergency purposes only, and not for routine operation. This statement has an added significance, also, when the water supply is artificially stored.

Furthermore, it is obvious that as the point of maximum efficiency is also the point of minimum hydraulic loss, the rate of runner deterioration at this point must also be a minimum. From this point on, the rate of runner deterioration is an accelerating progression, directly related to the degree of over-gate.

The points in favor of gating the turbine back to the point of best efficiency are; first, safe and efficient operation, particularly where long pressure conduits are involved; second, economy in the use of water under high heads, where the gross potentiality per second foot of water is great, and where artificial storage is a factor; and third, on account of runner deterioration, particularly in the case of very large turbines, where runner replacement involves a material revenue loss.

The matter of turbine gateage has not, in the past, received the attention it deserves at the hands of the purchaser. It does not particularly interest the manufacturer, and must be covered, if at all, by the customer's specifications.

With regard to the pitting and erosion of runners, it may be said that super-turbine development has now reached a stage where this condition is no longer primarily a problem of design, but of economics. In other words, if the customer so specifies, the manufacturer can select a specific speed and supply, at a price, a turbine in which the runner will have as long a period of useful life as the other major elements of the installation.

Such a specification on the part of the customer would, of course, involve additional capital expenditure for the generator as well as for the turbine, but, as against this aspect of the situation it must be realized that the modern super-turbine frequently has a capacity which enables it to earn upwards of $2,500.00 every twenty-four hours. Consequently, the lost revenue charge against runner replacement in a fully loaded unit may easily run as high as $25,000.00. If this should happen to be necessary every two years, it would be equivalent, on a 6% basis, to a capital charge of $200,000.00. Such being the case, it is evident that the choice of a proper economic specific speed is a matter deserving the most careful and mature consideration, being a factor of at least equal importance with proper gateage and elevation relative to tail-water.

The outstanding fact, in connection with the above discussion, is that the super-turbine of the present day is capable of converting into net mechanical energy all but seven per cent. of the gross potentiality of the water supply. Extreme conservatism in the fixing of specific speed, and the combined effect of further small refinements in mechanical design may possibly raise part gate efficiencies to some extent in the future, and thus produce a slightly more advantageous shape of efficiency curve, but it would really appear that the large Francis turbines of the present day embody the ultimate, for any type, in respect of water economy at the point of best efficiency.

The disability of the Francis turbine, in its finally developed form, is its failure to meet fully the coincident requirements of increasing capacity and speed under low and medium heads, in response to a commercial demand for large unit capacities and reduced installation costs. This disability, being inherent in the type, and purely a function of the practicable upper limit of specific speed, was susceptible of only a partial solution by reverting to the objectionable and obsolete multi-runner setting, so that the designers of both hemispheres attacked the problem from the only angle that promised an adequate solution; namely, the development of a new type of runner.

The effort in this direction resulted in the development of the so-called high speed propellor type runner, which, in its various subsidiary types, is now in commercial use, both in Europe and North America. Of these types, the Kaplan (European), and the Nagler (United States), have a closely similar design and method of functioning, the flow through the runner being purely axial. In the Dubs (European) and the Moody (United States) types, the mode of flow through the runner is more nearly analogous to that of the Francis type, with the further distinction, in the case of the Moody runner, that the direction of exit flow is diagonal with respect to the axis of revolution; hence the trade name by which this type of runner is known in Canada and the United States.

As previously intimated, the unique feature of the propeller type runner is the possession of a specific speed, ranging upward to a maximum which has not yet been fixed by inherent limitations or by installation cost, and so far in excess of the Francis type that it bids fair to revolutionize the development of large water-powers under low heads.

The primary elements of design which combine to give the propeller type runner its high speed characteristics are, first, a

designedly induced condition of bodily whirl in the mass of water passing through the speed ring; and second, the use of runner vanes having a greatly reduced length in the direction of flow, in proportion to their pitch, as compared with the Francis type.

The first of the above conditions is more or less common to all types of high speed runners. The second condition is also common in principle, but differs considerably in degree. In the Kaplan and Nagler types, the disparity between the pitch of the vanes and their transverse projected width, and consequently their area, is pushed to such an extreme limit that only four vanes are used, with a clear opening between them nearly equal to half their pitch. In the Moody diagonal type, on the other hand, six vanes are commonly used, and a very greatly increased area and projected width is obtained, for a given runner diameter, by allowing the vanes to overlap; in other words, by making the transverse projected width of the vanes greater than their pitch.

Inasmuch as the torque is a function of the tangential component of the effective difference in pressure between the face and back of the vane, the Kaplan runner tends toward a maximum intensity of pressure difference for any given head, power and specific speed, as compared with the Moody type. The disability of the Kaplan type, therefore, arises from the fact that it realizes this high value of specific speed only at the expense of a correspondingly high value of pressure and vacuum intensity on the vane surfaces, and this condition, in addition to the use of a high absolute exit velocity, imposes a more or less onerous restriction on feasible operating head, from the standpoint of vibration, and the elevation of the runner with respect to tail-water level.

In the case of the Moody diagonal runner, the design is such as to avoid excessive pressure increases and reductions on the face and back, respectively, of the vane, without impairing the specific speed, thus eliminating local regions of unduly low absolute pressure behind the vanes, and effecting a resultant gain in range of head application, without the accompaniment of vibratory or unstable draft-tube conditions, or embarrassing restrictions in connection with the relative elevations of runner and tail-water.

The above description covers, in a general way, the basic variation in objective upon which the Kaplan and the Moody types of high speed runner were conceived.

The Kaplan type runner has not as yet been used in Canada, but several installations of the Moody type have been completed or are under way. No official tests are yet available in connection

with these installations, but tests of a 16 inch model of a recent Canadian installation developed an efficiency of 90.75 per cent., and in the United States an official test efficiency of 90.9 per cent. was obtained on a 1,700 E.H.P. diagonal runner unit, having a specific speed of 146 (635 metric).

In the high speed runner, a generally favorable efficiency characteristic is an inverse function of the specific speed. In the case of the Kaplan type all tests showed such a pronounced efficiency peak that economical operation was practically possible only at one gate-opening, for any fixed vane angle, and in order to retain the high specific speed characteristic, it was necessary to have recourse to the only practicable means of obtaining an operable efficiency range; namely, to vary the vane angle synchronously with the gate-opening. This purely automatic expedient is now established as an essential element of the Kaplan turbine mechanism.

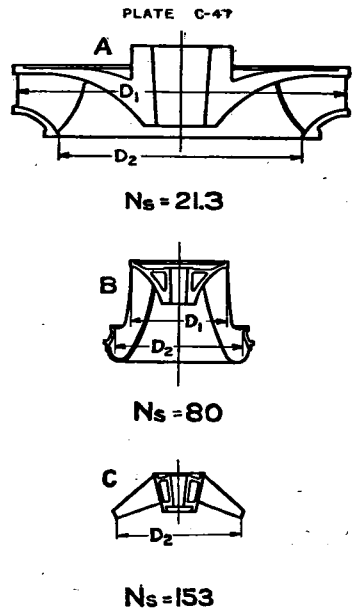
In the case of the diagonal type runner, the more moderate range of pressure differences results in a more normal efficiency characteristic, and an appreciable range of economical gate-opening above and below that of maximum efficiency. The question then arises as to whether the efficiency characteristic of the diagonal type runner, with fixed vanes, is such as to permit, under operating conditions, an economy in the use of water comparable with that which may be realized by a Kaplan type runner with adjustable vanes. The answer is in the affirmative if due cognizance is taken of the fact that a maximum of water economy is seldom necessary until the capacity of the installation reaches its ultimate designed limit. Such being the case, an intelligent designer can adjust the capacity of the individual units so that they may operate at all times within the range of economical gate-opening, as indicated by the efficiency contour. This phase of the problem, furthermore, becomes one of elementary simplicity when such an installation is operating in parallel with one or more plants in which Francis type turbines are installed, this being a more or less common condition of Canadian operation.

In future Canadian practice, therefore, it is reasonable to anticipate that dependence will be jointly placed on forethought in the primary elements of plant design and the intelligence of the operating engineer, rather than upon a very material increment of mechanical complexity, and consequent operating hazard, which results from the adoption of any purely automatic corrective agency in turbine design.

Plate C—47 illustrates three turbine runners, all drawn to the

same dimensional scale, and all developing the same power under the same head, but at an angular velocity corresponding to their respective specific speeds, as shown. Runner " A " is a typical high head runner, runner " B " a typical medium and low head runner, while runner " C " is a diagonal high speed runner capable of operating under heads of the same order as runner " B."

Two points of special interest in connection with this illustration are first, the great power capacity of the diagonal high speed runner as compared with its physical dimensions; and second, the



Comparison of turbine runners of equal power capacity.

fact that its discharge diameter (D2) is comparable with that of runner " B," so that in spite of the fact that it has nearly double the specific speed of the Francis runner, the absolute velocity of exit in the case of the diagonal runner is of the same order, and, therefore, susceptible of the same treatment as regards the limit of draft head.

Among the obvious advantages to be gained by the use of the propeller type runner, the following may be cited in particular:—

(*a*)—A greatly reduced weight of the revolving element of the unit, and consequently a corresponding reduction

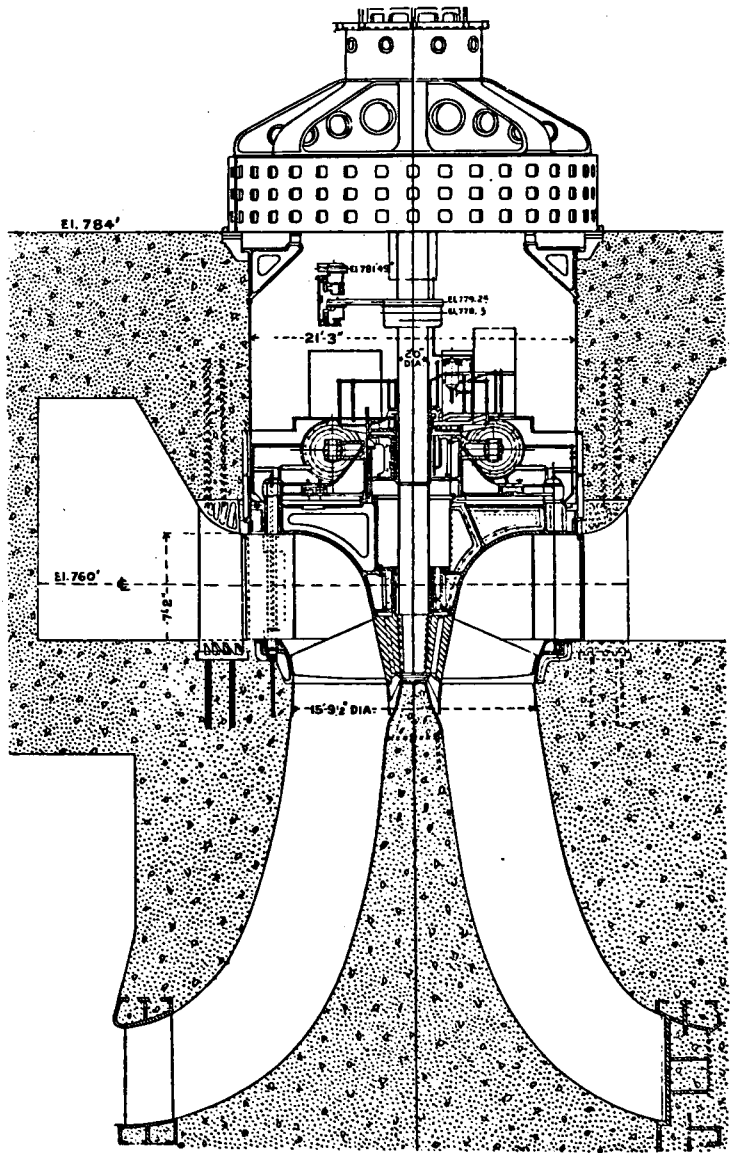


Plate C-48.— Cross-section of diagonal type runner installation.

in cost, not only of the turbine and generator, but of power house superstructure and cranes.

(*b*)—Large water passages, as compared with the Francis type runner, which provide much more favorable conditions for the safe discharge of ice and other foreign material.

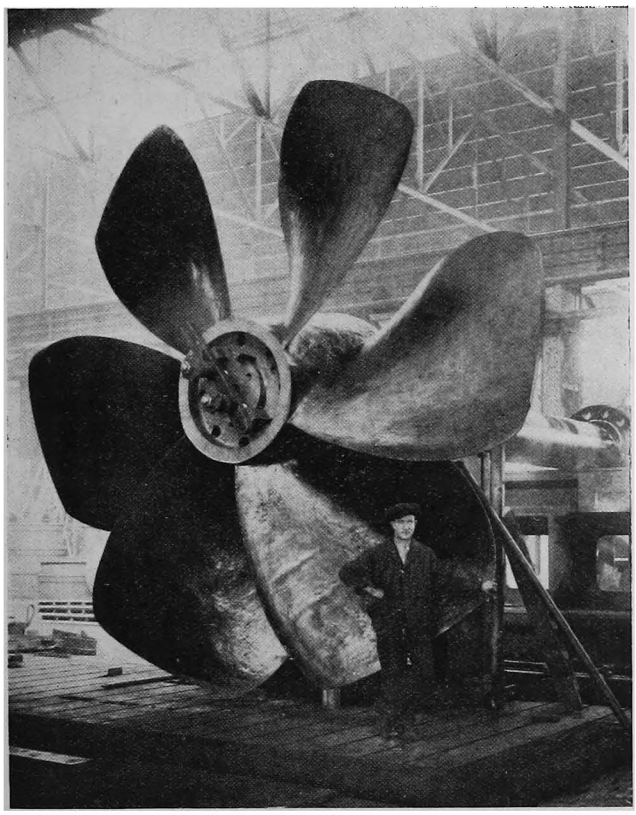


Plate C-49.—Diagonal type runner of 28,000 E.H.P. capacity.

(*c*)—Greater mechanical strength, as compared with the Francis type, due to the greatly reduced overhang of the vane from the crown of the runner. In the case of the diagonal type runner, the overlap of the vanes permits a very long connection between the base of the vane and the hub, and a consequent reduction in fibre stress.

Plate C—48 shows a cross-section through one unit of a group now in operation in a large plant in western Canada. The runners are of the diagonal high speed type, and develop 28,000 E.H.P. each, under a head of 56 feet, and at a speed of 138.5 R.P.M., or a specific speed of 153 (680 metric).

These units have been in continuous operation for a year, and at the outset a head of only 17 feet was available, instead of the designed head of 56 feet. They nevertheless operated at the designed normal speed, and produced the full corresponding proportion of their normal rating, developing meanwhile a specific speed of 230 (1,020 metric).

Plate C—49 is a shop view of the above runner, plainly showing the large vane area and short overlapping pitch, which is characteristic of the diagonal high speed type.

An interesting comparison is afforded by the fact that the Francis type runner illustrated on Plate C—35 would also develop 28,000 E.H.P. under a 56 foot head. This runner has a throat diameter slightly less than the diagonal runner, but it is 7 feet 4 inches higher, and exceeds it in weight by 108,000 pounds, or considerably more than 100 per cent. The speed of this runner under a 56 foot head would be only 75 R.P.M., as compared with an actual speed of 138.5 R.P.M. for the diagonal runner. This comparison is somewhat illuminating from the general standpoint of cost.

Plate C—50 is a cross-sectional view of a diagonal type runner installation now under construction in eastern Canada. These units will develop 30,000 E.H.P. each, under a 60 foot head, and a speed of 120 R.P.M., or a specific speed of 125 (556 metric). This is believed to be the highest limit of head yet reached with a propeller type runner.

It will be noted that both of the above installations use the spreading draft-tube, and in the latter case spiral discharge passages were provided.

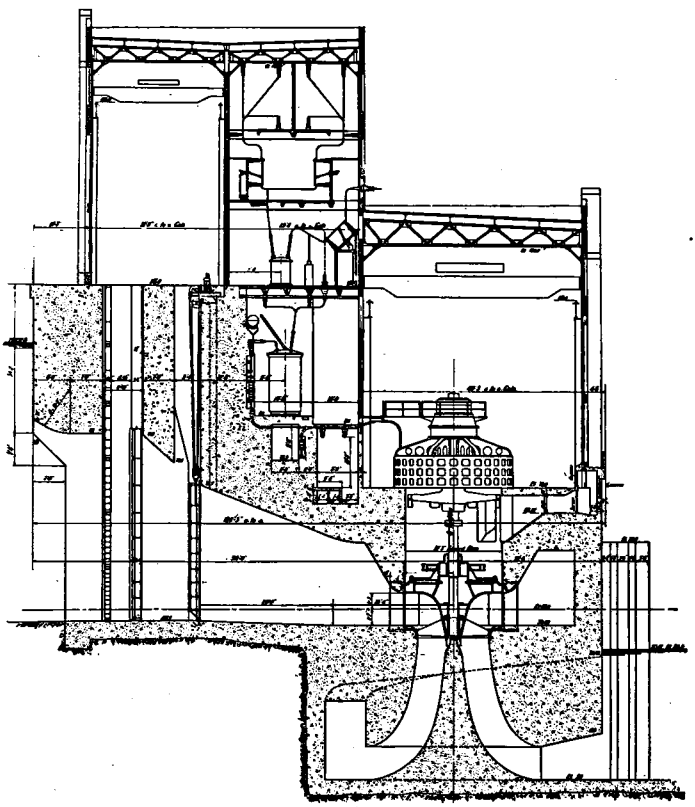
Among the minor features of interest, also common to both installations, may be noted the speed-ring stay-vanes, which were cast separately and set in the concrete during the construction of the scroll-cases. Also, the diffuser section of the draft-tube, instead of being held in suspension by a complicated and expensive system of reinforcement, is supported on separately cast stay-vanes, so designed and placed as to offer a minimum of obstruction to the discharge from the runner.

In addition to the two installations above mentioned, two others of smaller capacity are also in successful operation under heads

of 29 and 30 feet, and one is under construction for a head of 9 feet. All are of the diagonal runner type and have been built, as well as installed, in Canada.

Water-Wheel Generators.—As in the case of turbines, the most conspicuous feature of Canadian practice in generator construc-

PLATE C-50



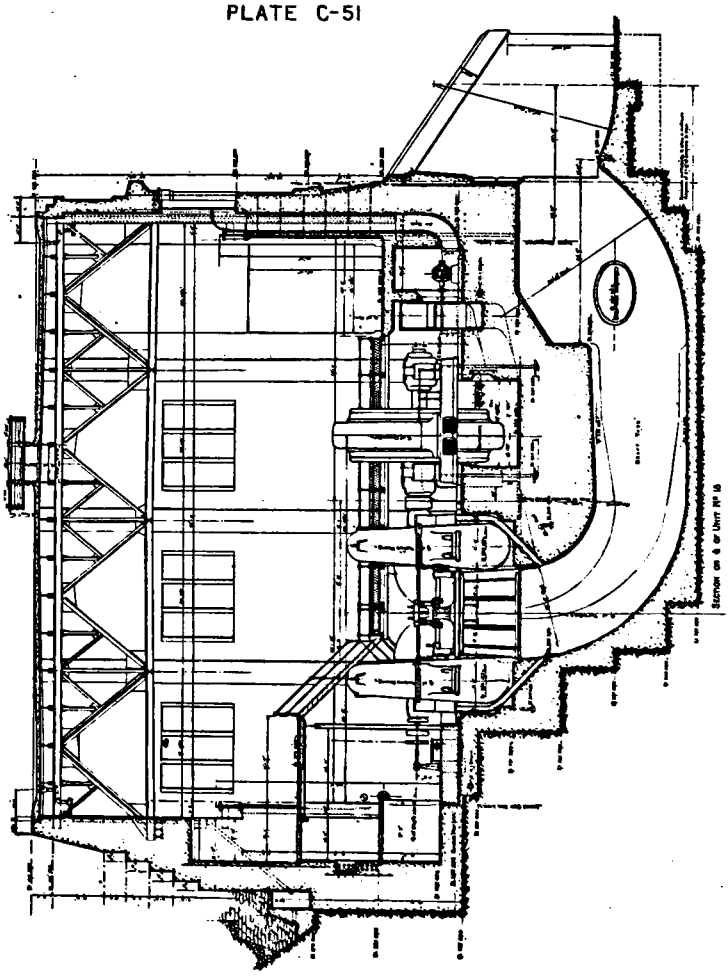
Cross-section of diagonal type runner installation.

tion, apart from size, and in fact, largely due to this factor, is necessarily a most pronounced general tendency toward the use of vertical settings, as evidenced by their adoption in most of the more modern installations now operating, as well as those under construction, or projected. The main reasons underlying this

phase of the situation having been covered, it is now only necessary to discuss the resultant effect on modern generator practice.

One factor which is is now proper to emphasize, as having

PLATE C-51



Horizontal setting with large pillow-block bearings.

contributed in a very essential degree to the vogue of the " super-turbine," and the popularity of vertical settings in general, is the highly perfected status of thrust-bearing construction.

The development of the art in this latter instance exemplifies a

condition often met with in the field of engineering, where an inherently sound principle, after having been applied in a primitive way, suffers a period of arrested development, and perhaps years afterwards is practically re-discovered, and becomes the basis of the ultimate solution.

In the early days of hydraulic turbine development, the step-bearing, a form of combined thrust and guide bearing located under the runner, was used almost exclusively for the support of the revolving element. The subsequent gradual increase in the speed and capacity of turbine runners then began to introduce problems of pressure intensity, depreciation and accessibility, which the designers of that day solved, not by improving the step-bearing principle, but by abandoning it, and inaugurating,

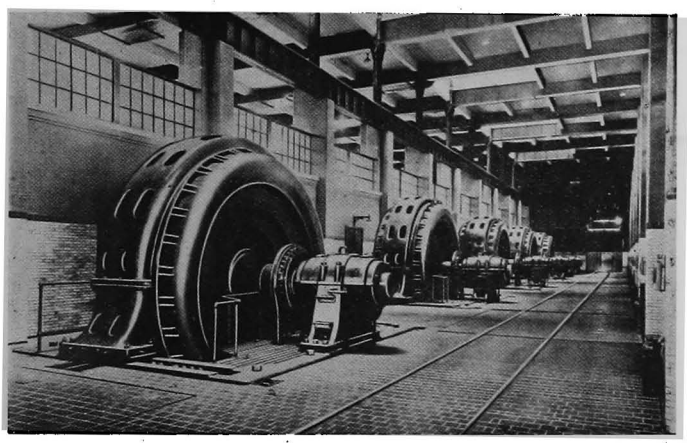


Plate C-52.—Typical installation of large capacity-horizontal units.

as a result, the era of the horizontal shaft turbine. This led to advanced development in bearings of the pillow-block type, together with the introduction of marine type thrust bearings to take up unbalanced runner thrust, a double requirement which gave rise to serious problems when the development of electrical generation and transmission called for continuously increasing turbine capacity and speed. The 20,000 H.P. horizontal unit shown on Plate C—51 fairly represents the climax of this trend of development in Canada, with water-cooled pillow-block bearings of the enormous dimensions necessary to keep bearing pressure within safe limits, and a rotor shaft having a diameter far in excess of torsional requirements, simply to minimize deflec-

tion. Plate C—52 illustrates another generator of similar type and capacity, as installed in a large Canadian plant.

The original turbines installed in 1896 at Niagara represented the first reversion to the primitive basic principle. They were the super-turbines of that period, and were of the vertical shaft type. The revolving weight of these units was partially suspended from, and partially super-imposed upon, a step-bearing located above the runner and immediately below the generator, thus removing one of the main disadvantages of this type of bearing, that of inaccessibility. A further important innovation was the application of external pressure to a film of oil which was forced in between the moving and stationary elements of the bearing. This

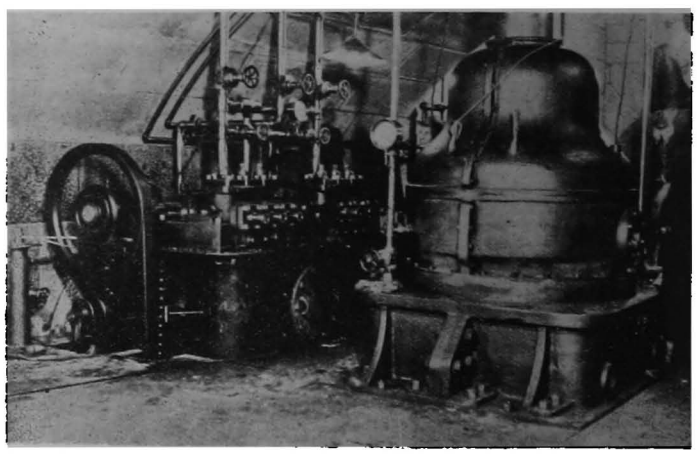


Plate C-53.—External oil pressure thrust bearing of 200 tons capacity.

oil was usually supplied by gear driven plunger pumps at pressures varying from 80 to 350 pounds per square inch, and maintained an oil film from two to four-thousandths of an inch thick between the bearing discs. Plate C—53 is a view of such a bearing, from a photograph taken in 1905 in a Canadian plant.

The oil pressure thrust bearing had a vogue of many years' duration, and some bearings of this type, such as the one illustrated, are still in operation. Their disabilities are; high investment and maintenance cost, mechanical complexity, and high temperature, resulting in low oil viscosity and high energy losses. Also, even a momentary failure of the pressure oil supply usually results in the loss of the bearing.

Finally, in America, about 1898, the ultimate conception was

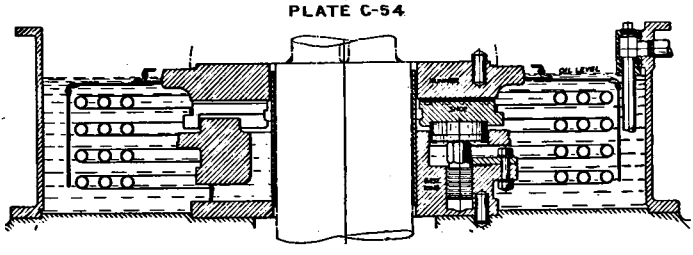
developed by Professor Kingsbury, as the true embodiment of a basic principle first established by the experiments of Tower in 1863, and afterwards mathematically demonstrated by Professor Reynolds. The Kingsbury principle, as exemplified in the various commercial types now in use in Canada and the United States, constitutes an outstanding example of the simple and efficient application of a natural law.

Briefly, this type of thrust-bearing has the following characteristics which distinguish it from its external oil-pressure prototype, and make it an eminently suitable mechanism for supporting, within comparatively small dimensional limits, the revolving weight of the largest hydro-electric unit.

(*a*)—The source of oil supply is static, and integral with the bearing itself.

(*b*)—The oil supply is " unlimited " in the sense necessary to conform with the laws of viscous fluids, as enunciated by Professor Reynolds.

PLATE C-54



Cross-section of thrust-bearing with segmental shoe.

(*c*)—The formation of the " pressure wedge " is not induced by any external agency, but by the motion of the bearing itself, and by providing for a very slight lack of parallelism between the stationary and moving elements.

(*d*)—The wedge pressure is a direct function of the speed of the moving element, and the thickness of the oil film is a direct function of the fluid temperature, which can be regulated within any desired limits by the simple expedient of water-cooling coils.

Plate C—54 shows a cross-sectional view of a bearing of the latest type, with non-circulating oil supply and water-cooling coil. Plate C—55 shows two views of the same bearing, one of the bearing itself partially assembled, and one of the housing and cooling coil. This bearing is guaranteed to carry a load of

1,000,000 pounds, inclusive of estimated maximum runner thrust.

In addition to the rigid segmental shoe type of thrust bearing shown in the above illustrations, Canadian practice also includes the use of a type of bearing in which the stationary element, or shoe, is in one piece, and the slight oscillatory movement necessary for the functioning of the " pressure wedge " is obtained by mounting the shoe, of comparatively light cross-section, on a multiplicity of springs.

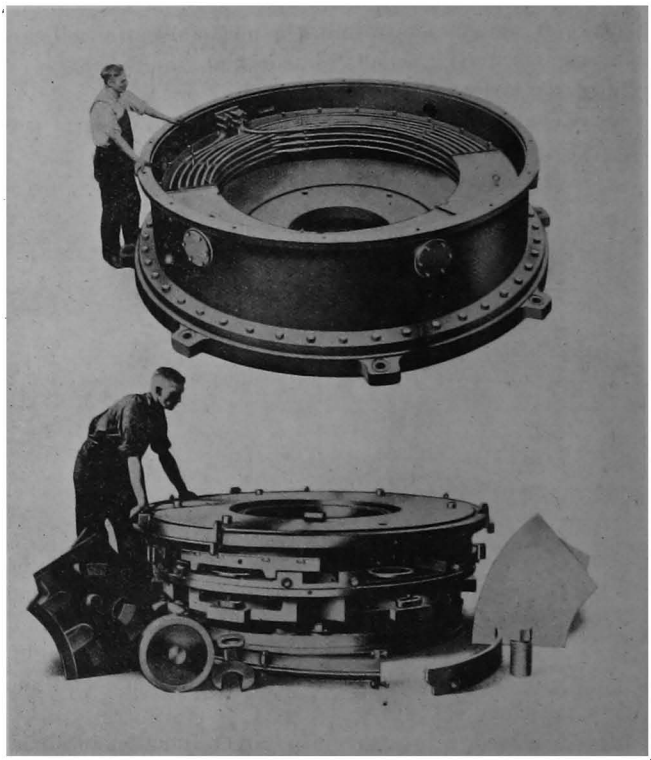


Plate C-55.—Thrust bearing with rigid shoe supports.

Plate C—56 shows a shop assembly of a large bearing of this latter type, of the same loading capacity as that illustrated on Plate C—55.

Both types of bearing are extensively used at the present time, and are giving satisfactory service in one or other of all the more modern Canadian installations.

In the matter of mechanical simplicity, and, therefore, dependability, the merit of the Kingsbury type bearing is evident. Also, the now almost universal practice of mounting the bearing over the generator represents the ultimate limit of development as regards accessibility.

The unique feature of the Kingsbury type bearing manifests itself, however, in the fact that unit pressures as high as 500

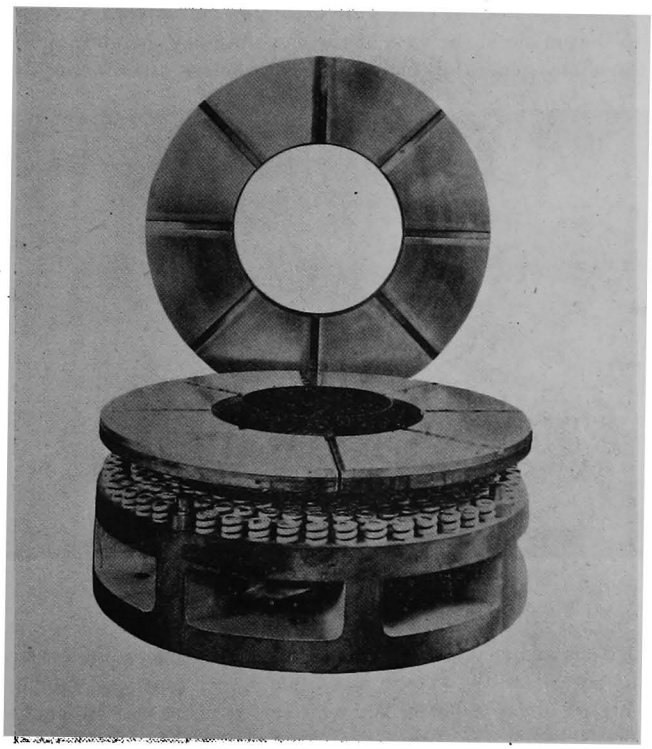


Plate C-56.—Thrust bearing with spring supported shoe.

pounds per square inch can be used with safety. This means that the basis of design does not need to be a predetermined limit of safe unit pressure, but can be, and usually is, a predetermined limit of lost power. In other words, the design of this bearing, for any specific installation, is primarily a problem in efficiency economics, and not of mechanical and dimensional limitations as governed by safe bearing stresses. Where units of large capacity are involved, the economic power loss seldom works out in excess

of one-tenth of one per cent. of the nominal generator rating, the effect of this being immediately reflected in the " speed-no-load " losses of the large modern generator, where the total friction and windage losses are now of the order of one-half of one per cent. of rated capacity.

Plate C—57 shows one of the most recent installations of this type of bearing, on a 41,000 E.H.P. unit in eastern Canada.

By reason of the fact that the electric generator has for many years been an efficient convertor of energy, no advance, comparable to that made in the case of turbine efficiency, has been effected in Canadian generator practice; nevertheless, the factor of in-

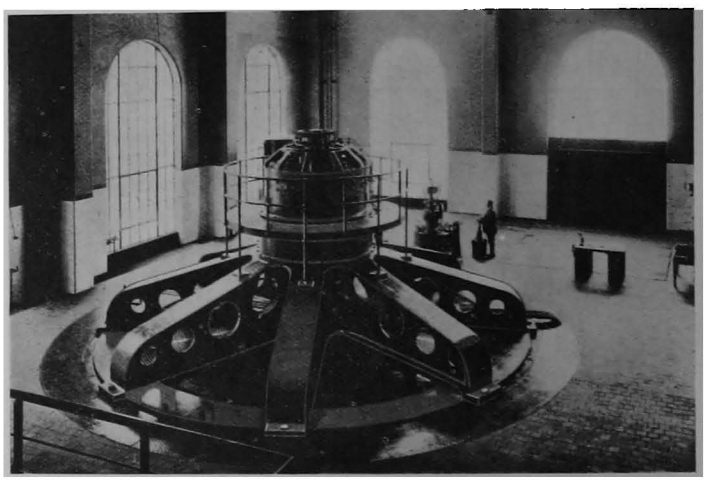


Plate C-57.—Large vertical unit with thrust bearing and direct connected exciter.

creased unit capacity has resulted in an appreciable improvement in this regard, to the extent that while 93 per cent. is a fair figure for ratings under 2,000 K.W., efficiencies of 96 to 97.5 per cent. are now realized, in generators of Canadian design and manufacture, for ratings ranging up from 20,000 K.W., and pressure of 11,000 to 12,000 volts, and in cases where the generator voltage is 6,600 or less, a further gain of one-half to three-quarters of one per cent. might be obtained.

Probably the most serious problems arising out of the present trend in Canadian practice have been those associated with the purely mechanical features of design. These conditions arose from the necessity of supporting the total revolving weight of the unit from the top of the stator frame; from the use of shafts

and circulating oil guide-bearings of large diameter; from the necessity of forced ventilation; and most important of all, from the necessity of maintaining the safety factor of the rotor structure as its weight and cross-sectional mass increased with the generator rating.

As regards this latter problem, Canadian practice embraces the use of two distinct solutions, with the same primary object in view; namely, to overcome, or to offset, the inherent weakness of large masses of steel in the spider casting.

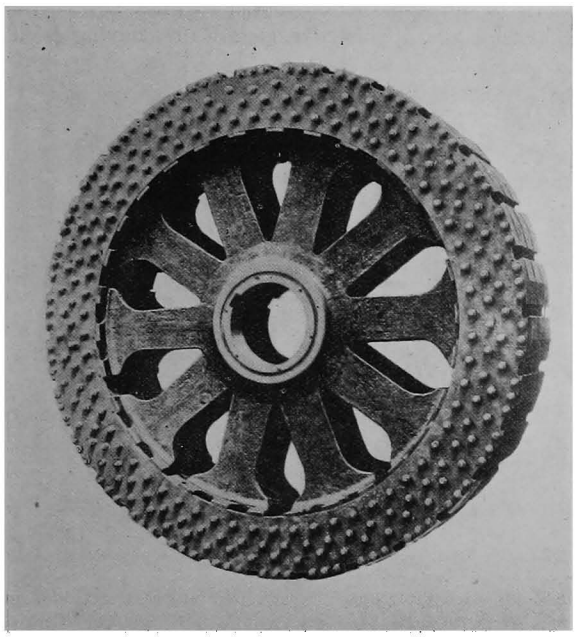


Plate C-58. - Generator spider with laminated rim.

Plates C—58 and C—59 clearly illustrate the two methods in question. The former view shows a type of construction in which the cast and annealed metal is limited to the hub and spider arms, the rim being composed of thin steel laminations dovetailed and wedged into slots in the ends of the spider arms, and held together by through-bolts. The merit claimed for this type of rim construction is that the thin section of the individual steel laminations assures the realization of the calculated safety factor.

Plate C—59 shows a type of spider construction in which the necessary requirements as to safety-factor are met by stacking

comparatively light rings, cast and annealed separately, and afterwards machined. The comparatively light section of these castings naturally reduces the liability of residual shrinkage strains subsequent to annealing, and the machining furnishes a more or less effective means of detecting lamination, porosity and other internal defects.

Both of the spiders illustrated are for generators of the same capacity, the rotor assembly, with shaft and pole-pieces complete, weighing something over 600,000 pounds in each case.

In the case of the construction shown on Plate C—59, the upper and the lower rings are inactive electrically, having been added

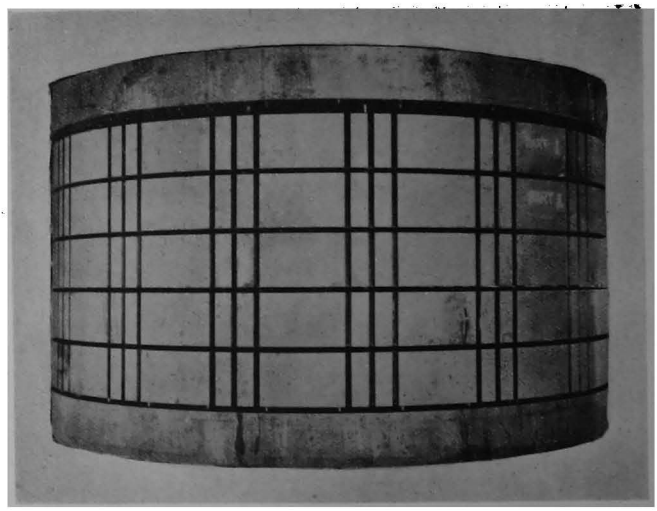


Plate C-59.—Generator spider with separately cast sectional rings.

for the purpose of augmenting the fly-wheel effect of the rotor. Also, the horizontal slots shown in this view are for ventilation purposes.

Ventilation is classed as a mechanical problem because, in generators of the class under discussion, it is in almost all cases necessary to dissipate heat by mechanical means. While nothing radical has transpired in Canadian practice under this head, the ventilation of generators has up to the present time definitely progressed as an art by careful attention to detail and gradual refinement of design, as generator ratings increased. It is now being subjected to further intensive study and experimental research from a more or less original viewpoint.

An interesting feature of recent Canadian practice, and closely related to this phase of the discussion, was originated in the design of the installation shown in section on Plate C—43. In this design, air is drawn at will from within or without the power house superstructure, into a closed chamber beneath the generator, and is discharged through flues passing up through the centre of the building and terminating in louvres on the roof. To make this system of ventilation effective, the main floor of the machine-room is located at the elevation of the top of the stator frame as shown.

The flow of air is primarily actuated by the fans on the generator rotor, and supplemented, as required, by motor driven exhaust-fans located beside the generators in the flues. When these exhaust-fans are in operation, the weight of air passing through each generator, in 2½ hours, is equal to the total weight of the generator itself; namely, 1,400,000 pounds.

The location of the machine-room floor, as above described, had the further advantage of providing ample space for all auxiliary equipment elsewhere than on a main floor, so that the space around the main units is wholly unencumbered except by the governor actuators and control-stands. This floor also has the virtue of materially reducing the unsupported length of the crane columns, and the extra space is provided at the additional cost of the floor only, as the roof clearances are independently governed by the height of the stator frame and the length of the generator shaft.

The cross-section on Plate C—45 shows a machine-room floor similarly located, and Plates C—57 and C—60 indicate the general appearance of the floor, with no part of the generator in view below the upper bearing bracket.

From the purely electrical standpoint, the main features arising out of the evolution of Canadian generator practice are, inherent regulation and fly-wheel effect, excitation, core loss, and insulation.

The gradual increase in unit capacity has been accompanied by proportionately smaller frame dimensions, and a much greater percentage of inherent voltage regulation, than was hitherto considered permissible. The primary reason for this trend of development has been the perfecting of the automatic voltage regulator, which is now a standard accessory in all important Canadian installations.

One disadvantage of the smaller frame dimensions is a corresponding reduction in fly-wheel effect, but this condition is more or

less offset by the fact that large generators are almost invariably connected to a transmission network, so that in the first place, large percentage load changes are not an ordinary condition of operation, and secondly, their inherent fly-wheel effect is supplemented by the very appreciable fly-wheel effect of the system as a whole.

The fundamental idea in all excitation systems is to use every reasonable means to insure continuity of service. This is usually effected by using two, and sometimes three, independent sources of supply. When the speed of the main units is suitable, it is common practice in Canada to use a direct connected exciter as the ordinary source of excitation. In other cases, particularly where direct connected exciters are not practicable, a central turbine driven service alternator installation, usually in duplicate, is used to drive individual motor-generator sets at each main unit; also, where foreign power is available, it is frequently used as an emergency drive for the motor-generators.

Plate C—60 shows a view of the machine-room of a large Canadian station recently constructed. In the background the main units may be seen, each with a direct connected exciter over the thrust-bearing, and in the foreground, one of a pair of 2,500 K.W. turbine driven service alternators, which supply all power required for the operation of plant auxiliaries. A motor-generator set is also provided as an emergency exciter unit to replace any of the direct connected exciters, if required. This emergency set may be operated from the service units above mentioned, or from a wholly external source of power.

The use of direct connected exciters has been the subject of considerable controversy, and there is still scope for argument in connection with economic dimensional limits, as governed by the speed of the main unit. On the other hand, an appreciable energy saving results from the fact that the direct connected exciter has the benefit of the higher efficiency of the main turbine, while at the same time the advent of the automatic voltage regulator has eliminated its main operating disability; namely, the reaction on field intensity due to inherent speed changes in the main unit, on varying load.

The design of magnetic circuits has of recent years been appreciably improved by the use of low loss medium silicon steel in core construction. In generators of large capacity the reduction in core loss, as compared with previous practice, ranges as high as one-half of one per cent. of rated capacity, for this item alone.

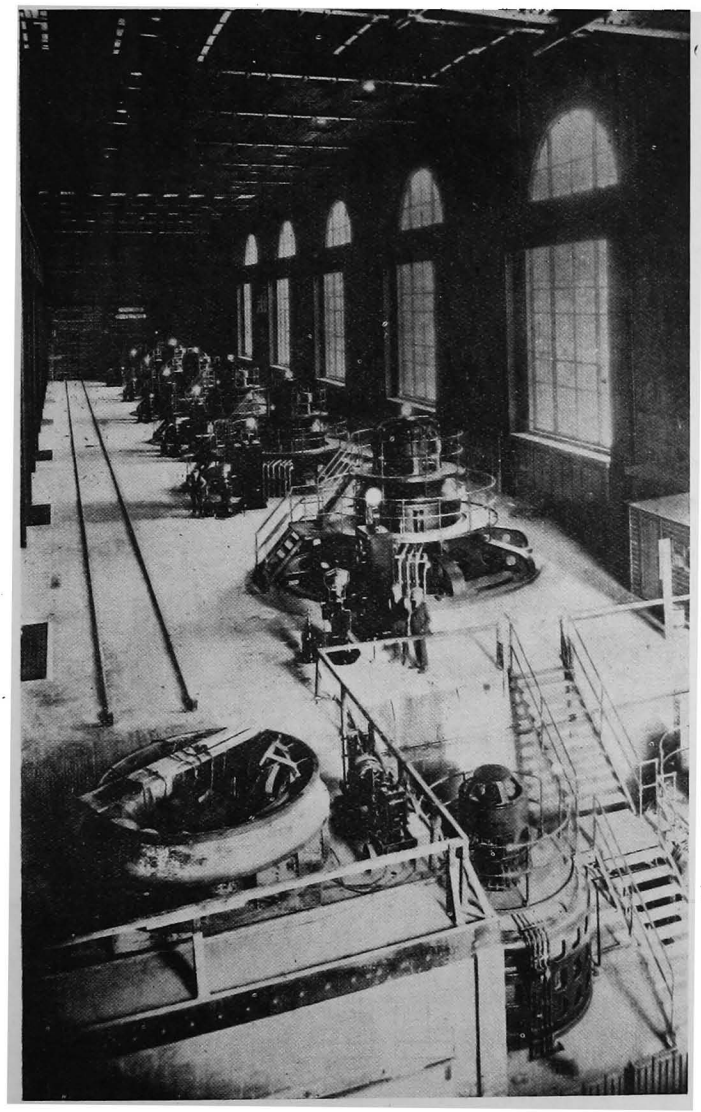
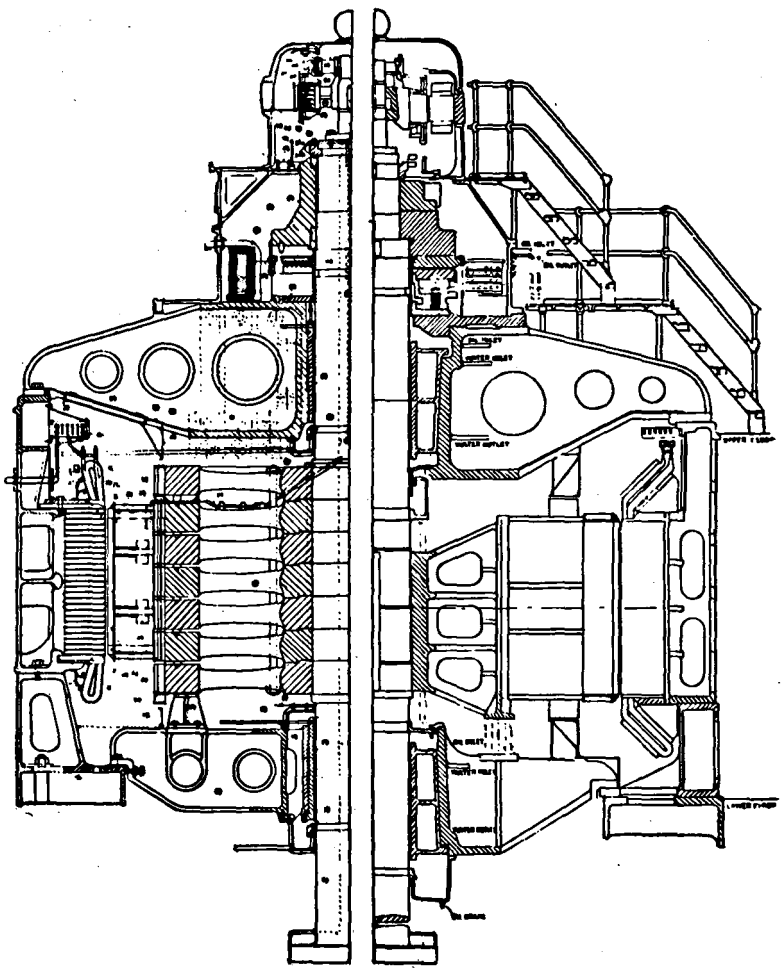


Plate C-60.—Machine room showing direct-connected exciters and service units.

A conspicuous feature of Canadian generator design, arising directly out of the vogue of the " super-turbine," has been the development in stator-coil insulation methods, as governed by

PLATE C-61



Typical large generator cross-sections.

mechanical considerations, and the use of higher temperature ratings. Here again, as in the case of rotor construction, Canadian practice includes the use of two more or less distinct types.

To differentiate briefly between these two types, which both employ mica as the dielectric base, it may be said that one type provides for a very high degree of heat resistance, but at the expense of flexibility, as the high percentage of sheet mica employed makes the coils stiff and brittle. On the other hand,

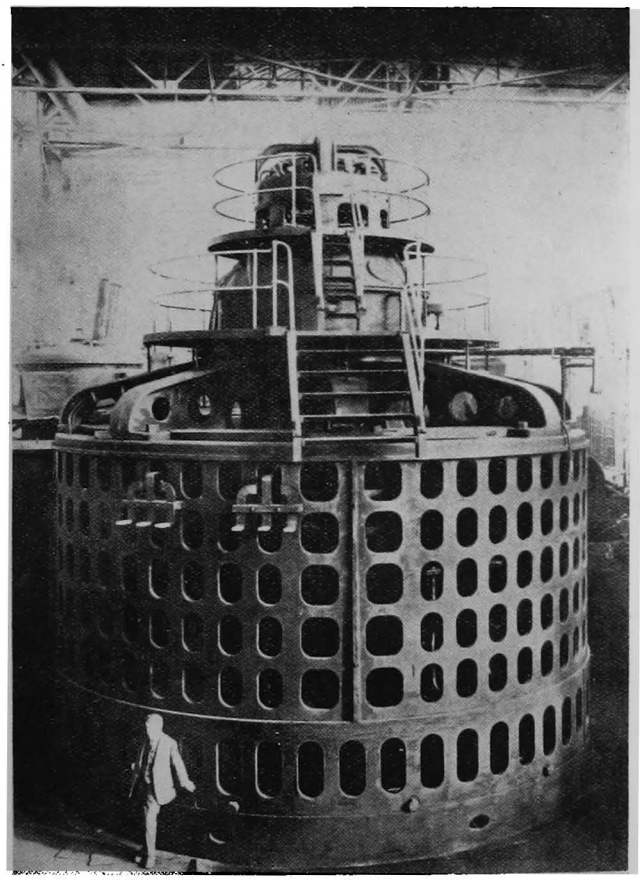


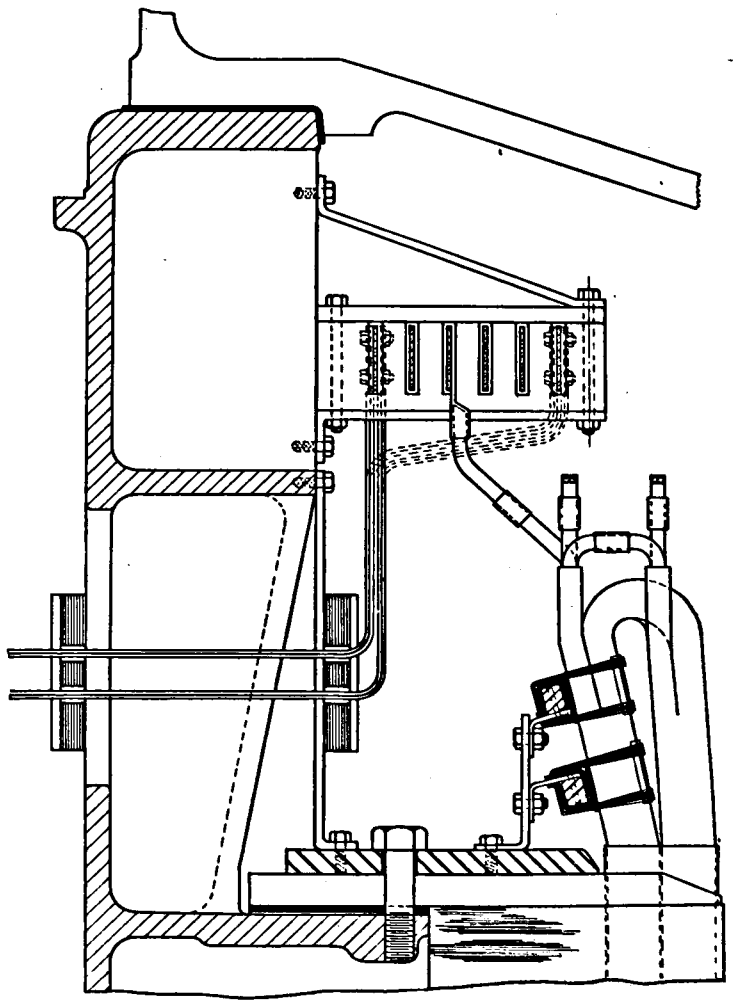
Plate C-62.—Shop assembly of 55,000 KVA. generator.

the second type provides for flexibility and convenience in handling, but at the expense of extreme heat resisting capacity.

There is very evident merit in the use of insulation with extreme heat resisting qualities in some types of motors, where heavy intermittent overloads are a necessary condition of operation, and

where the coils are short and stiff, but in large generators, rating upwards from 20,000 K.W., for instance, low temperature per-

PLATE C-63



Diagrammatic sketch of circumferential band bracing of end-turns.

formance is a very important economic characteristic of operation, and the necessity for high heat resistance, therefore, not such a

vital consideration. It is for this reason argued that a more equitable balance is attained by providing an insulation which has at once a reasonable and safe margin of heat resistance, with such a degree of flexibility as will permit handling, and a certain amount of distortion, without injury. This argument still leaves open the comparative hazard, as regards these two types of insulation, arising from the possibility of such a break-down as might result from the current rush of a dead short circuit, and it would seem that the ideal solution involves mechanical as well as dielectric considerations. Such being the case, the best insulation will be that having the highest heat resisting properties, even with the inevitable accompaniment of stiffness and brittleness,

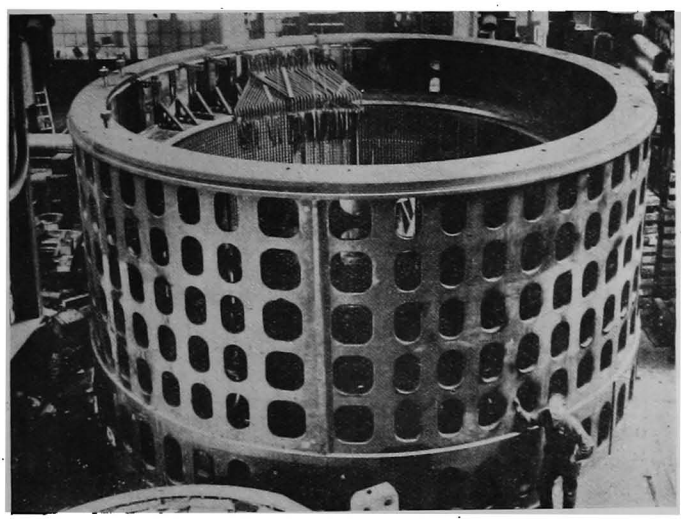


Plate C-64.—View showing radial bracing of end-turns.

if at the same time the slot anchorage and the bracing of the end turns can be so designed as to preclude any possibility of coil displacement or flexure.

Shown on Plate C—61 are two typical generator cross-sections illustrative of the above discussion, particularly as regards methods of rotor construction, thrust-bearing assembly and bracing of end turns. One cross-section shows a laminated spider rim, a thrust-bearing with rigid shoe supports and radial end-turn bracing applied to high heat resisting insulation. The other cross-section shows a machined sectional spider casting, a

thrust-bearing with a one-piece spring-supported shoe, and circumferential band bracing of end-turns applied to the flexible type of insulation.

Plate C—62 is a view of the stator frame of one of the generators shown in cross-section on Plate C—61, as assembled in the Canadian shop in which it was built.

The bracing of end-turns is a vital factor in the mechanical design of large water-wheel generators, owing to the enormous electrical stresses developed in the event of a dead short circuit. Plate C—63 illustrates diagramatically the so-called circumferential band method of bracing, which consists of two continuous steel bands, of channel section, to which the coils are securely fastened, and which, in turn, are attached to the spider rim by a bolted connection.

Plate C—64 is a view of the stator coils of a 55,000 K.V.A. generator in process of assembly. This view shows the radial knee-braces upon which the end-turns rest, and the hardwood cleats which are through-bolted to the knee-braces to hold the coils rigidly in place.

As in the case of the Francis type turbine, it is reasonably safe to venture the opinion that, as regards economy in energy conversion, the large Canadian built water-wheel generators of the present day are not likely to be demodernized by future advances in the art.

FUTURE TREND OF DEVELOPMENT.

If the future trend of water power development in Canada were considered in its relationship to other native power resources, as it properly should be, the scope of discussion would be enlarged far beyond the limits originally fixed. If, however, the discussion is confined to hydraulic development " per se," it may be stated with a fair degree of assurance that the future holds no prospect of revolutionary advances in the art, such as have taken place in the last twenty years.

The means of supporting revolving weights, of safely controlling static pressure, and of regulating long water-columns, have been perfected. The Francis turbine and the water-wheel generator have attained a degree of efficiency in energy conversion which leaves little margin for further improvement. The supremacy of concrete as the structural medium for permanent works stands unchallenged. The larger unit capacities now used in Canada are not likely to be greatly exceeded on sound premises, so that increased unit power concentrations will not in the future give rise to new problems of design.

It would seem, as a matter of fact, that the one conspicuous exception to the ruling condition is the high speed propeller type turbine, and even this advance in the art, while of a revolutionary nature, is more an actuality of the present than a possibility of the future, its merit as a distinct type having been already tested in commercial operation. In other words, the type has been created, and the future trend of development will be limited to the improvement of mechanical details, and to the more important matter of extending the range of feasible operating heads.

A less conspicuous but nevertheless important subject of future study is the pitting of turbine runners. As stated at a previous stage of the discussion, a means of prevention is fairly well established, but the agency of the actual pitting process is still more or less obscure, and may be due to erosion or corrosion, or a combination of both. If erosion is the controlling agency, then bronze runners should suffer more than those of cast-steel, which is not actually the case. If corrosion is the controlling agency, then cast-steel runners should suffer more than those of bronze, which is in accordance with ascertained facts. If corrosion is for this reason assumed to be the primary cause of the trouble, it follows that there must be some purely local condition, induced in and adjacent to the runner passages, which causes oxidation, otherwise the pitting action might as well occur in the scroll-case or speed-ring, which it does not. Under the circumstances, therefore, it might be reasonable to suppose that high velocity, impact and intermittent vacuum conditions, as induced by part-gate operation, tend to disrupt the molecular structure of the water and entrained air, with the result that sufficient free oxygen is released, in and adjacent to the runner passages, to cause pitting through the agency of corrosion.

A much simpler explanation of pitting action might be to the effect that certain portions of the runner surfaces are alternately wet and dry under operating conditions, due to the fact that the curvature and transitioning of the water passages at any point is only perfect for one critical velocity at that point. If, therefore, such an alternating cycle of conditions persisted continuously for long periods, the oxidation process would function more or less as in the case of an unprotected metal surface in the open air.

The actual cause of corrosion is not, however, essential to the argument, the point being that if the pitting of runners is due to corrosive action in any form whatever, a distinct advance in the art will be achieved if the ideal metal alloy can be evolved; in

other words, an alloy possessing the oxidation resisting property of bronze, with the strength and cheapness of cast-steel. The problem would then be solved by reason of the inherent characteristics of the material, rather than by the expensive alternative of low specific speed and low absolute velocities of entrance and exit.

Apart from the specific cases above dealt with, the general problem of the future trend of development will be largely governed by two factors; first, the ultimate necessity of developing water powers remotely situated and not favorably endowed by nature, with a resultant tendency toward increased capital and annual cost; and secondly, a general scale of labor and material costs greatly in excess of that which existed previous to the World War.

If, as previously observed, the above conditions cannot be offset to any appreciable extent by advancing the art from the standpoint of operating efficiency, it follows that future effort must be concentrated on maintaining the present status of efficiency, while at the same time aiming at reduced costs through simplification or revision of the methods and processes by which the present degree of efficiency has been attained.

Under this head, for instance, might be included the use of remote automatic control for low head developments of considerable size, as a means of reducing operating costs; the use of syphonic wheel-pits under low heads, as a means of reducing excavation, unwatering and substructure costs; the use of ejector turbines as a means of reducing the loss of power due to a disproportionate rise in tail-water level during high stages of flow; and finally, by the discovery and substitution of cheaper materials, such, for instance, as a new insulating material for generator coils, which would be cheaper and more workable than mica, and at the same time have equal dielectric efficiency and serviceability. This last possibility is, perhaps, the most important of all.

As a matter of fact, there may be considerable scope for the advancement of the art in the discovery or development of new materials and new combinations of metals, and it would be rash to state that radical and perhaps even revolutionary advances, along this particular line at least, are not a possibility of the future.

CONCLUSION.

In the opening chapter, the subject matter of this discussion was designedly limited to the more interesting and more or less dis-

tinctive features of Canadian practice in connection with hydraulic power production, and for an obvious reason. In citing these various features an effort has also been made to summarize, in a general way, the underlying theory involved, and to show that in every instance conformity to natural laws, and a rational comprehension of the phenomena of water in motion, has been the actuating motive.

At the same time, an attempt has been made to convey the impression, more or less by inference, that Canada not only possesses water power resources of enormous extent and value, but has spared no effort to develop them in a manner fully in keeping with their importance as a national asset.

If, therefore, the subject has been presented in such a way as to bring out these facts properly, and at the same time to impress the reader with the fact that in her proficiency in both the structural and purely engineering phases of the hydraulic art, Canada stands to-day on a par with any other nation in the world, the objective aimed at will have been realized.

RÉSUMÉ

En commun avec tous les pays possédant des ressources potentielles d'énergie hydraulique, la nature, l'importance et l'utilité de l'énergie hydraulique Canadienne est en premier lieu le résultat des facteurs purement climatériques de la température et de la précipitation associés, nécessairement, au cadre topographique du continent Nord-Américain.

S'étendant comme il le fait de l'Océan Atlantique à l'Océan Pacifique, et d'une zone tempérée jusqu'au delà du Cercle Arctique, le Canada embrasse toutes les phases du facteur de température à l'exception du tropical et sous tropical, et en ce qui concerne la précipitation, la marge de variation est également grande. Régi par le troisième facteur de la topographie continentale, le Canada possède de turbulentes rivières prenant leurs sources dans les pics élevés des Montagnes Rocheuses; d'immenses fleuves s'écoulant de l'immense plateau central du mi-Ouest et du bassin des Grands Lacs; et du côté de l'est vers la côte de l'Atlantique, une multitude de voies d'eau, grandes et petites, drainant les pentes des collines Laurentiennes, maintenues et régularisées par un nombre illimité d'élargissements en forme de lacs, dont beaucoup ont des superficies variant de 50 à 1500 milles carrés.

Il est évident, d'après la spécification générale esquissée ci-dessus, que le Canada doit par nécessité posséder des ressources en force hydraulique tellement grandes comme importance et si diverses comme type, qu'elles doivent permettre un champ des plus vastes possible à l'accomplissement de l'art de l'ingénieur et à l'initiative, en vue de leur développement et utilisation convenable et efficace. De plus, le développement et l'utilisation des ressources en énergie hydraulique du Canada a commencé depuis un grand nombre d'années, et il serait inconséquent d'entrer dans une revue détaillée et plus ou moins historique du progrès d'un tel développement et de ses phases adjacentes techniques et industrielles. On a donc assumé une

date à laquelle dans un sens moderne, le développement de l'énergie hydro-électrique a débuté au Canada, et en partant de ce point on a passé en revue le progrès général de cet art jusqu'à ce jour, en appuyant seulement sur celles des phases dans la suite de l'évolution, qui étaient régies par les limitations et les besoins primaires naturels qui ont donné à la pratique Canadienne une identité plus ou moins distincte.

On peut dire que l'histoire de la pratique moderne Canadienne hydro-électrique a eu son début en 1905 lorsque trois turbines verticales de conception et de fabrication Suisse, furent placées en service aux Chutes du Niagara. La caractéristique particulière de ces turbines était leur grande puissance, et depuis cette époque l'élément " Dimension " à fourni le tonique principal pour l'avancement de la production de l'énergie hydro-électrique au Canada, en ce qui concerne ceux des traits qui diffèrent de la pratique contemporaine ailleurs.

On ne doit pas déduire de la déclaration ci-dessus que le développement hydro-électrique, considéré comme un art, n'aurait pas progressé au Canada comme ailleurs, sans l'augmentation considérable de la capacité unitaire des turbines modernes. Le point est que, comme producteur directe du produit vendable, la turbine devint le point de foyer d'où rayonnait toutes les considérations essentielles portant sur la conception électrique et structurale, pour en arriver finalement à ce que la turbine puisse remplir sa function vitale de producteur de bénéfices avec un maximum de rendement. La réaction naturelle à cette condition, a été d'attirer l'attention sur les insuffisances et les imperfections du mécanisme même de la turbine, et de forcer la pensée technique dans des directions conduisant, non seulement au raffinement et à la simplification des modèles nouveaux existants, mais à la création de mécanismes ayant des caractéristiques nouvelles et perfectionnées. Ces perfectionnements et innovations ayant été faites, de temps à autre, pour se maintenir au niveau avec les besoins résultants du capital élevé investi dans les grandes turbines, il était facile, dans la plupart des cas, d'appliquer ces perfectionnements à de petites turbines, aussi bien qu'aux grosses unités, de telle sorte que la pratique de construction des turbines au Canada, a dans son ensemble, finalement reçu le bénéfice de l'amélioration dans l'art qui originellement vint de la demande de turbines de grande puissance unitaire, demande qui ne se rencontre nulle part ailleurs, excepté aux Etats Unis.

Les points plus ou moins spéciaux de la pratique hydro-électrique qui ont eu leur origine au Canada ou aux Etats Unis, tombent pour la plupart sous les titres suivants:—

1. Structures des entrées de canaux.
2. Canaux à ciel ouvert.
3. Longues tuyauteries.
4. Structures des baies avant.
5. Vannes.
6. Clapets de vanne.
7. Turbines.
8. Régulateurs.
9. Tuyaux de Tirage.
10. Générateurs.

Le progrès du Canada dans l'art hydro-électrique doit être attribué en premier lieu à certaines conditions naturelles, mais également à l'augmentation rapide des besoins d'énergie tant pour l'industrie que pour les usages domestiques. Ces facteurs, nécessitant comme indiqué précédemment le développement de la " super-turbine," ont aussi obligé les corporations productives d'énergie à améliorer d'une manière analogue l'efficacité de

distribution. En raison de ce fait la pratique Canadienne a atteint une certaine individualité par l'étude du problème de la glace, en relation avec le fonctionnement satisfaisant des stations hydro-électriques à des températures atteignant fréquement 40 degrés Far. au-dessous de zéro. (—40 degrés à—45 degrés C.).

Si l'on considérait la tendance future du développement de l'énergie hydraulique au Canada, en relation avec les autres sources d'énergie du pays, comme ceci devrait normalement être le cas, la porte de la discussion serait élargie très au delà des limites raisonnables. Si cependant, la discussion est confinée au développement hydraulique proprement dit, on peut spécifier avec un certain degré d'assurance, que l'avenir ne fait prévoir aucun perfectionnement révolutionnaire dans l'art de la turbine, semblables à ceux qui ont été réalisés durant les derniéres vingt années.

Les moyens de supporter des masses en rotation, de contrôler d'une manière sûre la pression statique et de régulariser de longues colonnes d'eau, ont été perfectionnés. La turbine Francis et le générateur pour turbine ont atteint un degré de rendement dans la conversion de l'énergie qui laisse peu de marge pour une nouvelle amélioration. La suprémacie du béton armé comme moyen de structure pour travaux permanents reste sans concurrent. Il est peu probable que les capacités des grandes unités utilisées maintenant au Canada soient beaucoup augmentées, de telle sorte que l'élément de " Dimension " seul ne donnera pas lieu dans l'avenir à de nouveaux problèmes de construction.

Le problème général de la tendance future de développement sera par conséquent largement gouverné par deux facteurs; premièrement, la nécessité finale de développer des chutes d'eau situées au loin et peu favorisées par la nature, avec une tendance résultante vers des prix de revient et des frais généraux plus élevés; et secondement, une échelle générale de prix de main d'oeuvre et de matériaux très supérieurs à celle qui existait avant la Guerre Mondiale.

Il peut, d'autre part, y avoir un vaste champ de développement dans la découverte ou l'amélioration de nouveaux matériaux et de nouvelles combinaisons de métaux, et il serait téméraire de dire, que des perfectionnements radicaux et même peut-être révolutionnaires, au moins dans cette voie particulière, ne sont pas une possibilité de l'avenir.

Le sujet principal de la discussion a été limité à dessein et pour une raison évidente, aux points plus intéressants et plus ou moins distinctifs de la pratique Canadienne, de production d'énergie hydraulique. En citant ces points variés un effort a également été fait de résumer d'une manière générale, la théorie fondamentale impliquée, et de montrer que dans chaque cas, la conformité aux lois naturelles, et une compréhension rationnelle du phénomène de l'eau en mouvement, a été le motif dominant.

En même temps, on a essayé de donner l'impression, plus ou moins par conclusion, que le Canada non seulement possède des ressources d'énergie hydraulique énormes comme étendue et valeur, mais qu'il n'a épargné aucun effort pour les développer d'une manière complètement en rapport avec leur importance comme actif national.

WATER POWER PRODUCTION AND POWER TRANSMISSION IN THE DUTCH EAST INDIES.

GENERAL PRINCIPLES, PRESENT ACTIVITY AND FUTURE POSSIBILITIES

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1. NECESSITY FOR ORGANISATION OF POWER WORK.

In former years the tremendous quantities of power available in the rivers of the Dutch East Indian Archipelago received as little attention from the Government as from private industry. The ever-increasing want of cheap power for industrial purposes and for the lighting of the growing European and native communities, and especially the necessity of substituting electric traction for steam traction on heavily loaded parts of the State railways, induced the Government of D. E. I., between twelve and fifteen years ago, to take up the matter of utilising the dormant sources of energy. Since August 1917, the *Service for Water Power and Electricity* has led the work of harnessing the available power and transmitting it to the centres where it can be favourably used. Next to the systematic search for, and examination of, water power, the planning and

erecting of State water power stations, and the giving of advice to parties wishing to utilise water power for special purposes, comes the work of planning methodical and economical systems for spreading the electric power over the largest possible area.

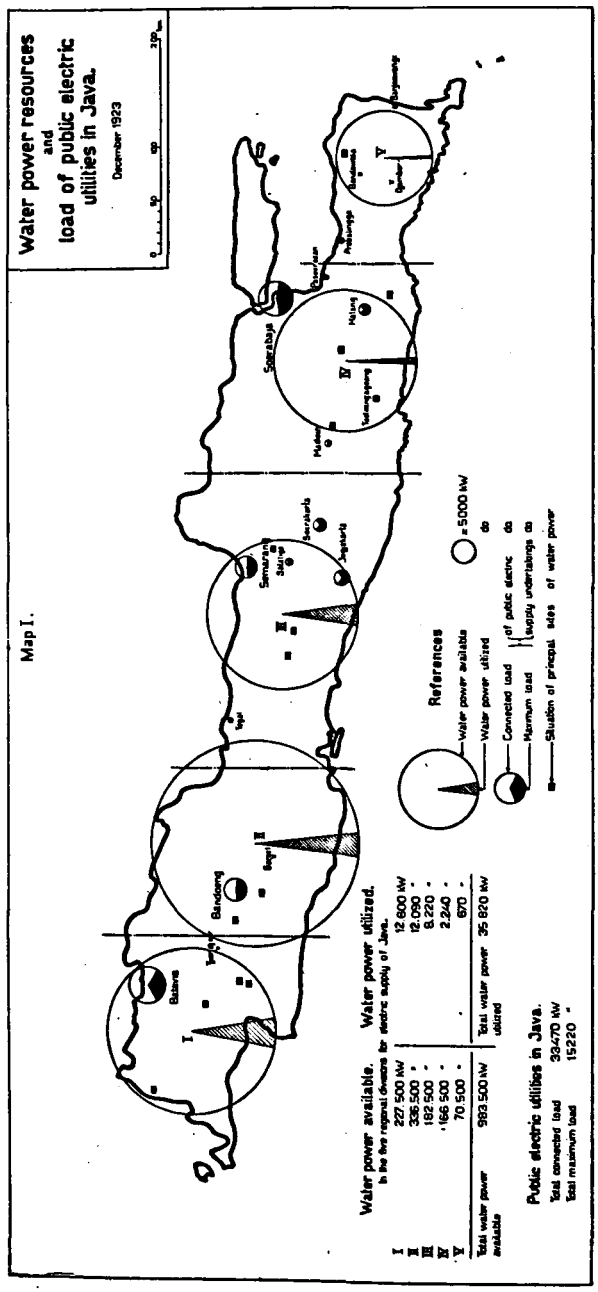
2. AVAILABLE WATER-POWER AND PRESENT POWER DEMAND IN JAVA.

In Map I. is given a graphical representation of the power-possibilities compared with the present consumption of electric energy on the Island of Java. Although in the larger islands, especially in Borneo and Sumatra, the amount of available power is very much greater, one must remember that the possibility of utilising the whole of these tremendous forces will only be realised in a far off future. It may happen that for some special purpose—for example, for the manufacturing of artificial manure or for any other chemical industry—one or other of the already investigated water power sources will be harnessed; on the whole, however, civilisation of the Archipelago, apart from Java is still such that quick development of the use of electricity cannot be expected during the lifetime of the present generation.

Java, however, has a large population—nearly 40 millions, as compared with some 15 millions for the united population of all the other islands. It is indeed about the most densely populated country in the world, numbering 275 inhabitants per square kilometre or over 700 per square mile. Nearly the whole of this population lives outside the big centres, which together do not contain many more than one million inhabitants. This fact is due to the splendid condition of the soil (of which a remarkably high percentage is under cultivation), a condition which makes agriculture the principal means of sustenance for the people.

3. URGENT NEED OF SYSTEMATIC WORK. JAVA DIVIDED INTO POWER DISTRICTS.

Looking at these natural conditions from the point of view of the power engineer, one realises that the extreme density of the population makes the utmost economy in the utilisation of the natural power a position of primary importance. From Map I. it can be seen that the total quantity of water power which is available in Java, does not amount to more than about $\frac{1}{25}$ H.P. per head of the population, *i.e.*, to less than the amount of natural power which is already being used in some parts of the U.S.A., and in European countries like Switzerland, North Italy and Norway. Of the


Water power resources and load of public electric utilities in Java.
December 1923
Map I.
Water power available.
In the five regional divisions for electric supply of Java.
I 227 500 kW
II 336 500 "
III 182 500 "
IV 166 500 "
V 70 500 "
Total water power available 983 500 kW
Water power utilized.
12 800 kW
12 090 "
8 220 "
2 240 "
870 "
Total water power utilized 35 820 kW
Public electric utilities in Java.
Total connected load 33470 kW
Total maximum load 15220 "
References
Water power available
Water power utilized
Connected load of public electric do
Maximum load supply undertakings do
Situation of principal sites of water power
≥5000 kW
Batavia
Tjikampek
Bandoeng
Tegal
Tjilatjap
Semarang
Djoana
Soerabaja
Modjokerto
Kediri
Malang
Tjandi Oedjoeng
Pasoeroean
Probolinggo
Banjoewangi

available quantity in Java, until now only a very small part has been used for the general electricity supply, as the maximum load of the public electric utilities does not amount to more than $\frac{1}{2000}$ H.P. per head of the total population. This power is almost exclusively used in half a dozen of the larger cities, and for the greater part it is generated in steam power plants.

Now, as the amount of the available power is limited in comparison with what can be found in other parts of the world, the task of the power engineer is to do his utmost to find the most economical method for the ultimate utilisation of all the natural power of Java. From Map I. it will be seen that, especially in the western part of the island, the situation and size of the principal water power sites is such that it should be quite possible to erect a system of transmission lines for the electric supply of the greatest part of the area. In the first and second power districts, a total amount of some hundreds of thousands of kilowatts, divided over half a dozen plants, is found within the limits of a few hundred kilometres.

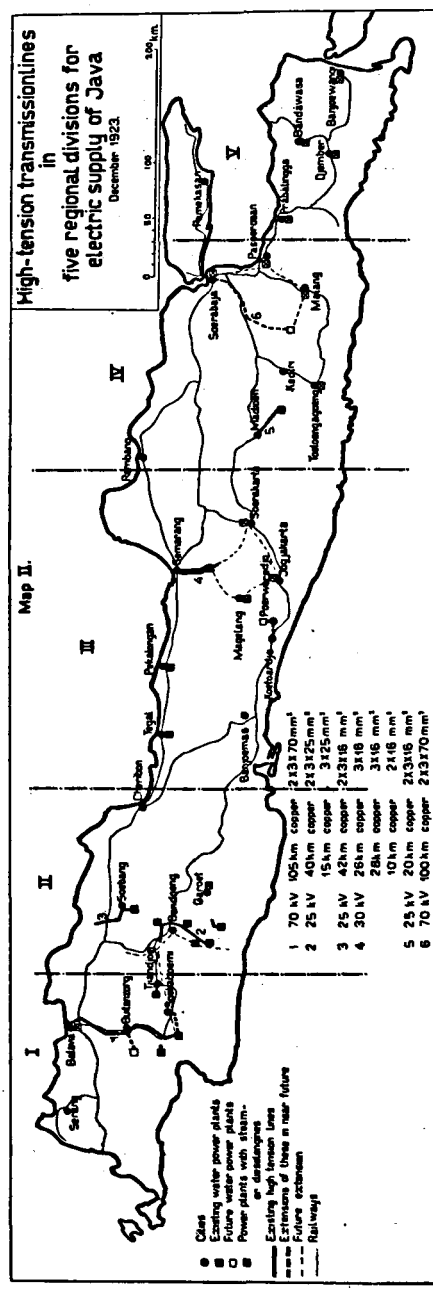
The Eastern part of the island is less fortunate in this respect—a consequence of the natural configuration of the country. In this part the highlands chiefly consist of big solitary volcanoes of conical shape, resulting in an unfavourable division of the river basins into smaller parts.

Still, some splendid possibilities for water-power development are to be found there, especially in the very densely populated agricultural and industrial districts south-west of Soerabaja.

4. 70,000 VOLT SCHEME IN FIRST POWER DISTRICT.

From Map II. it will be seen to what extent transmission of power over large distances is already taking place, and how far it will be practicable to extend existing schemes in the near future. The urgent need for the introduction of electric traction on the over burdened railways round Batavia and between Batavia and Tandjong-Priok, a need which will in the near future be extended to other lines in the same district, made it possible to start the development of a couple of water power sites. One of these is found between Buitenzorg and Soekaboemi on the river Tji Tjatih (ultimate installed capacity 30,000 H.P.), the other one is in the neighbourhood of Buitenzorg, on the river Tji Anten (ultimate installed capacity 45,000 H.P.).

A system of transmission lines, of a total length of about 125


High-tension transmissionlines in five regional divisions for electric supply of Java
December 1923
Map II.
I
II
III
IV
V
Cities
Existing water power plants
Future water power plants
Power plants with steam- or dieselengines
Existing high tension lines
Extensions of these in near future
Future extension
Railways
1 70 kV 105 km copper 2 1x 170 mm²
2 25 kV 40 km copper 2 1x 125 mm²
15 km copper 1x 125 mm²
3 25 kV 42 km copper 2 1x 116 mm²
4 30 kV 26 km copper 3 1x 16 mm²
28 km copper 3 1x 16 mm²
10 km copper 2 1x 16 mm²
5 25 kV 20 km copper 2 1x 116 mm²
6 70 kV 100 km copper 2 1x 170 mm²
Batavia
Serang
Buitenzorg
Tjikao
Pelabuhan
Soekaboemi
Tjandjoer
Bandoeng
Tjimahi
Garoet
Cheribon
Tegal
Pekalongan
Semarang
Nganjoemas
Magelang
Djokjakarta
Soerakarta
Madioen
Kediri
Malang
Pasoeroean
Probolinggo
Djember
Bondowasso
Banjoewangi

kilometres, is being built, connecting the two water power stations with each other, and with four sub-stations. Of these sub-stations one is erected near Buitenzorg, two others are in the neighbourhood of Batavia, and the fourth is in the centre of the European quarter of the last named city.

In this way it will be possible, by using a pressure of 70,000 volts for the transmission, to meet the demand for electric supply in the densely populated area between Batavia and Soekaboemi. For railway purposes the current is transformed from three-phase 70,000 volts, 50 cycles to 15,000 volts, direct current.

The distribution and sale of electricity, as far as Batavia and its suburbs are concerned, will be taken in hand by an existing private power company, which owns a large steam plant in that city. It is intended to keep this station in working order for the first part of the course of the contract, but to take it out of operation as soon as the water power system has proved to be absolutely reliable.

From then on, the steam plant will be used only in periods of water shortage or in case of damage to the water power or transmission system.

It is hoped that the first delivery by this power system will be made in the course of 1924.

5. CO-OPERATION OF GOVERNMENT WITH POWER COMPANY.

In the second regional power division, a water-power system of general electricity supply has been in working order for several years. This district consists almost exclusively of mountainous country and, as may be seen from Map I., a very big amount of water power is available. Up to the beginning of 1920 the scheme for production, distribution and sale of power was owned by a private company, which worked a small water power plant at the river Tji-Kapoendoeng, north of the capital Bandoeng. From that date the production and transmission of the power was taken in hand by the Government.

A new and more efficient station took the place of the former private plant, and three more water power sites were developed. Two of these have already been put into operation; the third and biggest one (36,000 installed H.P. on the river Tji-Sangkoej) will follow in the course of 1924. A special feature of the last mentioned plant is that a fall of 750 feet will be used. The normal head for water powers in Java varies between 300 and 500 feet.

One of the plants in this district is an automatic generating station, working from the tailrace of the above mentioned plant on the Tji-Kapoendoeng.

A favourable feature of this water power scheme is the possibility of storing up water for the plants on the Tji-Sangkoei from the wet season, for use during the dry season, by means of the damming up of a valley situated 4,700 feet above sea-level. The present accumulating capacity of this reservoir amounts to 10 million cubic metres (370 million cubic feet) of water. A future extension up to 20 million cubic metres, by raising the dams, is planned. A second reservoir, situated behind the first one, will contain another 24 million cubic metres.

For wireless purposes a steam plant has been built which is connected to the power scheme. It is to be expected that this steam plant will give a very welcome auxiliary supply in future dry years, but for the first period after the completion of the last water power station and reservoir no steam power will be needed.

A transmission line for 27,000 volts interconnects the different power plants and substations. In future it will become necessary to raise the pressure of this transmission line to 70,000 volts.

After the completion of the power schemes in the first and second power districts, it might prove useful to interconnect them by a 70,000 volt transmission line, thus gaining the advantage of mutual help in periods of water shortage.

Up to now the use of power is limited to the capital Bandoeng and townships in the neighbourhood. The largest consumption is found in the well-known wireless station on the Malabar mountain, which requires several thousands of kilowatts. It is to be expected that in the near future, railway electrification in this power district will be carried through.

For the distribution and sale of power in this district, a company on a community basis has been started, in which the Government, the provincial and municipal boards, and the already existing private concern each have a part.

6. DEVELOPMENT ON SMALLER SCALE IN CENTRAL JAVA.

In the third power district a water power scheme, connected to a 25,000 volts transmission system, delivering power to the capital Semarang and some smaller places in the vicinity, is worked by a

private company. A future extension of the transmission system to the cities Magelang, Djocjakarta, and Soerakarta, is planned. Some of the already existing Diesel plants in these cities will be kept in working order for the supply of power during periods of water shortage, while the remaining Diesel engines will be moved to other townships which are for the present out of reach of the transmission line.

There is an agreement between the Government and the power company to the effect that the water power scheme can be taken over by the former as soon as the need for further development makes this procedure desirable. This would result, first in the extension of the existing system on the Toentang river, eventually in combination with water storage for the dry season, and secondly in the harnessing of the water power of the Serajoe river, situated west of the former.

7. PROMISING PROJECT FOR SOERABAJA.

In the fourth power district, of which the commercial and industrial city of Soerabaja is the capital, a splendid opportunity for water power development is offered. Up to now, only one water power system for general electricity supply is in use. This system is situated on the river Tjatoer near Madioen and has been developed by the Government principally for the supply of power to the railway workshops. The distribution and sale of power to the public has been taken in hand by the municipality of Madioen.

All the other public plants in this district generate power by means of steam turbines or Diesel engines. A scheme has however been worked out by the Government to utilise the water power of the Konto river. A 70,000 volts transmission line of about 100 km. length will carry the power to Soerabaja, as can be seen from Map II. It has been calculated that the power can be sold to the power company at Soerabaja at a price which is lower than the cost of steam power, even if the expense of keeping up the existing steam and Diesel plants is taken fully into consideration.

Although the prospects of this scheme are very promising and the plans have been worked out in detail, it is to be feared that the Government will not be able to carry it through for some time owing to the present financial strain.

In the fifth power district only a few small public power systems, generating by means of Diesel engines, are in exploitation. As can

be seen from Map I., a water power development is possible, but it is not likely to be realised in the near future.

8. GENERAL FIGURES.

In the foregoing a general view has been given on what has been done so far in the way of generation, transmission and distribution of power for general use in the fertile island of Java, and on what may be expected in the future, if financial circumstances permit. In addition, a few figures may be given as to the cost of the power work in this part of the world.

The price of water power developments varies largely, as it is dependent upon the conditions and the size of the scheme. Under the present conditions it may be possible to build a large sized water power plant at a cost of not more than 200 Dutch guilders (£16) per installed H.P. For small stations which have to carry a big peak load, the cost may increase to from 800 to 1,000 guilders per average H.P.

For the erection of transmission lines (70,000 volts) an estimate of 12,000 to 14,000 guilders per km. can be given. This price includes the cost of the necessary ground for the poles and the inspection path (which is carried, at a width of 1 m., along the total length of the line), and the right of way for a belt of ground of about 20 metres wide, each side of the line.

The total yearly cost of a working scheme, including interest and depreciation, can be estimated at from 9 to 10 per cent. of the invested capital. A favourable feature is the low cost of labour. Existing schemes prove that it is possible to sell power to distribution companies up to distances of 100 kilometres from the water power site at a price of from 2½ to 3 cents (5 cents equal 1 penny) per unit. It is generally found in this part of the world that the cost of steam power exceeds this price considerably.

RÉSUMÉ.

Une description est donnée des principes généraux gouvernant les dispositions principales des projets de stations centrales hydrauliques, avec les possibilités présentes et futures de transmission de l'énergie électrique dans les Indes Orientales Néerlandaises. Le sujet est discuté sous les rubriques suivantes :

1. Nécessité de la transmission de l'énergie.

2. Forces hydrauliques disponibles et besoins actuels d'énergie à Java. Cette

partie est accompagnée d'une carte indiquant les forces disponibles et la consommation actuelle de force motrice à Java où l'énergie est en plus grande demande que partout ailleurs.

3. Nécessité urgente d'un travail systématique ; Java est divisé en secteurs de force motrice.

4. Projet à 70.000 volts pour alimenter la région à forte densité de population entre Batavia et Sockaboemi (cette énergie est transformée en courant continu à 1.500 volts pour traction électrique). On espère commencer à fournir du courant avant fin 1924.

5. Coopération entre les services Gouvernementaux, Provinciaux et Municipaux, dans les entreprises de transport de force.

6. Développement sur une petite échelle dans la région centrale de Java.

7. Un projet intéressant pour le Soerabaja en utilisant la force hydraulique de la rivière Konto et en transportant l'énergie à 100 Km. à 70.000 volts.

L'EVOLUTION DES IDEES EN MATIERE DE REGULARISATION DE L'ENERGIE HYDRO-ELECTRIQUE

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Si l'on jette un coup d'œil d'ensemble sur les conditions dans lesquelles il a été procédé à l'aménagement des forces hydrauliques dans ces dernières années, on ne peut manquer d'être frappé par les caractères que présente l'évolution considérable des idées en cette matière en France.

L'aménagement rationnel et intensif des forces hydrauliques y est de date assez récente. Sans doute, on trouve des exemples très anciens de moulins utilisant l'énergie des ruisseaux, ou des rivières, à l'aide d'organes extrêmement médiocres (routes, roues, etc.), mais, bien que le nombre de ces installations fût relativement considérable, leur puissance individuelle était tellement infime que la puissance totale correspondante restait très faible et à peu près négligeable au point de vue de l'économie nationale.

C'est en 1867-1869 que M.M. Fredet et Berges installèrent les premières usines hydrauliques vraiment dignes de ce nom. Les progrès techniques de la construction (turbines, conduites) furent rapides ; une véritable révolution fut due, une quinzaine d'années plus tard, au remarquable résultat des expériences réalisées par M. Desprez sur le transport de l'énergie électrique, expériences qui, en permettant d'utiliser l'énergie hydro-électrique loin de son lieu de production, auraient dû lui ouvrir des débouchés nouveaux et illimités. L'outil, tant en ce qui concerne la production que le transport, était donc créé. Malgré tout, la progression resta assez lente jusqu'à la veille de la Guerre, puisqu'au début de 1914 la puissance totale aménagée ne dépassait pas 550.000 kW.

Et cependant l'attention des industriels et des pouvoirs publics s'était nettement portée depuis plusieurs années vers cette nouvelle ressource nationale. Nous n'en voulons pour preuve que le fait qu'en 1902 se réunissait à Grenoble le premier Congrès de la Houille

Blanche ; qu'un second devait se réunir en 1914 et que dès 1908 les Ministères des Travaux Publics et de l'Agriculture avaient créé, d'un commun accord, des services spéciaux de grandes forces hydrauliques.

Il est donc certain que, malgré la création et les perfectionnements incessants du matériel technique indispensable, malgré le mouvement d'opinion très réel et les mesures d'organisation judicieuses prises, le développement des installations ne suivit pas la progression que l'on était en droit d'espérer.

La Guerre devait, tant en raison des besoins en énergie de la Défense Nationale que de la pénurie de charbon, donner à ces installations une impulsion nouvelle. Elle devait surtout, en orientant les esprits vers des horizons plus larges et vers des intérêts moins immédiats, donner aux problèmes qui touchent à l'utilisation des forces hydrauliques un aspect nouveau, les présenter sous une forme plus générale. Elle devait conduire, par des généralisations successives, à modifier les conceptions trop étroites que l'on se faisait jadis de la régularisation et de la répartition de l'énergie, et par là amorcer une ère de développements futurs qui sera, sans nul doute, infiniment féconde.

C'est l'histoire de ces variations successives, dans le rôle, l'emploi le mode d'association des usines de production d'énergie, que nous voudrions esquisser dans le présent rapport, en rappelant d'abord les différentes étapes parcourues en France, jusqu'à nos jours, et en résumant enfin les directives qui paraissent actuellement se dégager de l'examen des faits.

1ère Partie. HISTORIQUE de la RÉGULARISATION.

Nous distinguons trois périodes dans l'histoire de la régularisation, telle qu'on la conçoit de nos jours :

Les premiers promoteurs de la houille blanche concevaient l'usine isolément. Etablie toujours dans un pays de montagne d'accès souvent difficile, cette usine était presque toujours créée en vue d'une utilisation immédiate, sur place. Nous verrons comment on s'ingénie, dans cette période, à pallier aux irrégularités que sa situation isolée entraîne.

Bientôt, on acquiert la notion de l'aménagement d'ensemble d'un bassin, que l'on envisage pourvu de moyens de régularisation importants (réservoirs de haute altitude). C'est l'époque des plans d'aménagement établis par bassins, de la loi du 16 Octobre, 1919.

Enfin, on en arrive à l'idée moderne de la compensation hydraulique interrégionale de bassin à bassin, en associant ensemble des bassins à régime complémentaire.

a) Première période : l'usine considérée isolément.

Les premières usines construites n'avaient en général pas pour objet de produire l'énergie électrique pour la vendre. Elles se proposaient plutôt d'utiliser l'énergie hydrauliques pour les besoins d'une industrie ou d'un service déterminé, en passant par l'intermédiaire de la transformation électrique. De ce nombre étaient les premières usines des Alpes, affectées, soit à des papeteries (usine des Papeteries d'Albertville, sur le Doron de Beaufort), soit à des fabrications électro-chimiques (usines de la Plombière, sur l'Isère, construite par la Société Lyonnaise de l'Industrie électro-chimique " La Volta ; " usine du Giffre, sur le Giffre, construite par la Société électro-chimique du Giffre, etc.) ; les usines du P.L.M., sur l'Arve, destinées à l'électrification du chemin de fer du Fayet à Chamonix (usines de Servoz et des Chavants), etc.

Il est visible que l'usine ainsi isolée est exposée à deux inconvénients majeurs ; l'un est l'irrégularité saisonnière des débits, l'autre, le manque de souplesse de marche résultant du défaut d'accumulation journalière.

Pour pallier au premier de ces inconvénients, plusieurs solutions sont adoptées :

1°) La plus simpliste consiste à n'utiliser que le débit permanent de la rivière : l'équipement de l'usine correspond au débit d'étiage. Pendant 8 ou 9 mois de l'année, la plus grande partie du débit inutilisé par l'usine s'écoule par-dessus le barrage ou par des vannes.

Cette solution semble bien avoir été très fréquente, tout au moins au début. (Usines d'Avignonnet sur le Drac à la Société Grenobloise de Force et Lumière—Usines des Chavants sur l'Arve à la Compagnie des Chemins de fer P.L.M. Usines du Saillant sur la Vézère alimentant la Compagnie d'Electricité de Limoges, etc.).

On voit même assez souvent aujourd'hui des usines construites autrefois de façon à n'utiliser qu'une assez faible fraction du débit s'agrandir en installant simplement les ouvrages et organes nécessaires à l'utilisation d'un certain débit supplémentaire, cette utilisation étant reconnue maintenant rémunératrice. On conçoit sans peine qu'elle puisse l'être en effet si les ouvrages les plus coûteux (barrages, etc.), ont été construits dès l'origine de telle sorte que les dépenses complémentaires à faire soient relativement faibles. Comme exemple de ce genre nous citerons l'usine de Luzières, sur

l'Agout, qui, aménagée en 1913 de façon à utiliser un débit de 9 mètres cubes seulement, a été modifiée en 1919 de façon à utiliser un débit de 25 mètres cubes.

2°) L'usine étant équipée de façon à pouvoir utiliser un débit sensiblement supérieur au débit d'étiage, on lui accole une thermique, destinée à faire l'appoint dans les périodes où le débit de la rivière est insuffisant.

Un des exemples les plus connus de cette solution est celui de l'usine de Tuilières, construite il y a une vingtaine d'années sur la Dordogne, près de Bergerac. Une usine thermique d'une puissance de 14.000 kW. est accolée à l'usine hydraulique dont la puissance atteint 15.000 kW.

3°) Enfin, on trouve déjà dans les dernières années de cette première période quelques exemples d'une conception beaucoup plus parfaite : celui de la régularisation saisonnière par la création de réservoirs régulateurs importants. C'est ainsi que :

—l'usine d'Orlu, dans les Pyrénées, utilisait, sous une chute de plus de 900 mètres, les eaux du lac Naguilhe aménagé à l'altitude de 1850 mètres et dont la capacité atteignait 13 millions de mètres cubes. Elle servait de régulatrice aux autres usines que la Société Pyrénéenne possédait dans cette région.

—la Compagnie des Forges et Aciéries Paul Girod, à Ugine, demandait la concession de l'aménagement du Doron de Beaufort et de ses affluents, au moyen de chutes successives, régularisées par l'utilisation rationnelle du lac de la Girotte. Le cube emmagasiné par ce lac devait être d'abord de 17 millions de mètres cubes et il était prévu qu'il pourrait être porté à 28 millions. A la sortie de ce réservoir, l'eau devait être utilisée dans une série d'usines sur une hauteur totale de plus de 1.000 mètres.

—les 3 usines de la Pique Inférieure, Pique Supérieure et de Luchon dont l'aménagement avait été conçu par la Société Pyrénéenne d'Energie Electrique étaient destinées à marcher en parallèle pour fournir l'énergie à des usines électro-chimiques, la régularisation de l'ensemble étant assurée par l'usine de Luchon qui pouvait utiliser les eaux du lac d'Oo.

Mais l'emploi de ces réservoirs de haute chute, commandant directement l'usine de production, est évidemment subordonné à une situation géographique exceptionnellement favorable et peu fréquente.

Pour corriger le manque de souplesse du régime journalier, on arrive très rapidement à envisager la nécessite, là où la chose est possible, de fonctionner par éclusées à l'aide d'un petit réservoir

établi en amont. On laisse l'eau s'y accumuler pendant les heures où la demande est faible ou nulle, tandis que pendant les heures les plus chargées on ajoute au débit naturel du cours d'eau un prélèvement fait sur cette réserve. Pour éviter qu'il n'en résulte des inconvénients pour les usines d'aval, il suffit d'installer un bassin compensateur à la sortie de l'usine.

Ce système est celui que préconisait la circulaire du 26 Novembre, 1917, dans les termes suivants :

" Une usine a généralement un régime de fonctionnement variable aux différentes heures de la journée, d'après sa destination. Il est exceptionnel qu'elle puisse fonctionner à puissance constante pendant 24 heures par jour, même si elle est associée à une usine thermique de secours. Pour utiliser sans perte le débit journalier disponible, il lui faut un certain volant hydraulique constitué le plus souvent en amont par un bassin accumulant l'eau en excès pendant les heures les moins chargées et la restituant au moment des pointes. En outre, il faut que le débit maximum évacué par un établissement puisse être repris et utilisé par ceux d'aval, c'est-à-dire qu'il faut après chaque usine un bassin compensateur qui permette de rétablir la continuité de l'écoulement modifié par cette usine. Ces deux conditions sont nécessaires pour assurer à chaque établissement et à l'ensemble une certaine souplesse journalière sans gaspillage d'eau."

(*b*) *Deuxième période* : *la conception de l'aménagement par bassin.*

A la conception initiale de l'usine isolée ou à celle un peu plus parfaite du groupe d'usines, succède la conception de l'aménagement par bassin. On reconnaît que chaque cours d'eau constitue avec ses divers affluents un ensemble dont toutes les parties sont étroitement solidaires et que l'aménagement rationnel d'une section déterminée est intimement lié aux travaux entrepris ou prévus à l'amont. La bassin devient l'unité hydraulique.

L'expression de cette conception se trouve dans la loi du 16 Octobre 1919. En de multiples endroits, ce texte insiste sur la nécessité de prendre comme unité hydraulique un bassin entier. Sa tendance est surtout manifeste en deux articles :

1°) à l'article 3, où le législateur a considéré que le déversement des eaux d'un bassin fluvial dans un autre présentait une gravité telle que la concession ne pouvait, dans ce cas, être accordée que par le Parlement ;

2°) à l'article 28, qui prévoit que des réglements d'administration publique auront à déterminer " la forme et le fonctionnement des ententes que l'Administration pourra imposer sous sa direction et,

le cas échéant, avec son concours financier . . . aux divers concessionnaires ou permissionnaires établis sur les cours d'eau d'une même vallée ou d'un même bassin." Ce dernier article organise réellement la solidarité de fait entre les usines d'un même bassin, de manière à en afficher l'unité.

Mais la loi a fait plus encore ; elle a donné une valeur quasi réglementaire aux vastes plans d'aménagement établis par les services des forces hydrauliques, soumis ensuite à l'approbation de l'Administration supérieure et du Comité Consultatif des Forces Hydrauliques, et qui matérialisaient ainsi l'organisation par bassins, en la figeant en quelque sorte dans une forme à priori. Et ceci n'a pas été sans conduire parfois à une conception erronée de leur rôle.

S'il avait fallu en effet considérer ces plans d'aménagement comme le cadre rigide dans lequel devaient venir s'enchâsser tous les aménagements à réaliser ultérieurement, l'expérience n'aurait pas tardé à démontrer les très grands inconvénients pratiques d'une pareille conception.

Si, au contraire, on voulait bien se contenter de les considérer comme ayant simplement pour but de réunir sous une forme commode et claire la plupart des renseignements susceptibles d'intéresser les industriels (profils en long du cours d'eau, débit, nature géologique des terrains traversés, etc. . .), et comme donnant une indication approchée de ce qu'il était possible de faire sur ce cours d'eau—et c'était là leur véritable but—leur intérêt était et reste incontestable.

Les principaux plans d'aménagement publiés concernèrent : le bassin de l'Isère (1919)—le bassin de la Durance (1919)—le bassin de l'Arc (1920)—le bassin de la Romanche (1921).

Sous l'influence de ces tendances, suivies peut-être à un point de vue trop théorique, des propositions émanant soit de l'Administration, soit de l'initiative privée, furent faites pour des aménagements de bassins entiers, que les difficultés économiques des années suivantes allaient obliger à laisser pour quelque temps de côté ou du moins à ne réaliser que très progressivement. Comme exemple de tels projets, nous citerons :

(*a*)—L'aménagement de la Dordogne, depuis sa source jusqu'à son confluent avec la Gironde, dont la concession fut un moment envisagée comme devant être accordée à une Société unique, préoccupation dont on retrouve la trace dans l'Article 15 du Cahier des Charges annexé au décret concédant à la Compagnie des Chemins de fer de Paris à Orléans l'aménagement de la Haute-Dordogne.

(*b*)—L'aménagement de la Truyère.—Cette rivière et son affluent le Bès offrent à la fois d'excellents emplacements de réservoirs régulateurs et la possibilité de réaliser dans des conditions très interéssantes des chutes particulièrement puissantes.

La Société des Forces Motrices de la Truyère présenta en 1918 un projet grandiose concernant la région située un peu en aval du confluent Truyère-Bès. Ce projet prévoyait la construction d'un réservoir dit de Pradal, d'une capacité de 200 millions de mètres cubes ; celle d'un second réservoir, dit de Sarrau, d'une capacité de 50 millions de mètres cubes ; chacun de ces barrages devant être accompagné d'une usine établie à son pied ; enfin, la construction d'une usine à Brommat, utilisant sous une chute de 250 mètres environ l'eau sortant des réservoirs ci-dessus. La construction des réservoirs est aujourd'hui ajournée ; celle de l'usine est en cours, mais correspondra provisoirement à une puissance sensiblement moitié de celle primitivement prévue.

(*c*)—L'aménagement de la Tinée.—Le projet d'aménagement de cette rivière et des lacs de Vens et de Rabuons avait été dressé par la Société " Energie Electrique du Littoral Méditerranéen." Il comportait, avec des réserves d'une vingtaine de millions de mètres cubes, l'équipement d'une puissance totale de 140.000 H.P. utilisant plus de 2.200 mètres de hauteur de chute et pouvant produire environ 550 millions de kWh. par an.

La conception de l'aménagement par bassin a eu incontestablement cet heureux effet de faire considérer les questions d'aménagement d'assez haut, avec une vue d'ensemble suffisante, pour éviter les anomalies ou les erreurs graves auxquelles avait conduit quelquefois la conception primitive de l'usine isolée.

C'est à elle que l'on doit également d'avoir fait ressortir la nécessité d'obliger les usiniers d'aval qui ont profité des améliorations de régime dues à l'établissement de réservoirs régulateurs, à verser les indemnités de plus-value aux constructeurs de ces réservoirs, conception extrêmement exacte et équitable, et de nature à favoriser le développement si désirable de pareils réservoirs.

(*c*) *Troisième période : la compensation hydraulique interrégionale.* Les régimes naturels de tous les cours d'eau ne sont pas identiques. Partant de cette idée, et du fait que les cours d'eau descendant des Alpes et des Pyrénées ont leur étiage l'hiver et leurs plus hautes eaux au moment de la fonte des neiges, tandis que ceux qui descendant du Massif Central ont un régime contraire, on a songé à régulariser les énergies provenant de ces sources différentes en les superposant.

les maxima des unes correspondant aux minima des autres et réciproquement.

L'idée se trouvait déjà en germe dans certaines installations privilégiées, telles celles de l'Energie Electrique du Littoral Méditerranéen, qui dispose depuis de nombreuses années déjà d'une série d'usines hydro-électriques dont les unes, établies sur les parties hautes des cours d'eau descendant des Alpes ont leur puissance maxima au moment de la fonte des neiges, tandis que d'autres, établies sur les parties basses de ces cours d'eau ou sur des rivières dont la source est située à assez basse altitude (Argens-Siagne-Loup, etc.), donnent leur maximum de puissance pendant les mois les plus pluvieux.

Une généralisation de cette idée était fort tentante. Elle était d'ailleurs devenue possible grâce à une connaissance plus étendue et plus complète des régimes naturels des rivières en même temps qu'aux progrès réalisés dans le problème du transport de l'énergie.

Une étude de M.M. Duval et Lavanchy, parue dans la " Revue Générale de l'Electricité," du 24 Mars 1923, donne une idée assez précise des résultats que l'on pourrait attendre d'une combinaison partielle des énergies provenant des Alpes, du Massif Central et des Pyrénées. Considérant l'époque où le quart de la puissance moyenne disponible totale de chacune de ces régions serait aménagée, les auteurs arrivaient à cette conclusion que la réalisation de l'interconnexion entre ces 3 régions aurait pour effet d'ajouter à la puissance permanente de 755.000 kW., somme des puissances permanentes de chaque région considérée isolément, une nouvelle puissance permanente de 300.000 kW. provenant de la combinaison d'une partie des puissances saisonnières de chacune de ces régions. En d'autres termes, l'énergie permanente récupérée atteindrait 40 pour cent de l'énergie permanente des 3 régions considérées isolément.

La conjugaison de sources d'énergie hydraulique de régimes différents, si elle permet de transformer en kilowatts constants un nombre très appréciable de kilowatts irréguliers, ne constitue cependant pas, il s'en faut de beaucoup, une solution parfaite du problème de la régularisation. Si les régimes des Alpes et des Pyrénées d'une part, du Massif Central et des cours d'eau côtiers d'autre part, sont complémentaires, il ne le sont point exactement, ni en quantité, ni dans le temps. Les périodes d'étiage se superposent parfois et, même dans les années où il n'en est pas ainsi, les kilowatts correspondants à la période des hautes eaux des rivières

du Massif Central seront toujours insuffisants pour équilibrer le déficit des cours d'eau des Alpes et des Pyrénées.

Si donc l'idée de la compensation interrégionale est fort intéressante, elle est loin de résoudre le problème d'une façon complète.

On ne peut pas ne pas être frappé, au terme de cette étude rapide de l'historique de l'aménagement et de la régularisation des usines hydrauliques, par les analogies que présente ce problème, avec la question tout à fait connexe des usines marémotrices.

On sait, sans qu'il soit utile d'insister sur les principes d'utilisation des marées, qu'une usine marémotrice isolée souffre, comme l'usine isolée que nous considérions dans la première période, d'un double inconvénient : Irrégularité diurne, due au mouvement de la mer— Irrégularité périodique, due aux périodes successives de vive eau et de morte eau. Les remèdes, jusqu'ici théoriques que l'on a envisagés pour pallier ces inconvénients, rappellent singulièrement ceux dont nous venons d'esquisser l'histoire : Tout d'abord, par le choix d'un cycle approprié, on a cherché à corriger l'usine par elle-même (emploi du cycle à double effet, emploi de bassins conjugués) ; puis, imitant les solutions que les plans d'aménagement fournissaient pour corriger entre elles les usines d'un même bassin, on a cherché à accoler à une usine marémotrice une usine d'eau douce établie en amont sur une rivière débouchant dans la baie aménagée. C'est de cette solution que procède le fonctionnement envisagé pour l'usine marémotrice de l'Aber Vrac'h. L'énergie produite par cette usine devant être extrêmement variable, on a prévu un peu en amont d'elle, sur cette même rivière de l'Aber Vrac'h, une usine appelée Usine de Diouris, accolée à un réservoir d'accumulation d'eau. L'usine de Diouris est destinée à combler les creux de l'usine marémotrice, et comme le débit de la rivière ne serait pas suffisant pour permettre à la régularisation de s'effectuer d'une façon convenable, il est prévu que pendant les périodes où l'usine marémotrice disposera de sa plus grande puissance, une partie de cette dernière sera utilisée à envoyer par pompage de l'eau dans le réservoir de Diouris, cette eau venant s'ajouter au débit naturel de la rivière. L'ensemble Aber Vrac'h-Diouris forme ainsi un tout assez bien régularisé.

Enfin, imitant la solution de régularisation par compensation de bassins à régime différent, on a proposé le fonctionnement d'usines marémotrices par " bassins associés " distincts et indépendants, solution que l'énormité des dépenses à engager rend souvent problématique, mais qui n'en établit pas moins, au point de vue de la

filiation des idées, une parenté bien nette entre les divers modes d'utilisation de l'énergie de l'eau.

Il nous reste maintenant à montrer quelle dernière transformation ont subi ces idées et quelles directives actuelles paraissent se dégager des études et des projets actuellement en cours.

2ème Partie. LES IDÉES ACTUELLES.

Jusqu'à ces derniers temps tous les efforts tendaient donc à régulariser la production de l'énergie. Les progrès réalisés à ce point de vue au cours des 3 périodes distinguées ci-dessus, consistaient surtout à étendre cette régularisation à des ensembles de plus en plus importants : de l'usine ou du groupe d'usines au bassin, du bassin à un ensemble de régions de régime différent.

Cependant, au fur et à mesure que des études plus approfondies permettaient de se rendre compte avec une précision croissante de ce qu'il était possible d'attendre de ces divers systèmes ou de leur combinaison, on était amené à reconnaître leur insuffisance, en même temps que l'impossibilité matérielle de régulariser même approximativement par l'aménagement de réservoirs ou la compensation interrégionale l'ensemble de la production de l'énergie d'origine hydraulique sur le territoire.

C'est alors que se fit jour une idée nouvelle : la régularisation parfaite, et d'ailleurs impossible, est-elle vraiment si désirable ? Ce que l'on veut, en somme, c'est avoir de l'énergie au moment où l'on en a besoin. Les besoins n'étant pas constants il n'est pas indispensable que la production le soit elle-même ; il vaudrait beaucoup mieux au contraire qu'elle variât parallèlement à la demande.

A la conception de la régularisation idéale correspondant à une production, représentée sur le graphique par une horizontale se substituait ainsi celle d'une courbe de la production modelée sur celle de la demande et la recouvrant.

D'autre part, la courbe de la demande n'étant pas elle-même d'une rigidité absolue, l'idée venait immédiatement à l'esprit de s'efforcer d'agir sur elle de façon à la rapprocher dans toute la mesure possible de celle de la production.

Agir sur la courbe de la demande de façon à la rapprocher le plus possible de celle de la production ; s'efforcer parallèlement d'obtenir une production se modelant sur la demande ; arriver par ces deux efforts concordants à superposer le mieux possible les deux courbes ; réduire ainsi au minimum l'importance des usines de secours ; telles sont en définitive les directives qui paraissent s'imposer à nous aujourd'hui.

Les moyens pratiques d'atteindre ce but sont de 3 sortes :

1°) régularisation de la demande par l'association d'utilisations différentes ;

2°) mise en commun de toutes les ressources ;

3°) utilisation rationnelle de l'ensemble des moyens de production et de régularisation.

I. RÉGULARISATION DE LA DEMANDE PAR L'ASSOCIATION D'UTILISATIONS DIFFÉRENTES.

L'idée n'est pas nouvelle. Les premiers exploitants d'usines n'ont pas tardé à s'apercevoir qu'une étroite spécialisation dans l'utilisation de l'énergie hydro-électrique était, sauf cas exceptionnel, d'un très mauvais rendement.

Cette remarque se trouve déjà très nettement formulée dans les lignes suivantes écrites en 1902 :

" La tendance générale est de multiplier les emplois de la force dont on dispose sur un point et la prospérité des installations semble varier en raison de la multiplicité de ces emplois. Telle usine exclusivement consacrée à une seule fabrication, se soutient péniblement contre la concurrence de ses rivales, tandis que telle autre, ou l'on a su varier les produits, apparaît avec les signes d'une incontestable prospérité."[1]

Ce qui dès l'origine s'était révélé vrai pour l'usine isolée reste vrai pour un ensemble quelconque d'usines.

Quelles sont les principales utilisations de l'énergie hydro-électrique ?

On peut, en première approximation, les diviser en 5 catégories qui sont par ordre d'utilisation décroissante :

(*a*) l'électro-chimie, excellent client susceptible d'absorber une production continue et même de s'accommoder d'une production variable, pourvu que ces variations ne soient pas trop brusques.

(*b*) la traction à laquelle, lorsque l'électrification des chemins de fer d'intérêt général se sera développée, correspondra une excellente utilisation, de l'ordre de 6.000 Heures, ce qui tiendra : à la compensation qui s'effectuera spontanément entre les diverses lignes électrifiées lorsque ces lignes seront en très grand nombre ; à l'emploi sur certaines lignes ou pour certains usages (manœuvres) de matériel à accumulateurs, ces accumulateurs étant rechargés pendant les heures creuses ; à la possibilité de modifier les horaires de certains trains de façon à atténuer les pointes.

(*c*) la grosse industrie, excellent client dans les usines à marche

[1] Les installations hydro-électriques dans la région des Alpes par M. de la Brosse (1902).

continue ; dans les autres cas, client moyen dont la durée d'utilisation est égale à celle de la journée de travail, soit environ 8 heures par jour.

(*d*) la distribution. Le coefficient d'utilisation des réseaux de distribution varie fortement suivant la nature de la clientèle desservie. Si la principale consommation est celle qui correspond à l'éclairage, à la petite force motrice, etc., le coefficient d'utilisation reste voisin de 2.000 heures. Si, au contraire, la distribution alimente un réseau de tramways important ce coefficient peut atteindre 4.000 heures.

(*e*) Les réseaux ruraux ; très mauvais clients auxquels correspond une durée d'utilisation de quelques centaines d'heures seulement, ce qui explique que ces réseaux ne soient viables eux-mêmes qu'à la condition de comprendre des agglomérations d'une certaine importance ou de bénéficier de larges subventions de la part des pouvoirs publics.

La place tenue dans cette énumération par la clientèle médiocre et l'importance de la puissance qu'elle est susceptible d'absorber montrent que la simple association de ces différents débouchés ne suffirait pas à donner une utilisation d'ensemble très satisfaisante.

Il peut sans doute se faire que dans certaines régions dont la dotation en bons clients est particulièrement heureuse, on arrive par un simple groupement des producteurs et des consommateurs à un résultat très satisfaisant ; un excellent exemple d'une pareille solution est celui qui est donné par l'Union des Producteurs d'Energie Electrique des Pyrénées-Occidentales.

Mais si l'on veut améliorer l'utilisation moyenne de l'énergie sur l'ensemble du territoire, atténuer l'importance des pointes correspondant aux heures de travail normal et, pendant l'hiver, aux heures d'éclairage, la solution devra être cherchée dans un développement de la vente d'énergie aux heures creuses et particulièrement la nuit.

Ce développement ne pourra être obtenu que par la réalisation simultanée des deux conditions suivantes :

(*a*) créer de nouvelles installations électro-chimiques ; améliorer le coefficient d'utilisation des réseaux de distribution, par exemple par l'installation dans les appartements d'appareils accumulateurs de chaleur chauffés électriquement pendant la nuit, par l'emploi pour les transports en commun de véhicules à accumulateurs chargés pendant les heures creuses, par le développement des pompages, de nuit etc.

(*b*) pousser les clients à s'intéresser à ces nouveaux emplois de

l'énergie en accordant pour ces utilisations des tarifs particulièrement bas.

Quelque considérable que soit l'intérêt des développements auxquels prêtent ces idées, nous ne nous y livrerons pas ici, cette question devant faire l'objet d'un rapport spécial de la délégation française.

II. MISE EN COMMUN DES RESSOURCES.

La mise en commun des ressources se trouvera réalisée lorsque toutes les usines d'une certaine importance seront reliées au réseau national de transport dont la construction est en cours.

Il est permis d'attendre du fonctionnement de ce réseau les résultats les plus heureux; il atténuera l'importance relative des pointes momentanées, celles-ci ne se produisant pas simultanément dans tous les centres de consommation; il réalisera la liaison interrégionale dont on a déjà indiqué les avantages et liera les centres de production[1] d'énergie hydraulique à ceux d'énergie thermique; il jouera enfin le rôle d'un énorme volant régulateur dans lequel les usines nouvelles viendront déverser l'énergie dont elles n'auront pas le placement dans leur région et auquel, au contraire, les industries anciennes dont les besoins développés dépassent les disponibilités viendront emprunter le complément nécessaire.

La carte ci-jointe représente schématiquement l'état actuel de ce réseau—on n'y a fait figurer que les lignes dont la tension dépasse 60.000 volts; l'échelle de ce document n'a pas permis de distinguer les différentes tensions, mais ces renseignements sont donnés dans le tableau qui l'accompagne. Les lignes sont classées en trois catégories:

(*a*) lignes en service ou en construction;
(*b*) lignes ayant fait l'objet d'une demande de concession et dont par conséquent la construction doit avoir lieu à bref délai;
(*c*) enfin, lignes dont la construction est envisagée.

On n'a fait figurer dans cette dernière catégorie que celles de ces lignes dont la construction est envisagée pour un avenir très prochain, les seules dont le tracé puisse être indiqué avec une certaine exactitude.

Il est tentant en effet d'établir a priori un schéma général que l'on

[1]Cette liaison entre eux des centres de production hydraulique correspondant à des régions différentes ou des centres de production hydraulique et thermique ne doit pas se faire d'usines à usines, mais bien de centre de production à centre de consommation. On aperçoit immédiatement en effet que c'est le moyen de réduire au minimum la longueur sur laquelle l'énergie doit être transportée et d'éviter la construction de lignes ne fonctionnant que pendant des périodes très courtes.

présenterait comme un plan formel, répondant au but que se propose le Réseau National. Ce serait, à notre avis, faire œuvre aussi vaine que d'arrêter " ne varietur " un plan d'aménagement de bassin. La consistance d'un tel réseau ne saurait être fixée a priori, abstraction faite des contingences économiques ou financières variables à chaque instant. L'essentiel est que chacun des tronçons qu'on en réalise prenne sa place dans un tout harmonieux et cohérent.

La construction du Réseau National ne peut être que la résultante d'initiatives émanant de collectivités ou de personnalités très diverses. On peut citer jusqu'ici les méthodes suivantes, qui ont toutes été appliquées concuremment :

(*a*) le Réseau d'Etat des Régions Libérées, constitué par la ligne à 120.000 volts Vincey, Nancy, Landres, Mohon et un certain nombre de lignes secondaires à tension inférieure à 60.000 volts établies dans les départements sinistrés ; ce réseau a été construit aux frais et sous la direction de l'Etat, immédiatement après la guerre, pour permettre la reprise normale de la vie dans les régions dévastées.

(*b*) les lignes établies par des Sociétés privées concessionnaires :

Les lignes à 120.000 volts : Truyère—St. Etienne-Roanne—St. Germain-des-Fossés — Roanne-Villefranche — St. Etienne-Grenoble, concédées à la Société de Transport d'énergie du Centre.

Les lignes à 120.000 volts : La Viclaire-Lyon—St. Etienne-Lyon-Villefranche, concédées à la Société de Transport d'énergie des Alpes.

La ligne à 120.000 volts Chancy-Pougny—Le Creusot, concédée à la Société Rhône et Jura.

La ligne à 120.000 volts Beaumont-Monteux—St. Etienne, concédée à la Société Energie Electrique de la Basse-Isère.

Les lignes à 60.000 volts : Forges d'Abel—Bayonne—Oloron—Nérac, dont la concession a été demandée par la Société des Forces Motrices de la Vallée d'Aspe, etc.

(*c*) les lignes établies par les réseaux de chemins de fer en vue de leur électrification :

Lignes à 150.000 volts Toulouse—Lannemezan—Pau—Dax—Bordeaux, construites par la Compagnie des Chemins de fer du Midi.

Lignes à 60.000 volts établies par cette Compagnie pour desservir ses sous-stations de traction.

Lignes à 150.000 volts (établies de façon à pouvoir être transformées en 220.000 volts) actuellement en construction par la Compagnie P.O. entre Paris et le Massif Central.

Lignes à 90.000 volts dont cette même Compagnie entreprend la construction pour desservir ses sous-stations de traction, etc.

(*d*) les lignes à haute tension établies par certaines sociétés distributrices :

Lignes à 100.000 volts Calais—Boulogne, Abbeville, Amiens, Arras, Hazebrouck, de la Société Electrique du Nord-Ouest.

Lignes à 60.000 volts : l'Isle-Jourdain—La Rochelle, de la Société des Forces Motrices de la Vienne, etc.

Le mode d'exploitation de ces lignes à haute tension varie naturellement beaucoup suivant le propriétaire de la ligne et le but dans lequel elle a été construite. Les unes sont exploitées par une société unique ; c'est le cas des lignes de la Société des Forces Motrices de la Vallée d'Aspe. D'autres, par un groupement mixte libre de producteurs et de consommateurs ; c'est ainsi que la Société de Transport d'énergie des Alpes est constituée par un consortium dont font partie : la Société d'Electro-Chimie, d'Electrométallurgie et des Aciéries Électriques d'Ugine, la Compagnie du Gaz de Lyon, la Société Hydro-électrique de Lyon, la Compagnie Electrique de la Loire et du Centre, l'Union Electrique, la Société Générale de Force et Lumière, la Société des Forces Motrices du Chérau, la Société de la Haute-Isère, la Société des Forces Motrices de la Tarentaise, la Société Lyonnaise des Forces Motrices du Rhône, la Société des Aciéries de la Marine et d'Homécourt.

D'autres lignes enfin sont exploitées par un groupement mixte contrôlé par l'Etat ; c'est le cas des lignes du Réseau d'Etat dont l'exploitation a été confiée à deux Sociétés : la Société de Transport d'Energie du Nord et la Société de Transport d'Energie de l'Est, dont l'Etat contrôle la gestion. Les lignes des Compagnies de chemins de fer rentrent elles-mêmes dans cette dernière catégorie, en raison des pouvoirs de contrôle étendus que possède le Gouvernement sur ces Compagnies.

Les Cahiers des charges des concessions de transport fixent les tarifs maxima des droits de péage que les concessionnaires sont en droit d'exiger des usagers et stipulent en outre l'obligation pour ces concessionnaires d'assurer, dans la limite de la capacité normale de leurs lignes, les transports d'énergie destinés à des services publics.

Ajoutons enfin que, afin d'éviter que la mauvaise volonté éventuelle de quelques personnes ne gêne ou n'empêche de réaliser dans les conditions les plus satisfaisantes la construction ou l'exploitation de lignes de transport d'énergie à haute tension, la loi du 24 Juillet, 1922, reconnaît à l'Etat les droits suivants :

"Dans le but d'assurer une utilisation plus complète et une meilleure répartition de l'énergie électrique, qu'elle provienne d'usines thermiques ou hydrauliques, l'Etat, s'il n'en prend lui-même l'initiative, pourra obliger les producteurs, et au besoin, les distributeurs d'énergie, les départements, communes et services publics d'une même région, intéressés sous une forme quelconque à un transport d'énergie électrique, à constituer sous sa direction et, le cas échéant, avec son concours financier, un organisme collectif spécial, en vue de construire et d'exploiter un réseau de lignes de transport à haute tension destinées notamment à joindre les usines productrices entre elles et aux sous-stations de transformation d'où partent les lignes de distribution.

"Si certains des producteurs ou distributeurs d'énergie dont l'Etat juge le concours indispensable à la réalisation d'un organisme collectif de cette nature, ou à son développement normal dans la suite, refusent leur concours, l'Etat peut, après avis du Comité d'Electricité, se substituer à eux soit par rachat de leurs installations si l'acte qui les autorise prévoit cette eventualité, soit par voie d'expropriation, conformément à la loi du 3 Mai, 1841, après que l'utilité publique en aura été prononcée par décret en Conseil d'Etat."

On voit que ce texte donne à l'Etat tous les pouvoirs nécessaires pour coordonner les efforts individuels dans le sens le plus favorable à l'intérêt général et assurer la construction ou l'exploitation rationnelle du réseau de transport qui commence à s'ébaucher sur le territoire français. Il comporte même, au profit de l'Etat, un véritable droit de coercition, sans aucun doute délicat à exercer, mais dont l'affirmation aura évidemment le plus grand poids pour orienter les initiatives ou vaincre les résistances injustifiées.

III. UTILISATION RATIONNELLE DES MOYENS DE PRODUCTION ET DE RÉGULARISATION.

On peut donc envisager un avenir lointain où les groupements de consommation étant organisés de la manière le plus rationnelle, et tous les moyens de production étant susceptibles de se prêter un mutuel appui grâce à une interconnexion, il faudra exploiter ou faire exploiter cet ensemble de manière à tirer le meilleur rendement possible des diverses sources d'énergie disponibles.

Il ne faut pas se dissimuler que cette exploitation d'ensemble se heurtera à des difficultés techniques. Quel que soit leur intérêt, ce n'est pas sur ce sujet que nous voudrions attirer l'attention, mais seulement sur les idées théoriques qui, dans le cadre de notre étude, nous paraissent commander l'utilisation rationnelle des ressources.

Tout d'abord, la centralisation des moyens de production imposera de tirer de chaque usine le maximum de rendement que son régime hydraulique permet.

Or, il est des usines dont la production est une donnée à priori, sur laquelle nous n'avons aucune action efficace. Ce sont les usines construites sur les parties basses des cours d'eau et marchant au fil de l'eau. Elles utilisent sous une chute toujours faible des débits qui peuvent être considérables, par exemple dans le cas du Rhône, du Rhin, de la Dordogne, etc.

Il n'est sans doute pas tout à fait impossible de faire varier dans une certaine mesure la puissance de ces usines d'une heure à l'autre du jour en faisant au moment des pointes un appel un peu plus fort à l'eau du bief amont, ce qui a pour conséquence de faire baisser le niveau de la retenue de quelques centimètres ; mais ces variations restent toujours assez faibles ; on ne peut espérer d'autre part améliorer beaucoup leur fonctionnement par l'effet régularisateur des réservoirs qui pourront être construits à l'amont, car le supplément de débit susceptible de provenir de ces réservoirs ne sera jamais qu'une fraction extrêmement faible du débit moyen de la rivière à hauteur de ces usines.

On se trouve donc dans l'obligation absolue de prendre leur puissance quand elle se présente et telle qu'elle se présente. Il est dès lors naturel de les utiliser à satisfaire à chaque instant la plus grande partie possible de la demande.

La situation des usines marémotrices est tout à fait comparable à celle des usines de basse chute dont il vient d'être parlé. Ces usines marémotrices pourront, suivant la nature des cycles adoptés pour leur fonctionnement, donner une courbe de puissance plus ou moins régulière, mais dans tous les cas cette puissance variera très fortement d'une époque à l'autre de l'année et d'une heure à l'autre de la journée.

Pour obtenir la régularisation de la production, ou mieux son adaptation à la demande, il conviendra d'orienter les travaux dans les voies suivantes :

A. Construction de grands réservoirs saisonniers concentrés dans les endroits qui se présentent géographiquement et géologiquement dans les conditions les plus favorables.

Les emplacements des réservoirs possibles se trouvent en France inégalement répartis entre les trois régions montagneuses des Pyrénées, des Alpes et du Massif Central.

Dans les Pyrénées, les emplacements sont très rares et de peu d'étendue. On n'y trouve guère qu'une demi-douzaine de lacs

naturels, dont la capacité serait susceptible d'être un peu augmentée par la création de digues permettant de surélever leur niveau, mais restera toujours faible. Les emplacements des réservoirs artificiels sont pratiquement inexistants.

Par contre, les quelques lacs naturels utilisables comme réservoirs offrent le précieux avantage d'être situés à une altitude considérable permettant d'utiliser leurs eaux sur une très grande hauteur, ce qui donne un très grand prix à chaque mètre cube d'eau accumulée.

Ainsi, les eaux du lac d'Artouste situé à la partie supérieure de la Vallée du Gave d'Ossau, dont la Compagnie des Chemins de fer du Midi a entrepris l'aménagement, pourront être utilisées dans les trois usines d'Artouste, de Miégebat et du Mourat, construites par cette Compagnie sur une hauteur totale de 1.300m.

Dans les Alpes, les emplacements des réservoirs sont assez nombreux ; on y trouve à la fois des lacs naturels susceptibles d'être utilisés pour la régularisation (lac de Genève, en partie suisse, en partie français, lac du Bourget, lac d'Annecy) et des emplacements de réservoirs artificiels dont quelques uns de très grande capacité. Par exemple :

Le réservoir de Serre-Ponçon, sur la Durance, dont la capacité pourrait atteindre 600 millions de mètres cubes.

Le réservoir du Chambon, sur la Romanche, d'une capacité de 80 millions de mètres cubes.

Une série de réservoirs sur le Verdon dont la capacité totale pourrait atteindre 500 millions de mètres cubes.

Les réservoirs de la Tinée, etc.

La région du Massif Central ne possède guère, en dehors du lac de Guéry dont la capacité est d'ailleurs faible, de lacs naturels susceptibles d'être utilisés comme réservoirs. Elle est par contre très riche en emplacements de réservoirs artificiels. Les plus importants sont situés sur la Dordogne : réservoir de la Cellette, dont la construction est entreprise par la Compagnie des Chemins de fer de Paris à Orléans (capacité : 200 millions de mètres cubes) ; réservoir du Chambon, sur la moyenne Dordogne, dont la capacité atteindrait 500 millions de mètres cubes. D'autres, d'une importance encore très notable, quoique moindre, se trouvent sur deux affluents de la Dordogne ; la Cère et la Diège ; leur aménagement est dès maintenant envisagé par la Société des Forces Motrices de Firminy pour celui de la Cère et par la Société de Pont-à-Mousson pour celui de la Diège.

La Dordogne ou ses affluents ne sont d'ailleurs pas les seules rivières de cette région offrant de belles possibilités d'accumulation. Il faut au moins leur ajouter la Truyère dont il a déjà été parlé plus haut.

Enfin, une série de rivières (Vézère, Vienne, etc.,) offrent dans leur cours supérieur un certain nombre d'emplacements de réservoirs d'importance individuelle assez faible mais qui, en raison de leur nombre, seraient susceptibles de produire un effet de régularisation très appréciable.

B. Suréquipement systématique des usines commandées par ces réservoirs. Sans rechercher en effet une production importante de kWh., il faudra que ces usines puissent fournir à la demande des pointes très importantes en kW., aux périodes de défaillance des autres usines.

L'emploi des canaux d'amenée en charge, lorsque la technique de leur construction sera dégagée des incertitudes et des hésitations présentes, semble de nature à augmenter encore la souplessse de ces puissantes usines de pointe.

C. Emploi d'usines thermiques. Ce n'est pas ici la place de s'étendre longuement sur les usines thermiques. Il suffit de mentionner à leur sujet que la tendance actuelle est de les faire de plus en plus considérables, ce qui permet d'obtenir un rendement très supérieur. C'est un nouvel exemple de cette tendance à la concentration déjà si nettement manifestée dans certaines autres grandes industries.

Le choix des emplacements à donner aux thermiques, de leur importance, de la nature du combustible, etc., est question d'espèce. Elles devront toujours être largement prévues pour garantir contre des déficits trop considérables de la production hydrauliques en cas d'année très sèche.

Il ne semble pas qu'on soit dès maintenant en mesure d'assigner aux unités de ces trois catégories d'usines un rôle fixe dans la production d'ensemble. On aura intérêt, suivant les périodes de l'année, suivant la qualité des utilisations, suivant la proportion respective des puissances équipées, soit à assurer la partie constante des fournitures par les usines au fil de l'eau, régularisées par les usines de réservoirs, en réservant aux thermiques les rôles de secours et de pointes, soit plutôt à régulariser les usines au fil de l'eau par des thermiques dont la marche saisonnière pourrait être ainsi aussi continue que possible ; les usines de lacs serviraient alors d'usines de pointes.

En tous cas, il apparaît que la concentration de moyens de production dans une seule main deviendra, à ce moment, indispensable, quelque inconvénient qu'elle puisse présenter dans un pays où le morcellement actuel et où l'individualisme commercial, et même technique, sont développés à un très haut degré. Cette concentation pourra-t-elle n'être exercée que par un contrôle d'Etat, analogue à celui qui intervient aujourd'hui et dont les attributions seraient étendues? ou, au contraire, nécessitera-t-elle un remaniement dans l'organisation commerciale et industrielle de la production d'énergie? C'est ce qu'il est à peu près impossible de pronostiquer dès l'abord.

CONCLUSIONS.

Que conclure de l'exposé qui précède? Deux constatations au moins paraissent s'imposer: l'une est que, au cours de sa récente et rapide évolution, la question de la régularisation de l'énergie hydraulique n'a progressé qu'en s'étendant à des ensembles de plus en plus complexes; de l'usine isolée au bassin fluvial, du bassin à la région ou à un groupement de régions; de là à l'ensemble du pays. L'autre, que les progrès déjà réalisés et ceux dont la réalisation peut être considérée comme prochaine paraissent avoir dépendu ou devoir dépendre beaucoup moins des perfectionnements techniques réalisés—perfectionnements dont on ne saurait cependant nier l'importance, tout au moins comme condition de réalisation de ces progrès—que d'une conception plus exacte, plus rationnelle, du problème considéré sous son aspect économique et commercial.

Cette évolution est-elle près d'atteindre son terme? C'est bien peu probable. Des idées évoluant avec une rapidité égale à celle constatée ici ne se cristallisent pas subitement. D'ailleurs, bien des problèmes dont l'heureuse solution peut avoir des conséquences considérables sont loin d'être résolus, tels ceux de l'utilisation de l'énergie des marées, de l'accumulation de l'énergie dont on n'a pas l'emploi immédiat sous une forme la laissant disponible pour une utilisation ultérieure, etc. Rien enfin n'autorise à supposer que l'extension signalée plus haut à des ensembles de plus en plus complexes vienne s'arrêter aux frontières et que l'énergie électrique ne puisse faire bientôt comme les autres marchandises l'objet d'un commerce international.

Le champ reste donc vaste pour tous ceux qu'intéressent ces questions, qui désirent les faire progresser et contribuer à leur heureuse évolution. C'est le mérite des réunions comme celle-ci que de stimuler ces activités.

LISTE DES LIGNES ELECTRIQUES A TENSION DE 60,000 VOLTS ET AU-DESSUS.

(Lignes en service, en construction, ou pour lesquelles une demande de concession a été présentée.)

Société concessionnaire.	Ligne.	Longueur.	Tension.
Société Electrique du Nord Ouest	Arras-Hazebrouck-Calais-Boulogne-Abbeville-Amiens-Arras St-Omer-Dunkerque	500 Km.	100.000 V.
Réseau Electrique d'Etat des Régions Libérées (Sté T.E.E. de l'Est)	Mohon-Landres-Nancy-Vincey Conflans-Amanvillers	230 Km.	120.000 V. 65.000 V.
Cie Lorraine d'Electricité	Vincey-Pouxeux Pouxeux-Delle	210 Km. 85 Km.	65.000 V.
Sidérurgie Lorraine	Longwy-Thionville *Circuits :* (Landres-Rohon-Micheville-Thionville-Auboué-Amanvillers, etc.)	120 Km.	65.000 V.
Sté Alsacienne & Lorraine d'Electricité	Nancy-Chambrey-Sarrebourg-Schirmeck	385 Km.	65.000 V.
Electricité de Strasbourg	Strasbourg-Haguenau Strasbourg-Schirmeck Strasbourg-Turckheim	140 Km.	70.000 V.
Forces Motrices du Ht-Rhin	Turckheim-Mulhouse (frontière)	75 Km.	135.000 V
Forces Motrices de la Loue	Besancon-Mouthier Mouthier-Pontarlier	42 Km.	60.000 V.
Sté Energie Electrique Rhone et Jura	Chancy-Pougny-Le Creusot	150 Km.	120.000 V
Sté Hydro-Electrique de Lyon	Ugine-Lyon	170 Km.	70.000 V.
Sté Gle Force et Lumière	Moutiers-Lyon	156 Km.	70.000 V.
Société de Transport d'Energie des Alpes	Lyon (Bron)-Viclaire Lyon (Bron)-Villefranches/Saône Lyon (Bron)-St. Etienne	425 Km.	120.000 et éventuellement 150.000 V.
Société de Transport d'Energie du Centre (Loire-Auvergne; Cantal-Loire; Alpes-Loire; Loire-Jura)	St. Etienne-Roanne-St. Germain des Fossés Brommat (Truyère)-St. Etienne Grenoble-St. Etienne (St. Chamond) Roanne-Villefranches/Saône	480 Km.	120.000 V.
Sté Energie Electrique de la Basse-Isère	Beaumont-Monteux-St. Etienne (St. Chamond)	83 Km.	120.000 V.
Energie Electrique de la Sorgue et du Tarn	Le Truel-Béziers	107 Km.	120.000 V.
Sté des Mines et Fonderies de Zinc de la Vieille Montagne	Thuriez-Viviez	75 Km.	60.000 V.
Sté des Forces Motrices de la Vallée d'Aspe	Forges d'Abel-Laruns Forges d'Abel-Bayonne Oloron-Nérac Agen	350 Km.	60.000 V.
Chemin de fer du Midi	Toulouse-Ax-les-Thermes Toulouse-Lannemezan-Pau-Dax-Bordeaux Eget-Lannemezan Laruns-Pau	900 Km.	150.000 V. et 60.000 V.

Société concessionnaire.	Ligne.	Longueur.	Tension.
Chemin de fer P.O.	Eguzon-Paris	750 Km.	150.000 et 90.000 V.
	Eguzon-Vernéjoux	350 Km.	150.000
	Vernéjoux-Eygurande-Commentry-Nevers (Saincaize)		220.000
	Eguzon-Limoges - Brive - Souillac-Vernéjoux-Coindre-Eygurande - Chermont-Ferrand	625 Km.	90.000 V.
	Laurière-Commentry		
	Commentry-St. Germain des Fossés	80 Km.	120.000 V.
Sté des Forces Motrices de la Vienna	Isle - Jourdain - Faymoreau - La Rochelle	222 Km.	60.000 V.
Union d'Electricité	Gennevilliers (Paris) Creil	55 Km.	60.000 V.
	" Mantes	45 Km.	
	" Meaux	40 Km.	
	" Corbeil	20 Km.	

Lignes Electriques de tension au moins égale à 60.000 V :

——— *En service ou en construction.*

— — — *pour lesquelles une demande de concession a été présentée.*

– – – – *dont la construction est envisagée pour une date prochaine.*

N B — *Quand plusieurs lignes à tensions égales ou différentes suivent un même tracé, elles ne sont représentées que par un trait unique à fin de ne pas surcharger la carte.*

RÉSUMÉ.

The paper surveys the history of progress in the function, use and method of application of hydro-electric power stations in France.

It is divided into two parts : the first recalls the different stages of evolution up to the present day, the second deals with actual methods employed.

FIRST PART, HISTORY OF REGULATION.

This may be divided into three distinct periods.

(*a*) *1st Period, the Power Station as an isolated entity.*

The first power stations had as their sole aim the production of the current necessary for some specific enterprise. Such isolated stations met with two difficulties : interseasonal irregularity and lack of flexibility in operation. The first of these two difficulties was met either by being content to utilise only the permanent discharge or else by using a thermal station by way of auxiliary. The second was surmounted by building some sort of reservoir upstream to balance the daily load, and a compensating pool downstream.

(*b*) *2nd Period, Regulation within a Catchment area.*

It was realised that every watercourse together with all its tributaries forms a complete system for hydraulic exploitation. This is manifested in the law of October 15th, 1919.

This was the period of the most important regulation works.

(*c*) *3rd Period, Inter-regional Hydraulic Compensation.*

Rivers flowing from the Alps and from the Pyrenees have their water shortage during winter, and the maximum discharge when the snows thaw, while those in the centre of the country have a converse régime. When this was realised, people turned their attention to using the power from these two sources in conjunction with one another. The result of this combined working is full of interest but does not constitute a perfect solution to the problem since the two different régimes do not exactly supplement one another either in quantity or in time.

SECOND PART, ACTUAL METHODS.

It is not worth while looking for a perfect system of regulation. The important thing is to have the power when it is wanted. The old conception of ideal regulation was that it should be graphically represented by a horizontal line. This has given way to an endeavour to make the production curve follow the demand curve. The demand curve is by no means regular and the problem becomes one of attaining a production curve as nearly as possible coincident. Three methods have been adopted to arrive at this.

1. *Regulation of load by supplying a varied selection of demands.*

The main uses of hydro-electric power may be classified under five categories in decreasing order of demand : Electro-chemistry, traction, industry in general, distribution and agriculture.

Mere combination of these different demands would not suffice to provide a very satisfactory evenness of load. It is necessary to create a sale for current during times of flood water by establishing the necessary works and raising the load factor of those existing, and also by putting a specially low price on such current.

2. *Pooling of Resources.*

This will only be a practical possibility when every power station of any importance is connected to the National Transmission network now under construction.

3. *Good methods of production and rational regulation.*

For power stations with a fixed output there is no remedy. Such stations are to be found on the lower reaches of the rivers and operating on the flow alone; with these it is necessary to take the power as it comes and when it comes. The same holds good for tidal power stations

In order to regulate production according to demand, it is necessary to adopt the following measures:

(a) Construction of large seasonal reservoirs.
(b) The provision of surplus plant in stations governed by these reservoirs.
(c) Employment of thermal stations.

In conclusion, it is stated that two facts are clear. One is that in the recent rapid development of hydro-electrics the question of regulation has only progressed in so far as the tendency has been towards combinations more and more complex in character. The other is that the developments already accomplished and those that may be regarded as imminent appear to depend much less on technical improvements than on a more precise and rational conception of the problem from its economic and commercial aspect.

This evolution is not yet finished. Important problems such as the harnessing of tides, the accumulation and storage of power which may be available for use when it is wanted, are far from being solved. The field is still wide for all who have an interest in the subject, for all who wish to help and contribute to its progress and success.

It is the privilege of a gathering such as this to stimulate activity in this direction.

ENERGIE HYDRO-ELECTRIQUE

M. MAROGER

INTRODUCTION.

Dans un des rapports de la délégation française sont exposées les solutions envisagées en France pour la régularisation des forces hydrauliques. Ces solutions sont, en dehors de la régularisation des chutes elles-mêmes par la création de réservoirs accumulateurs, la connexion entre elles des usines hydrauliques établies sur des bassins à régime différent et la connexion des usines hydrauliques avec de Centrales thermiques, cette double connexion pouvant d'ailleurs être réalisée simultanément.

Dans un autre rapport, il est traité des réseaux de transport, et il est montré comment ces réseaux peuvent servir tout à la fois à cette double connexion et au transport de l'énergie jusqu'aux régions de consommation—il est indiqué également comment ces réseaux sont construits et exploités.

Dans le présent rapport sera exposé comment on envisage l'utilisation, tant technique que commerciale, de cet ensemble d'usines et de réseaux, de manière à en tirer le meilleur parti.

I.

En France, les Usines hydro-électriques ne sont pas en général, dans une même région productrice (Alpes, Pyrénées-Massif Central) ni même sur le cours d'une rivière, entre les mains d'une seule Société.

Ce fait s'explique aisément, par les conditions mêmes dans lesquelles est née et s'est développée l'industrie de la houille blanche.

LES USINES HYDRAULIQUES ONT ÉTÉ CONSTRUITE :

Soit par des Sociétés de distribution, en vue de l'alimentation du secteur qui les intéressait—Ces secteurs ont des importances très variables (leur action s'étend parfois sur une fraction d'un département, parfois sur 2 ou 3 départements)—Les premières usines choises se trouvaent donc à proximité de ce secteur; par la suite les secteurs sont allés construire des usines à des distances de plus en plus grandes du centre de consommation, à mesure que

se généralisait la pratique des plus hautes tensions de transport; - Soit par des Sociétés d'électrochimie ou d'électro-métallurgie qui installaient leurs usines d'utilisation en pleine montagne, le plus près possible des usines de production.

Les mêmes errements continuent. Et c'est ainsi que les Cies. de Chemis de fer, lorsq'elles ont entrepris leur électrification, ont cherché d'abord à s'assurer la concession de chutes qu'elle équiperaient elles-mêmes en vue de leurs besoins particuliers.

Actuellement on voit toutefois se dessiner une tendance à la création de Sociétés nouvelles, cherchant à aménager des chutes d'eau, non plus pour faire directement elles-mêmes de la distribution au public ou de l'électro-chimie, mais pour vendre leur énergie à des secteurs de distribution ou à des industriels.

Pour toutes ces raisons, les chutes d'eau en France se trouvent en de nombreuses mains et non pas groupées sous le contrôle d'un trust puissant—C'est ainsi, pour prendre un exemple, que les 15 chutes importantes (de 5 à 30.000 kilowatts) équipées ou en cours d'aménagement dans les Pyrénées entre la Garonne et l'Océan ressortent à cinq Sociétés différentes (dont la Cie. des Chemins de fer du Midi).

De même, les chutes en cours d'aménagement dans le Massif Central (région de la Creuse, Haute Dordogne et Truyére) appartiennent à 6 Sociétés différentes (dont la Cie. du Chemin de fer Paris-Orléans).

Ces différentes usines, qui vont avoir à utiliser un même réseau de transport, seront obligées, par la force même des choses, de conclure entre elles une entente. On ne voit pas, au point de vue technique, qu'il puisse en être autrement: chaque usine ne peut pas débiter sur le réseau à son gré—On ne le voit pas davantage au point de vue commercial—à moins qu'il n'y ait à l'autre bout du réseau qu'un seul client qui absorberait toutes les disponibilités des différentes usines, comment chaque usine retrouverait-elle ses propres kilowatts-heures entre les différents clients desservis et réglerait-elle sa fourniture au prorata des demandes de ses propres clients?

Un premier groupement devra donc inévitablement se former entre les usines susceptibles de se relier à un réseau de transport déterminé—C'est ainsi que lorsque la Cie. du Midi eut décidé la construction de son réseau à 150.000 v. allant des Pyrénées sur Toulouse et Bordeaux, les usines situées dans la région des Pyrénées desservies par ce réseau (partie occidentale des

Pyrénées, entre le Val d'Aran et l'Océan) se sont presque aussitôt groupées.

Il en sera vraisemblablement de même dans le Massif Central lorsque la Cie. P.O. mettra en service une ligne reliant la Dordogne à Paris.

Les usines ainsi groupées vont mettre en commun leurs disponibilitées, ce qui permettra, par une première régularisation à l'intérieur du groupement, d'assurer une meilleure utilisation des ressources aménagées—On comprend aisément qu'une usine spécialisée à un emploi déterminé est en général mal utilisée, soit que sa puissance soit supérieure aux besoins actuels qu'elle doit desservir, soit que son régime hydraulique ne corresponde pas au graphique de l'utilisation (notamment au moment des hautes eaux), soit même, pour les usines affectées à des fabrications électrochimiques ou électro-métallurgiques, qu'elles puissent trouver, à certaines époques de l'année et pour une partie de leur énergie du moins, un débouché plus lucratif de leur puissance par la vente aux secteurs de distribution.

Le premier travail du groupement sera donc de procéder à une statisque serrée de ses ressources, d'étudier à fond le régime de ses différentes usines hydrauliques, d'étudier également à fond les besoins de ses adhérents, de façon à bien connaître ses disponibilités et le meilleur emploi qu'il en peut faire.

Il pourra ainsi jouer son premier rôle, que est un rôle technique, un rôle de dispatcher général, chargé de régler la manœuvre des robinets des usines et le déversement des excédents sur les grandes artères du réseau de transport.

A côté de ce rôle technique, ce groupement a un rôle commercial : trouver un débouché aux disponibilités du groupement—Et ce rôle commercial lui-même a un double aspect :

Les débouchés étant donnes, trouver, soit auprès de Groupements analogues fonctionnant dans des bassins à régime différent, soit auprès de possesseurs d'usines thermiques, soit en créant lui-même des usines hydrauliques sur des cours d'eau à régime différent ou des usines thermiques, l'énergie complémentaire qui, ajoutée à celle dont dispose le groupement, permettra de faire face aux besoins de ses débouchés ; soit rechercher et au besoin faire naître des débouchés nouveaux susceptibles de s'accommoder du régime des disponibilités du groupement—par exemple, des débouchés saisonniers—

En d'autres termes, il faut donc, tout à la fois, modeler les disponibilités sur les débouchés et modeler les débouchés sur les disponibilités—De la sorte, on peut espérer arriver, par approximations successives, à une utilisation intégrale de la puissance aménagée, ce qui est le but de l'opération.

II.

Nous allons examiner maintenant quels sont ces différents débouchés, quel est leur régime d'utilisation. Nous indiquerons en même temps les bases de tarification qu'on peut leur appliquer.

Les premiers débouchés de notre groupement sont:

les secteurs de distribution

les Cies. de Chemins de fer d'intérêt général électrifiées

Le secteur de distribution alimente, dans sa zône, soit directment, soit indirectement, les consommateurs d'éclairage et de force motrice, soit dans les villes, soit dans les campagnes. Il alimente également, en général, les tramways et les chemins de fer d'intérêt local. Il groupe donc en somme tous les besoins d'une zône déterminée—Ce n'est qu'accidentellement, à moins qu'elle n'ait une importance particulière, qu'une industrie consommatrice sera raccordée directment au superréseau et alimentée sans intermédiare par le Groupement.

Au contraire, les Cies. de Chemins de fer d'intérêt général sont alimentées directment par le superréseau, en dehors du secteur local de distribution. (1).

On connaît l'allure générale de la courbe des besoins d'un secteur de distribution, notamment avec sa pointe d'hiver, à la tombée de la nuit—Notons que ce secteur ne demandera à notre groupement qu'une partie de son énergie, car il préexiste et dispose déjà de ressources, soit thermiques, soit hydrauliques, et il réglera sa demande de manière à tirer le meilleur parti de l'ensemble de la puissance dont il dispose et disposera.

Il faut se rappeler que nous parlons d'usines hydrauliques raccordées aux centres de consommation par de longues et couteuses lignes de transport. Les capitaux immobilisés dans l'ensemble des installations sont donc considérables, et les frais d'exploitation relativement faibles.

(1) On sait que le systéme adopté en France, pour l'électrification des Chemins de fer d'intérêt général, est le courant continu 1500 volts. Ce système comporte l'établissement, le long des voies à électrifier, de sous-stations de transformation espacées pratiquement de 20 à 30 kilomètres, et alimentées par des artères à 60,000 ou 90.000 volts.

Le Groupement cherchera alors à retirer une rémunération déterminée par kilowatt mis à la disposition de son client, et ce dernier aura tout intérêt, pour faire baisser le prix du kilowatt-heure, à assurer la meilleure utilisation possible de la puissance mise à sa disposition.

On a toutefois à peu près complètement renoncé en France au tarif au kilowatt-an, et on adopte généralement le tarif bi-nôme comportant :

Une prime fixe par kilowatt souscrit,

Une taxe proportionelle par kilowatt-heure.

Pratiquement, le groupement dont nous nous occupons trouvera dans les secteurs de distribution une clientèle qui lui assurera une utilisation assez variable suivant les secteurs, mais il ne doit pas compter, en moyenne, en tirer plus de 3.000 heures d'utilisation de la puissance souscrite—En outre, le secteur prendra parfois de l'énergie en dépassement de la puissance souscrite, à un tarif qui dépendra essentiellement des disponibilités du groupement aux époques auxquelles le secteur aura besoin d'énergie.

Les Cies. de Chemins de fer ont une utilisation beaucoup plus régulièrement répartie pendant les divers mois de l'année et les diverses heures de la journée—Sur les lignes importantes, on en arrivera même sûrement, avec la traction électrique, à modifier les conditions d'exploitation, de manière à avoir un trafic de nuit au moins égal, sinon supérieur, au trafic de jour—Par contre, la puissance instantanée varie dans de larges limites suivant la demande du réseau—On admet en général, que la puissance de pointe d'un réseau électrifié est de l'ordre 2½ fois à 3 fois la puissance moyenne, ce qui revient à une utilisation de l'ordre de 3.000 heures de la puissance de pointe, assez semblable à celle que nous avons trouvée tout à l'heure.

Notons en passant, bien que cela sorte un peu de notre sujet, qu'une différence très sensible existe toutefois entre ces deux catégories de clientèle : dans un secteur, qui utilise 3.000 h. la puissance sera presqu'uniquement demandée pendent 8 à 10 heures par jour ; la demande sera très faible le reste du temps. Par suite, pour utiliser complètement l'énergie disponible, il faudra disposer de vastes bassins d'accumulation journalière, capables de retenir le presqu' entier dêbit de la rivière pendant 12 à 14 heures—Au contraire, dans un service de traction, les pointes sont très rapprochées et réparties pendant toute la période de 24 heures—Une accumulation beaucoup moindre sera donc suffisante.

III.

La double clientèle dont nous venons de parler se traduira finalement pour le Groupement, par l'obligation de tenir en certains points déterminés une puissance déterminée à la disposition de tel ou tel client.—Il pourra donc facilement tracer le graphique cumulé de ces puissances, et des quantités d'énergie dont il devra disposer aux divers jours de l'année.

Il faudra noter que ces puissances et quantités d'énergie sont imposés au groupement par ses clients et qu'il n'en est pas maître —Sans doute; le Groupement peut prendre ou refuser tel ou tel client, mais une fois qu'il le prend, il doit l'alimenter suivant ses besoins.

Ce sera l'affaire du groupement d'aménager des chutes en proportion du graphique dont nous venons de parler.

Mais on peut dire qu'en général, étant donné le régime des rivières de France, on ne peut pas espérer arriver à modeler assez exactement les ressources en énergie sur la graphique, de manière à obtenir une utilisation complète; on aura des excédents de hautes eaux et des excédents de nuit que les secteurs de distribution ne pourront utiliser.

Précisons tuotefois que nous visons ici les régions de la France où l'énergie électrique est surtout d'origine hydraulique—Il en va tout autrement lorsqu'il s'agit d'amener de l'énergie hydraulique dans un région de forte consommation jusq'alors alimentée en énergie thermique, comme c'est le cas pour Paris—Il est bien certain alors que, tant que la puissance des usines hydrauliques, même en hautes eaux, reste inférieure à la puissance thermique installée, on peut trouver l'emploi des excédents, qui iront remplacer les kilowatts-heures faits par les thermiques.

Nous voulons viser les régions de houille blanche, suréquipées en usines hydrauliques, et sous équipées en thermiques, c'est à dire celles où l'énergie hydro-électrique fournit la plus grosse part des besoins, tant en puissance qu'en quantité, et l'énergie thermique la plus faible.

Il faudra alors faire naître ou grandir d'autres besoins, susceptibles de s'accommoder des résidus dont disposera le Groupement.

On aura en général, deux solutions—La vente à d'autres groupements analogues fonctionnant sur des bassins à régime différent; l'électro-chimie et l'électro-métallurgie.

Nous avons déjà envisagé le cas de notre Groupement se procurant de l'énergie complémentaire auprès d'autres groupements;

inversement, il peut, à d'autres époques de l'année, céder de l'énergie, soit aux mêmes groupements, soit à d'autres—Ce sont alors des échanges d'énergie : par exemple, l'énergie surabondante d'hiver du Massif central ira compléter les Alpes ou les Pyrénées alors en étiage; inversement, pendant l'été, ces dernières compléteront le Massif Central.

Mais on ne peut être certain de trouver là une civilisation complète des résidus, car les besoins des groupements voisins en énergie complémentaire sont une donnée sur laquelle notre groupement n'a aucune action, et ces besoins ne seront pas forcéement du même ordre que les disponibilités de notre groupement.

Resten alors les industries électro-chimiques ou électro-métallurgiques—

Ces industries peuvent en général s'accommoder d'un régime beaucoup plus variable que les secteurs de distribution. Il ne faudrait pas croire cependant qu'elles peuvent se contenter uniquement d'énergie de hautes eaux ou d'énergie de nuit, c'est à dire ne marcher que quelques heures par jour ou quelques mois par an.

Pour qu'elles puissent amortir leurs installations, il faut qu'elles soient assurées de disposer d'une certaine quantité d'énergie annuelle—Elles peuvent sans doute ralentir leurs fabrications pendant une partie de l'année, mais pour éviter des stockages excessifs et pour assurer le maintien de leur personnel spécialisé, elles ne peuvent guère fermer complètement, même pendant quelques mois, et doivent en étiage disposer encore d'une certaine puissance—Quant au régime journalier admissible, il dépend essentiellement des procédés de fabrication; mais rares sont ceux qui peuvent s'accommoder d'une puissance variable d'un instant à l'autre de la journée.

On peut admettre, en moyenne, que l'industrie électro-chimique ou électro-métallurgique accepte de marcher pendant 4 mois par an au 1/3 de sa puissance : par exemple, une usine équipée pour 15.000 kilowatts pourra réquire sa demande à 5.000 kws. pendant 4 mois environ, soit le 1/3 de l'année.

Les fours, ou l'électrolyse, pourront en outre à certaines heures de la journée, notamment aux heures de points, ralentir leur régime, mais dans une assez faible proportion à 20 pour cent par exemple).

Certains procédés, comme l'acide nitrique par l'arc, l'électrolyse

de l'eau pour la production de l'hydrogène, ont une souplesse beaucoup plus grande qui paraît permettre d'utiliser des disponibilités de quelques heures (creux de nuit, creux de midi à deux heures, etc.).

Une puissante industrie électro-chimique ou électro-métallurgique apparaî donc comme le complément indispensable d'un grand groupement de production d'énergie hydraulique. Un tel groupement devra donc s'efforcer, notamment par des tarifs appropriés, de faire naître à proximité de ses chutes, des industries de ce genre, en favorisant surtout celles qui, par leur nature, sont susceptibles de se plier le mieux au régime de ses disponibilités.

Un four à carbure est un excellent mangeur d'énergie de hautes eaux; à côté, une fabrication d'acide nitrique par l'arc permettra d'utiliser les déchets de courant journalier. Pour réduire la gravité des crises économiques susceptibles d'atteindre tel ou tel produit, on aura d'ailleurs intérêt à avoir comme clients, des industries différentes.

Il faudra ici une très grande souplesse de tarifs, qui sont d'ailleurs étroitement limités par le prix que peut payer l'industrie considérée—Par exemple, le Groupement pourra avoir intérêt à consentir un prix bas pour une tranche continue de 5.000 kilowatts, si l'industriel s'engage en même temps à absorber 10.000 kilowatts d'énergie de hautes eaux. Il pourra, dans le même ordre d'idées, faire des prix particulièrement réduits aux industriels qui utilisaraient des residus d'énergie de nuit.

Cette connexion de la clientèle électro-chimique et de la clientèle de distribution a une importance économique considérable—En effet, le coût de l'aménagement des chutes d'eau en France est actuellement tel que le prix de revient du kilowatt-heure est le plus souvent supérieur au prix limité que l'électro-chimie estime pouvoir supporter. L'électro-chimie risquerait donc de ne plus se développer, si elle ne pouvait espérer trouver auprès des groupements tels que ceux que nous envisageons, une partie de l'énergie dont elle a besoin—Il lui faudra par contre assouplir ses méthodes de fabrication pour se plier au régime irrégulier de la fourniture et il n'est pas douteux que des progrès sont à faire dans ce sens.

Il ne serait d'ailleurs pas exact de dire que la distribution paie pour l'électro-chimie—Les deux débouchés s'entr'aident. Sans doute le fait de tirer de la partie de l'énergie vendue aux distri-

buteurs un prix plus rémunérateur permet au groupement de consentir des prix particulièrement bas à l'électro-chimie—Par contre celle-ci, en assurant la pleine utilisation de la puissance aménagée, permet au groupement de ne demander aux distributeurs qu'une partie de ses charges annuelles et de se contenter par suite de tarifs plus bas.

IV.

En définitive, le schéma général de l'organisation peut être résumé comme suit :

Dans chaque région productrice d'énergie hydraulique, un groupement de producteurs, organe technique et commercial, qui disposera des disponibilités de ses adhérents et utilisera le réseau de transport qui, partant de la région productrice, va desservir les centres de consommation importants ou se relier aux autres régions de production.

Fourniture de l'énergie en gros par le groupement producteur aux différents secteurs de distribution locaux ou aux grandes Cies. de Chemins de fer.

Entente entre groupements ou avec des usines thermiques voisines pour trouver l'énergie complémentaire nécessaire.

Près de chaque groupement, puissante industrie électro-chimique ou électro-métallurgique, de manière à assurer l'utilisation aussi complète que possible des excédents.

Bien entendu, il ne s'agit là que d'un schéma général. La forme des groupements notamment pourra varier suivant les circonstances. Ce groupement s'il n'a ni usines ni lignes, pourra être une Société à très faible Capital. Il pourra au contraire, revêtir la forme d'une super Société englobant les Sociétés adhérentes.—Il pourra ou non, construire lui-même des usines et des réseaux—Nous ne sommes actuellement, en France du moins, qu'au début d'une évolution dans l'organisation de la production et du transport de l'énergie d'origine hydro électrique, et nous n'avons pu, dans le présent rapport, que marquer l'aspect d'une première phase de cette évolution.

RÉSUMÉ

In the above report the author has shown, both technically and commercially, how the power produced and distributed by Water Power plants can best be utilised.

At the present time, there seems to be a tendency to form new companies to equip hydro-electric plants simply to sell current to distributing systems or industrial works.

For this reason the water power plants in France are in the hands of a large number of private Companies; these various works, which will now have to use a common distributing system, must come to some mutual arrangement, both technically and commercially.

Groups will have to be formed, and in each group a preliminary regulation will make for a better utilisation of the power of the different works of the group.

Each group must obtain accurate statistics of its resources, make a thorough study of the characteristics of each water power plant and find out exactly the power requirements of each of its members in order to know exactly its available power and the best use which can be made of it.

The author then reviews at length the possible markets and explains the basis of the price systems which can be applied.

The chief markets are:—

(1) The distributing systems.

(2) The electrified railways.

Details are given of their respective characteristics, and suggestions are made for a better load balance, particularly by means of a suitable system of charging for the distributed energy and a rearrangement of the train schedule for the railways.

In France the price per kilowatt-year has been practically abandoned and a double tariff is generally used:—

One fixed rate per Kilowatt.

One proportional rate per Kilowatt-hour.

The group will find customers among the distributing systems and among the electrified railways.

For purely hydraulic power districts other uses must be found for the available surplus of power, such as sale to other similar groups working in districts having different climatic conditions, electro-chemistry and electro-metallurgy.

For instance, during the winter the mountains of Central France can supply power to the Alps and the Pyrenees, which are then at low water; conversely, during the summer these can feed the Central part.

But such exchanges will only absorb part of the power and the balance will have to find an outlet in the electro-chemical or electro-metallurgical works.

Details are given regarding the best working conditions for such works. The author concludes with the statement that a powerful electro-chemical and electro-metallurgical industry is the indispensable completement of any large hydraulic power group.

A very great elasticity in rates will be required and both kinds of loads for general distribution and for electro-chemical use can be considered as helping each other to obtain lower prices for each.

In France the organisation of production and distribution of hydraulic power is in its infancy, and this report can only be considered as dealing with the first phase in its development.

WATER POWER ON INLAND WATER-WAYS

MINISTERIALDIRECTOR GLEICHMANN,
Dr. Phil., Dr. Ing.

I.

GENERAL PRINCIPLES FOR CONSTRUCTION AND WORKING.

CANALISATION OF RIVERS. NAVIGATION.

Water power and waterways are closely related if—as is usual with rivers in hilly districts and in mountainous regions of medium height—the water level has to be raised by weirs to obtain even at low water level a navigable channel of sufficient width and depth. By this the river is divided into various sections like an artificial canal, and offers better conditions for navigation. The speed of travelling downstream, it is true, is reduced because the stream velocity is diminished in consequence of damming the river. On the other hand motive power and time is saved for upstream traffic for the same reason. The difference of levels between two sections is overcome by the use of locks.

UTILISATION OF POWER.

The head formed by each dam or weir offers an opportunity for utilising water power, as considerable volumes of water usually flow down, of which the navigation locks require only a very small part. The head rarely exceeds 2—3 metres in older installations even at low water level. This is dependent upon the construction of the weirs. Although water turbines make it possible to work with a considerably smaller head, 0.5 metre and less, the high running expenses make it prohibitive to erect many small power stations.

INFLUENCE OF WEIR CONSTRUCTION UPON POWER DEVELOPMENT.

In the more ancient ways of canalising rivers, pin weirs were adopted on account of cheapness, but this type of weir is not suitable for power purposes. As the pins have to be fixed by hand, the lengths and weights are limited and consequently limit the head of water. This system allows large quantities of water

to run off unutilised, which is no use for navigation and a disadvantage for power purposes. Pin weirs must be opened when floods or drift-ice threaten and can only be put into operation again when the danger of freezing is past. If this precaution is neglected the pins may become bound together by ice, the working of the weir is endangered at the very time when it should act in the most reliable manner, and for a long time there will be no head of water. This is immaterial for navigation as it ceases during the winter, but for power purposes such long interruptions are impossible. This explains why pin-weirs have not been utilised for power purposes.

The construction of weirs must allow for the raising of large heads, and complete storage of the water according to volume and time. These requirements can only be achieved by installing tightly fitting roller or sluice weirs, equipped with machinery for quick regulation and arranged in such manner that they may be lowered below the normal position to facilitate the flow of drift-ice. It is admitted that they are more expensive to build than pin weirs, but on the other hand, they are cheaper to operate, with the result that in important waterways these types alone are considered, even if no use is made of the water for power purposes.

HEAD.

A decision as to what level a river is to be dammed in each case is no longer arrived at by technical considerations; only the surrounding country is considered so as to keep alterations of the subsoil water level and danger of flooding within reasonable limits.

A small number of heads is advantageous for navigation as the time required for going through locks is shortened. On the other hand a large head is useful in so far as with high water levels, a diminished head is compensated by larger quantities of water, the power remaining nearly constant, and operation can be kept up when floods occur. Heads up to six metres are frequent in canalised sections of more recent date; in some specially favourable cases this figure may even be exceeded. At Neckarsulm, for instance, the Neckar is dammed up to eight metres with a maximum volume of 94 and 100 cubic metres, and at Wieblingen a head of 8.5 metres is obtained. In the Danube-Kachelet for a maximum volume of 700 cubic metres, the head is 7.65 metres; at low water it rises to 9.2 metres.

While in the older installations the maximum power output

obtained is from 2,000—3,000 H.P., the modern ones reach from 6,000—10,000 H.P., and in large streams a multiple of these figures can be obtained.

SITE OF POWER STATION IN RELATION TO NAVIGABLE CHANNELS.

For the site of power works in relation to the weirs, two systems are employed. The four power stations on the Main at Mainaschaff, Krotzenburg, Kesselstadt and Mainkur have a Prüssman system pier containing the turbine plant built up between the flood gate and navigable channel, causing a divided weir. (See Fig. 1). The construction was expensive because the site in the middle of the river required a careful and solid foundation and protection against floods; in addition, constant draining was necessary to keep the building pit dry, being surrounded by water on all four sides. Moreover the unloading of machinery from boats proved difficult in connection with the insular site. The working of the plant has shown that with the water inlet at right angles to the direction of flow, the lower pair of turbines consumed 26 per cent. more water than the upper set * The position of the turbine inlets at right angles to the river flow is therefore not good.

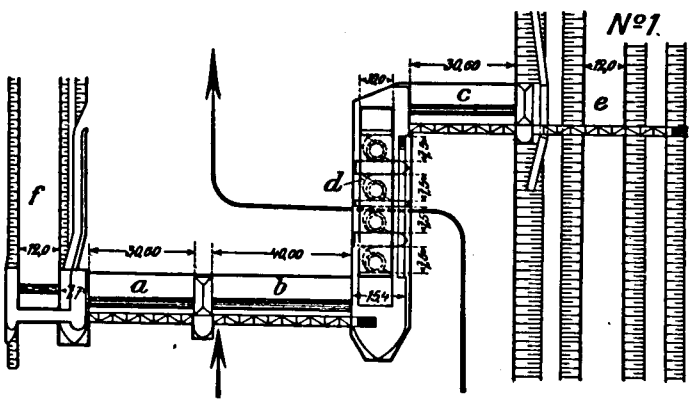

Fig. 1.

INDEX TO FIG 1.

Weir installation with utilisation of water power, situated along a waterway. Mainaschaff, Krotzenburg, Kesselstadt, Mainkur, with power station built in the river (hydro-electric plant pier).

a = left flood gate
b = navigation way
c = right flood gate
} roller weirs.
d = hydro-electric plant pier.
e = lock.
f = channel for rafts.

* In each case two turbines drive one generator through bevel wheels. The lower one gives an output of 600 KW. while the upper one produces 475 KW. only.

As the pier, containing the plant, does not take up space on the river bank, this system may be of advantage in towns or when there are very high river banks. This type of pier owing to its considerable disadvantages is not going to be considered in the further stages of canalising the main river. Preference will be given to a design which places the plant on the bank in line with the axis of the weir. (See Fig. 2). The locks are

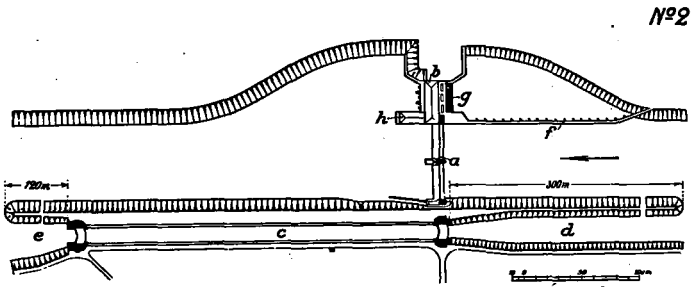

Fig. 2.

INDEX TO FIG. 2.

Weir installation with utilisation of water power, situated along a waterway. Power station is located in line with axis of weir.

a = roller weir.
b = power house.
c = lock.
d = headrace to lock.
e = tail race from lock.
f = ice deflector.
g = grating.

situated on the opposite side of weir. To prevent danger to towed vessels by current from the channels carrying the water for power purposes, guide channels are provided at both ends of the lock, giving the train of vessels a stretch of still water. At the dam in the Danube above Passau (see Fig. 3) the double lock could be placed in a chord of the river bend. There as well, the still waters in the approach to the locks serve as protection from the turbulent waters for power purposes.

In spite of these arrangements, navigation and power plant can not be worked well along side one another unless the head is kept as equal as possible. At medium and higher levels the influence of navigation upon the working of the power plant and vice-versa is small; at low level sudden demands by the power plant are serious to navigation. The head must not be diminished too much, nor must the water be kept back to a large extent, as otherwise the vessels will run aground. The plant is therefore compelled to work on an even load. It depends upon special circumstances whether a moderate heading during the day is

permissible for the purpose of running on a bigger load during the evening hours.

To be able continually to observe and regulate the desired

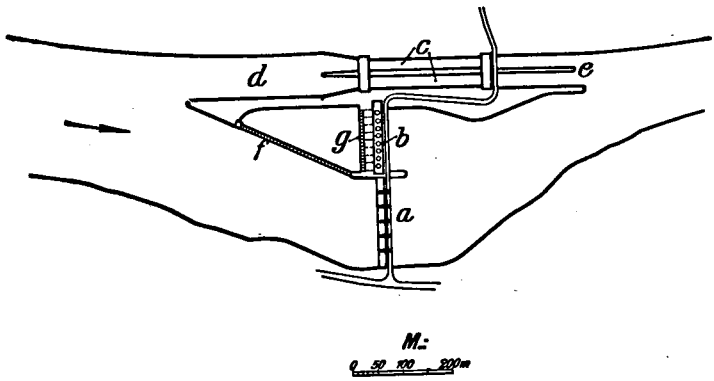

Fig. 3.

INDEX TO FIG. 3.

Weir installation with utilisation of water power in the Kachlet in the Danube above Passau.

a = sluice weir.
b = power house.
c = locks.
d = headrace to lock.
e = tailrace from lock.
f = fine grating.
g = coarse grating.

water level, recording gauges for head and tail races as well as remote control gear for the motors working the roller weirs are installed in the power stations on the main.

VELOCITY OF FLOW IN SIDE CHANNELS.

Conditions become more difficult than in a canalised river if the power plant is situated in a side channel for the purpose of obtaining big heads, and especially if these channels contain locks to shorten the waterway by taking a short cut across a bend in the river. Without utilising water for power, navigation could be kept up in waters without flow. Without navigation the channel carryring water for power purposes only could be constructed at the least cost with the smallest cross-section for velocities of 1.5 m/secs. Such velocities in artificial channels are not favourable for navigation. Upstream high towing power would be necessary. Downstream the velocity would be too high and the danger of damage to vessels would increase. It should be possible to drop anchor, but to prevent damage to the bed of channel, this would have to be protected by a layer of stones at heavy expense. If the formerly used velocity of

30 cm/sec. were to be admitted an uneconomical and large cross-section would be necessary to supply the maximum volume of several hundred cubic metres. As sufficient data are not yet available, care should be taken before decision. For the head of the navigation way on the rivers Neckar and Main a mean profile velocity of not more than 0.5 to 0.7 m/sec. has been stipulated when carrying the maximum volume of water.

POWER WORKS IN CONNECTING CANAL BETWEEN TWO RIVER AREAS.

The same principles are valid for canals connecting two canalized river areas. Considerable differences in levels have to be overcome if such canals have to traverse hills of medium height between the river areas. Conditions for utilisation of water for power are favourable if the highest level in the canal can—as well as the water necessary for navigation—be continuously supplied with a considerable volume of water from another catchment area with a free fall by means of a feeder channel.

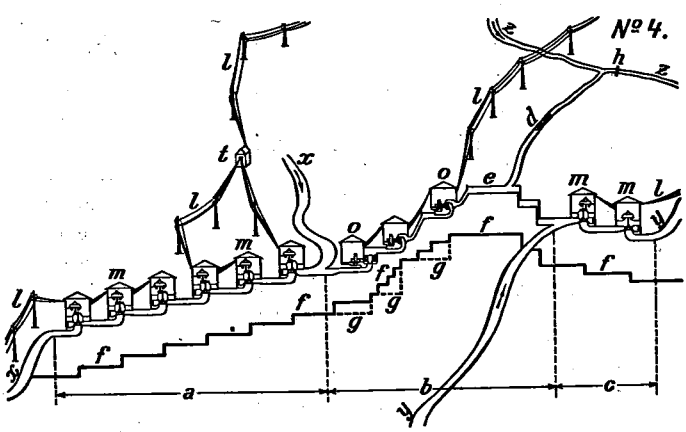

Fig. 4.

INDEX TO FIG. 4.

x—x and y—y are separate navigable rivers.
x—x is canalized in section a.
y—y is canalised in section c.
a and c are to be connected by canal b.
The water from z—z flows for navigation and power purposes to b by means of the dam h and the feeder channel d over the highest level e.
In a and c the locks f—f and power stations m—m are located on the same spot.
b contains a smaller number of power stations o to obtain higher heads by connecting the smaller heads f.
From m and o electric current is transmitted by mains l to transformer stations t and further into the distributing network of the country.

If the working volume of water has to be supplied to such a canal by pumping stations, the commercial value of such a waterway, which depends solely upon traffic, is questionable because of the high running expenses for pumping plant which has to overcome high lifts. Fig. 4 shows the connection of a group of waterways with power stations, in which two canalised river areas (similar to the Main-Danube connection) are connected by a canal. If it is possible by full use of the lie of the country in the hilly part to place several locks, each with a head of 10 metres, close together in such a manner that the several heads can be connected up to one large head for power purposes with separate power work canals, such power works gain considerably in value because the cost of construction is lessened. Moreover every possibility must be taken care of to build reservoirs to enable the power stations to take variable loads. Power stations on such canals are superior to those situated on rivers, as they are independent of floods and rubble deposits and suffer less from drift-ice.

POWER STATIONS IN CONNECTION WITH BARRAGES.

A special group, indirectly connected with waterways, are power stations on barrages in side valleys of navigable rivers. The principal object of such barrages consist in the supply of make-up water to navigable rivers in times of low water to keep up the necessary depth in the navigation channel or to supply water for artificial canals. All water taken from the barrage can be utilised by the power station. Such a barrage power station can cope with the daily fluctuations in the demand of electric current if the tail race is connected to an equalising reservoir. It cannot, however, freely dispose of the great advantages, which a huge reservoir gives to a power station, inasmuch as the draining of the reservoir depends on the schedule of supply of make-up water, which is dictated by the level of the navigation channel. Whereas the supply of electricity requires an increased amount of water power during winter and a decrease during summer, navigation requires that the water collected is reserved for summer. These varying requirements for the utilisation of water during the year have to be taken into consideration in the plan of the power station.

II.

SPECIAL POINTS OF VIEW.

REDUCTION OF CONSTRUCTIONAL COST. INCREASE OF OUTPUT.

CONSTRUCTION.

Water power from rivers belongs to the low pressure systems; it causes consequently high cost in construction. All technical improvements have to be applied so as to place it on a competitive level with other sources of power. Saving is only possible by applying the most perfect method of construction so as to produce works of highest quality with least possible cost for maintenance to withstand the destructive forces of flowing water. Every unnecessary loss in head is, with the small total head, a considerable and constant loss in the gain of power; consequently, all constructions taking part in conducting the water, such as headrace * gratings, spiral inlet, suction pipe and tail race have to be arranged for the lowest possible loss in pressure.

MACHINERY.

The main share in reducing costs lies with the machinery for water power. The aim has to be high efficiency, large units with high speed in order to keep the weight of the electrical machinery as low as possible.

FRANCIS TURBINE.

The Francis turbine, which up to now was solely utilised for low heads, has been considerably improved upon by largely increasing the gap between guide vanes and runner as well as by reducing the blade surface and numbers. Such turbines are running in the hydro-electric power stations of the Main at Mainaschaff, Krotzenburg, Kesselstadt and Mainkur on heads between 0.94 and 2.4 metres at 33 R.P.M.

PROPELLER WHEELS.

A new departure of great promise for the utilisation of low heads came with the most recent invention of Kaplan, constructing turbines on the propeller principle with or without adjustable impeller blades. This type has become now the turbine par excellence for low heads. The dimensions of the Francis wheels

* According to modern rules concrete channels are being built with a loss of head of 5 to 8 cm. in 100 metres=.05—.08 per cent., while formerly earth work channels had 40 to 50 cm. in 1,000 metres=.4—.5 per cent.

are limited while the propeller wheels are unlimited in diameter, as they are constructed without outer rim and interchangeable single blades. This enables this type to deal with larger volumes of water (87.5 cu.m., with 7.65 m. Kachlet-Danube (see Fig. 5); 35.5 cu. with 5.3 and 29 cu. m. with 2 m. Viereth-Main) and the number of units in a water power station becomes smaller.

SPEED OF PROPELLER WHEELS.

The extreme diminution of blade surface, the particular shape and the omission of the outer rim have permitted an unexpected increase in speed. This facilitates their erection in conjunction with the generator as the working speed is already so high with a small head that direct coupling of the generator becomes possible.

CONSTRUCTION OF POWER STATION.

These properties lead to the construction of a single wheel turbine with vertical shaft and horizontal ferro-concrete spiral intake. The horizontal water inlet and vertical water outlet offer hydraulically the most favourable conditions for complete utilisation of head. This gives an advantage in efficiency of several per cent. as compared with a horizontal shaft. For this reason the vertical shaft has been introduced even where higher heads have been available, where formerly the high speed multi-wheel turbine with horizontal shaft prevailed. With the vertical shaft arrangement the foundations of the power house require the least excavation and concrete. The electrical machinery is situated above flood level of tail race. Two power houses on the Rhine-Main-Danube waterway are being equipped with this type of turbine at 75 R.P.M. The Main power house at Viereth has three diagonal propellers that can be taken apart * each of 2,000 H.P. with a head of 5.3 metres, while the Danube power station at Kachlet is equipped with 8 axial propellers † each of 7,500 H.P. with a head of 7.65 metres.

The improvement in the higher speeds is shown by the specific speeds ‡ The Francis wheels of the older Main power station were built for high speeds and have:—

ns=320 with H=2.44 m. and N. — 870 H.P.
ns=530 with H=0.94 m. and N. — 220 H.P.

---

* Turbine works of Fritz Neumeyer A.G., Munich.
† Turbine works (for two turbines) of Voith and Escher-Wyss.
‡ The specific speed ns is the speed of a one-horse power turbine with a 1 m. head. It serves the purpose of comparison of speeds of the various types of turbines.

The propeller wheels of the works at Viereth have:

ns=410 with H=5.3 m. and N. — 2,000 H.P. and
ns=745 with H=2 m. and N. — 950 H.P.

GEAR WHEEL DRIVE OF GENERATORS.

If direct coupling becomes too costly at speeds below 75 and smaller outputs than 3,000 H.P. the application of a vertical spur-wheel gear, running in oil under pressure, with efficiencies above 98 per cent. and a ratio of transmission of 1: 10 or even higher, frequently offers better solutions than a bevel-wheel gear with double helical teeth which is applied to the four power stations on the Main, giving the generator a speed of 167 at a ratio of transmission of 1: 5. Generators may be run at a speed of 500—750 with a spur-wheel gear whereby the efficiency will be better than with direct coupling, so that the loss in gearing is partially compensated. This arrangement is applied to two works of the Neckar at Wieblingen and Neckarsulm and to two smaller stations on the Oder at Koppen and Jannowitz.

SEGMENT FOOTSTEP BEARING.

The objection to the vertical shaft was comprehensible as long as there was not a reliable footstep bearing available to take the heavy load of generator, turbine and vertical water pressure. The formerly existing difficulties have been overcome by the footstep bearings built according to the principles of Michell. In these bearings the thrust plate is divided into segments, symmetrically supported, which force the oil wedge-wise under the footstep ring.

EFFICIENCY OF PROPELLER WHEELS.

Last, but not least, propeller wheels have a five per cent. better efficiency than Francis wheels. The yearly output increases, the output unit becomes cheaper and earnings increase.

POSITION OF PROPELLER WHEEL.

Special care is to be given to the position of the propeller wheel in relation to the tail race level and to the shape of the suction pipe, so as to avoid a sinking of the pressure on the lower side of the blades up to the evaporation limit of the fluid, which would cause corrosion *

WORKING PLAN OF A RIVER POWER STATION.

In Fig. 5 the volume of water curve Q, as a mean over 20 years, and the useful head H appertaining thereto are drawn above the

* See "Experimental Research in the Field of Water Power," Prof. D. Thoma, Transactions of W.P.C. Vol. II.

time base line T (365 days). The volume of water which can be usefully applied *i.e.*, 700 cu. m., is divided up among eight turbines, and can be fully utilised over 130 days. With the decrease of the water volume as shown in curve a—h, units will have to be cut off to allow the remaining ones to run at high efficiency, because this decreases quickly from half load down wards with fixed blades. The hatched spaces show by how much each of the working turbines remains below full admission. The

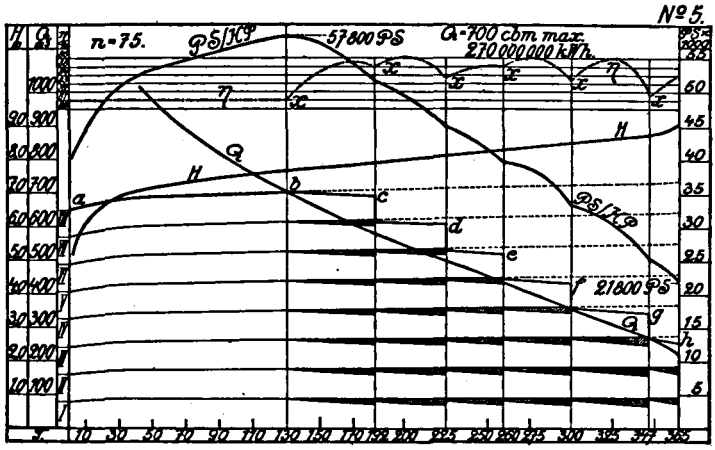

Fig. 5.

INDEX TO FIG. 5.

Operating plan of a river power work.
T = time 365 days.
Q—Q = volume of water in relation to time of utilisation
H—H = useful head.
PS/HP = output in H.P.
η = efficiency.
I—VIII = hydro-units.
n = speed.
The surface bounded by the base line and the curve a, b, c, d, e, f, g, H diminished by the hatched spaces gives the total useful water during one year.
The curve a—h shows how many turbines are at work.

result of the output obtained is given by curve P.S./H.P. Curve $\eta - \eta$ shows the decreasing efficiency with decreasing admission. Its points can be raised if several units are equipped with adjustable propeller wheels. The efficiency of such turbines is a good one even with a small load; they consume the water which is not used up by the other turbines working with full admission. It is evident that by starting and stopping turbines at the right moment the works can be kept up to a high yearly efficiency.

The efficiencies used for the purpose of this sketch are taken

from preliminary studies and do not give those actually obtained with the trial wheels which are considerably better.

POWER WORKS ON CANALS AND BARRAGES.

The constructional costs of power stations on canals and barrages are considerably more than with river power works, because these stations work with a higher head and belong to the group of middle and high pressure installations. * There is no need to enter into their details here.

III.
ECONOMIC VIEWS.

UTILISATION AT PROPER TIME.

The technical means are available to obtain from low-pressure water power, which is not cheap under conditions prevailing in Germany, the highest possible yield out of the resulting product of volume of water and its head. Further, it is imperative for economical results to utilise at every moment in a complete and advantageous manner the current water volume which is uniform during a day but otherwise variable, due to the considerable alterations in atmospheric precipitations according to the seasons. As the working of a power plant must not interfere with the regular water supply of the waterways it must be run on an even load.

WORKING IN CONJUNCTION WITH LARGE DISTRIBUTING NETWORKS.

This becomes possible if the electric current from hydro-electric plants feed into a network having a constant demand night and day all the year round, and which can use up the whole of the current the plant can produce. River power works must take the base load of such networks while the peaks have to be taken by stations deriving their water power from storage basins, and if this should not be sufficient, steam or similar stations have to complete the requirements.

A supreme management must rule with a strong hand the working of such conglomeration of varied power stations in a comprehensive manner and on economical principles to be able to obtain the highest total efficiency.

BALANCING OF LOAD.

The general supply of electricity has developed to such an extent, that the various areas of current consumption have been combined

* Low-pressure water power up to 10 metres.
Middle pressure water power from 10 to 50 metres.
High pressure water power above 50 metres.

into several large districts. Further development will cause these large districts to combine for the purpose of supplying surplus water or steam power from one district to neighbouring districts needing power. This balancing of power which becomes hereby possible and which is favourable to the ratio of base load and peak load is likewise favourable to the complete utilisation of current from power stations along waterways.

USEFUL QUANTITY OF WATER.

One is therefore justified in constructing hydro-electric works of larger capacities than up to the present. While formerly such works were designed for capacities which were available for at least 270 days during the year, to-day it is possible, owing to the increased possibilities of application, to utilise volumes of water which are available on 130-100 * (in exceptional cases 80) days on a 10 years' average at least. Calculation of working expenses will show the limit to which one can go. The economy decreases from a certain capacity downwards as the kWh. figure which can be utilised does not increase in proportion to the cost of construction.

So as not to increase unnecessarily the cost of construction, the number of machine units has to be fixed so as just to deal with the water capacity. Emergency sets can be dispensed with because the machines can be built so securely that at high water level all of them can be in action while they can be examined and overhauled at the times of low water.

SITE OF POWER STATION IN RELATION TO AREA OF CONSUMPTION.

It is of advantage for the utilisation of current from hydro-electric stations along waterways if the latter cross areas with a demand for current; moreover long transmission lines are thus dispensed with unlike those of stations situated a long way off in the mountains. The cost of current increases therefore only slightly on account of transmission.

VALUE OF WATER POWER ALONG WATERWAYS.

The economic prospect of power gained from waterways depends up to what degree it is able to compete with the current produced by steam or similar plant, as the current gained by the use of coal is the standard. The cost of construction of the hydro-electric station alone, without weirs and other expenses in connection with banking the water in the river, but including the

* Water volume of 130 days in Danube-Kachlet.
Water volume of 100 days in Neckar and Main.

cost of the short power work canals, as necessary according to figs. 2 and 3, will in a few favourable cases be cheaper, but generally speaking according to capacity dearer than the constructional cost of a modern steam station. Water power stations show an advantage in the running expenses because the cost of maintenance, renewals, attendance, lubrication and cleaning materials are less than in steam stations. The amortization of capital favours hydro-electric stations, as they last longer than steam stations and amortization can be carried over a longer space of time. Thus the difference of the running cost becomes considerably smaller than that of the constructional costs. If water power becomes an equivalent substitute for steam power, the economic advantage of the former gains its full value. Such gain can be utilized for covering the expenses of the power works, but besides this, interest can be paid on a considerable portion of the constructional cost of the whole installation which (as for instance, weirs, canals, navigation channel and locks), serve the water way entirely or partially.

If water power is not an equivalent substitute for steam power when it is interrupted during times of flood and drift-ice, and has then to be replaced by steam or similar power, there remains as an advantage for the water power chiefly the saving in cost of coal, and to a lesser degree the saving in attendance, working materials and maintenance of machinery. The gains from this cover only a small part of the expenses for the working of the installation for navigation purposes or common expenses for the latter and the power station, besides the expenses for the power station itself.

The quantity of coal which can be credited to the current derived from water power depends upon the degree of efficiency up to which the heat has been utilized. The progressive improvements in this direction cause the water power works to improve, on their part, the construction and working of their stations.

WATER POWER AS A MEANS FOR FINANCING NAVIGATION WAYS.

It is costly to canalize rivers in hilly and mountainous districts, consequently the earnings from navigation are not sufficient to cover the financing of the waterway beyond the running expenses. The importance of inland waterways in relation to general traffic will improve if water power can be utilised to such an extent that the earnings contribute to pay for the interest on capital invested in construction.

WATER POWER PRODUCTION—GENERAL

RÉSUMÉ.

1. *Notions générales pour la construction et l'exploitation.*

Les rivières à grande chute sont divisées en sections par l'installation de barrages afin que la voie navigable ait toujours un sillage suffisamment large et profond. Les écluses ne consommant que peu d'eau, l'eau de rivière au gradin de chute est pour la plus grande partie disponible pour la production de force motrice.

On ne peut utiliser intégralement la force hydraulique qu'au moyen de barrages étanches.

On ne peut produire la force d'une manière économique que si la chute de la rivière est divisée en peu de grands gradins, autant que l'agriculture l'admet.

La position des centrales de force motrice dans l'axe du barrage prolongé est à préférer à celle dans le sens de la rivière.

Dans les canaux latéraux servant en même temps à la production de force et à la navigation, la vitesse du courant ne doit pas atteindre une limite dangereuse pour la navigation.

Un canal navigable destiné à joindre deux rivières navigables, séparées par des chaînes de hauteur moyenne, ne sera économique qu'en combinaison avec l'exploitation des forces hydrauliques.

2. *Notions particulières.*

Réductions des frais de construction, augmentation du bénéfice.

Il faut réduire les frais des forces hydrauliques coûteuses sans porter préjudice aux qualités, soit au moyen de systèmes parfaits de construction et de turbines à haut rendement, afin que les dépenses d'exploitation deviennent insignifiantes et le bénéfice annuel considérable.

Pour les faibles chutes les roues à propulseurs suivant les inventions de Mr. Kaplan sont particulièrement pratiques, puisque de telles roues permettent de passer des quantités d'eau plus considérables, ont une plus grande vitesse et de plus hauts rendements que les systèmes connus jusqu'ici.

Par conséquent l'installation de la centrale de force motrice est avantageuse à la turbine à une roue à arbre vertical. On cite des exemples.

A l'aide du plan représentant le régime d'une centrale de force hydraulique d'une rivière on démontre, comment il faut exploiter intégralement la quantité d'eau disponible et la chute utile correspondante.

3. *Considérations économiques.*

Afin d'obtenir un niveau d'eau constant pour la navigation il faut charger toujours également les centrales de force motrice. La puissance dépendant du débit d'eau variable peut être exploité intégralement, si les centrales de force motrice sont combinées avec des réseaux de distribution à grande étendue dont elles fournissent la charge fondamentale.

Cette possibilité de combinaison permet de choisir la quantité d'eau d'exploitation plus grande qu'autrefois.

La valeur des forces hydrauliques des rivières comparées aux centrales de force thermique est discutée et on en déduit qu'on ne peut pas réaliser de voies navigables dans des contrées montagneuses, s'il n'y a pas de forces hydrauliques, dont les bénéfices permettent de faire, pour une certaine partie, le service des intérêts.

THE DEVELOPMENT OF GERMAN WATER POWER.

MINISTERIALRAT KRIEGER.

With regard to the size and nature of her water power Germany is behind the specially favoured neighbouring countries, for instance, Switzerland and Scandinavia. It is only in the southernmost part of Germany, in the Black Forest, in the small portion of the Alps belonging to Germany, and in the areas crossed by rivers carrying water from those mountains, that relatively favourable conditions exist for the development of valuable water power. But a few valuable possibilities can be found in the secondary chains of mountains and on the rivers of Central and North-East Germany. The biggest useful single step fall has been found to be 350 metres.

Bavaria has taken a careful census of its developed and undeveloped water power resources. During September, 1921, an official memorandum on the " Utilisation of Water Power in Bavaria " was issued by the Department for the Utilisation of Water Power and the Supply of Electricity, a branch of the Bavarian Ministry of the Interior, giving the yearly average water power available as 12,000,000,000 kW. hours.

The total of Germany's water power, developed and undeveloped is, of course, considerably in excess of this figure. The development of water power in Germany has gained a new impetus as compared with the time honoured method of utilising water power for strictly local purposes such as driving mills, smithies, etc., through the improvements made in hydraulic machinery, and more especially since it has been demonstrated that energy gained hydraulically can be transmitted easily and reliably over great distances by means of electricity. This demonstration has been made for Germany by Oskar von Miller in the electrical transmission of energy, obtained from the Neckar, near Lauffen, to the grounds of the Electrical Exhibition at Frankfurt A.M. (1891) 170 kilometres away, after a similar successful attempt on a smaller scale in 1884 to transmit power electrically during an exhibition at Munich. During the following period of development of large water powers, *i.e.*, direct

river power stations in Bavaria with little head, built, up to the first decade of this century by private contractors or municipalities, the most favourable local conditions were preferred without regard to the possibilities of utilising the remaining portions of the river. This utilisation of separate parts of a river by private enterprise was excusable economically on the ground that water power could hardly compete with steam power at the pre-war prices of coal. Nevertheless the conviction gained ground, even before the war, that Germany's water power reserves are valuable natural reserves and should, therefore, be considered and managed as public property, that all waste must be avoided and that the State must have control, if not the management, over their development and utilisation. As the result of this conviction, various German States appointed officials to survey the water power resources of their various countries and to supervise and regulate their utilisation. In Bavaria a separate Department for the Utilisation of Water Power and the Supply of Electricity has been attached to the Chief Surveyor's Department of the Ministry for the Interior. In Baden the State Department for Roads and Waterways has been entrusted with the task of giving directions for the development of water power and the sequence of the various contracts and to adapt the regulations to the requirements of the industry, etc.

DIRECTIONS FOR THE UTILISATION OF WATER POWER IN GERMANY.

The following important principles for the supervision and control of the utilisation of water power in States with greater resources of hydraulic power were laid down:

1. The exploitation of water power must be sanctioned by the State. This sanction should be granted for a limited time only. After 50-70 years all such recently built water power stations should become Government property without compensation. All plans and drawings must be submitted to and approved by Government supervisors. The work must be carried out under Government control.

2. Private builders of water power stations are granted the right to expropriate the necessary ground if the new enterprise wholly or partly serves public interests.

3. The intended development of a portion must fit into the scheme laid down for the whole river.

4. Because the development of water power means the exploitation of public property and the erection of buildings which must be

considered permanent by reason of the small possibility of altering them at a later date every source of power must be developed to its maximum output. A hydraulic power station generally outlasts the scheme for which it was erected, and it must, therefore, not be limited in size to the originally required output, sacrificing thereby the possibilities of more profitable development later on. This maximum of economy in development demands the observation of the following points.

(*a*) The general exploitation scheme of a river must aim at the complete utilisation of the total fall taking into consideration any existing power stations and special local conditions such as the junction of tributary streams the position of settlements on the river and the economical development of single reaches.

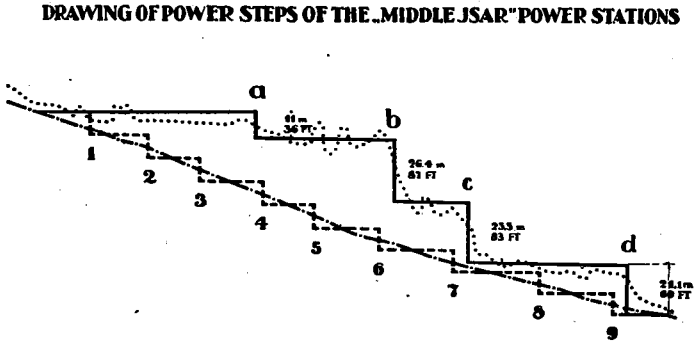

Fig. 1.

Drawing of power steps of the " Middle Isar " power stations.
Utilisation of a reach of the Isar river below Munich, 51 km. long.
(– · – · – · – · river Isar)
The original plan provided for the utilisation of the gross fall of 88 m. in 9 steps (each of 9-10 metres)1 to 9.
(– – – – – Utilisation in 9 steps along the river).
The development has been carried out in 4 steps : a (11 m.), b (26·4 m.), c (25·3 m.), d (21·1 m.). Tandem arrangement.
(———————— Actual development in 4 steps).
(..... Country surrounding development).
95 per cent of the gross fall is utilised. The management of the 4 power step is carried on from step a.

(*b*) The development of the fall of a single section must take place in the smallest number of steps and be placed under one management.

(*c*) The existing absolute fall is to be transformed into the highest effective fall obtainable.

(*d*) The irregularity of water during the various seasons is to be equalised by storage lakes as far as possible. In Germany many instances exist for the provision of storage lakes to correct the annual water supply on short rivers.

To prevent the storage lakes from silting up through gravel and mud they must be arranged as far away from the main river bed as possible. The entry of pebbles and mud into the storage lakes is to be prevented by racks or by-passes between main river and storage lake.

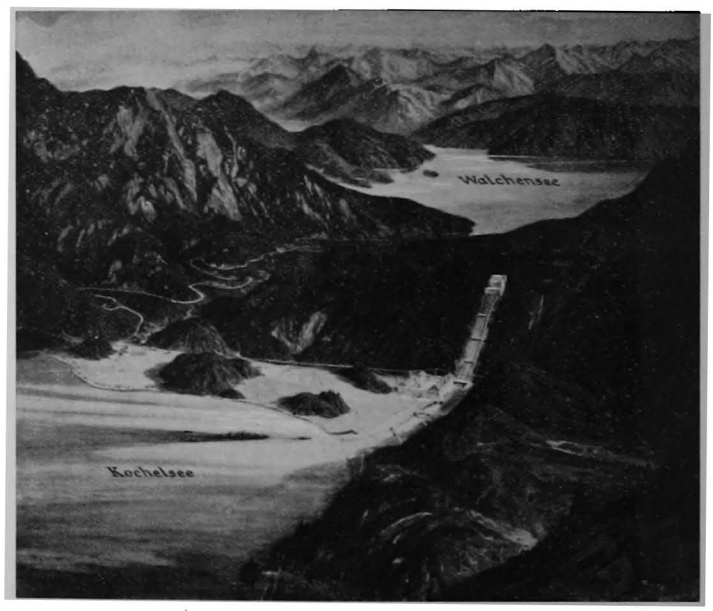

Fig. 3.
Walchensee power station. General view.

Where water is drawn from the storage lakes to meet sudden calls upon the power station during the day counter-reservoirs must be provided for the even discharge of the tailrace into the river bed. For the storage of smaller reserves of power water, canals on the upper reach can be used by the raising of the canal banks and the corresponding weir-heads.

The walls and sides of the canals must be strengthened to withstand the temporarily quicker flow of the water.

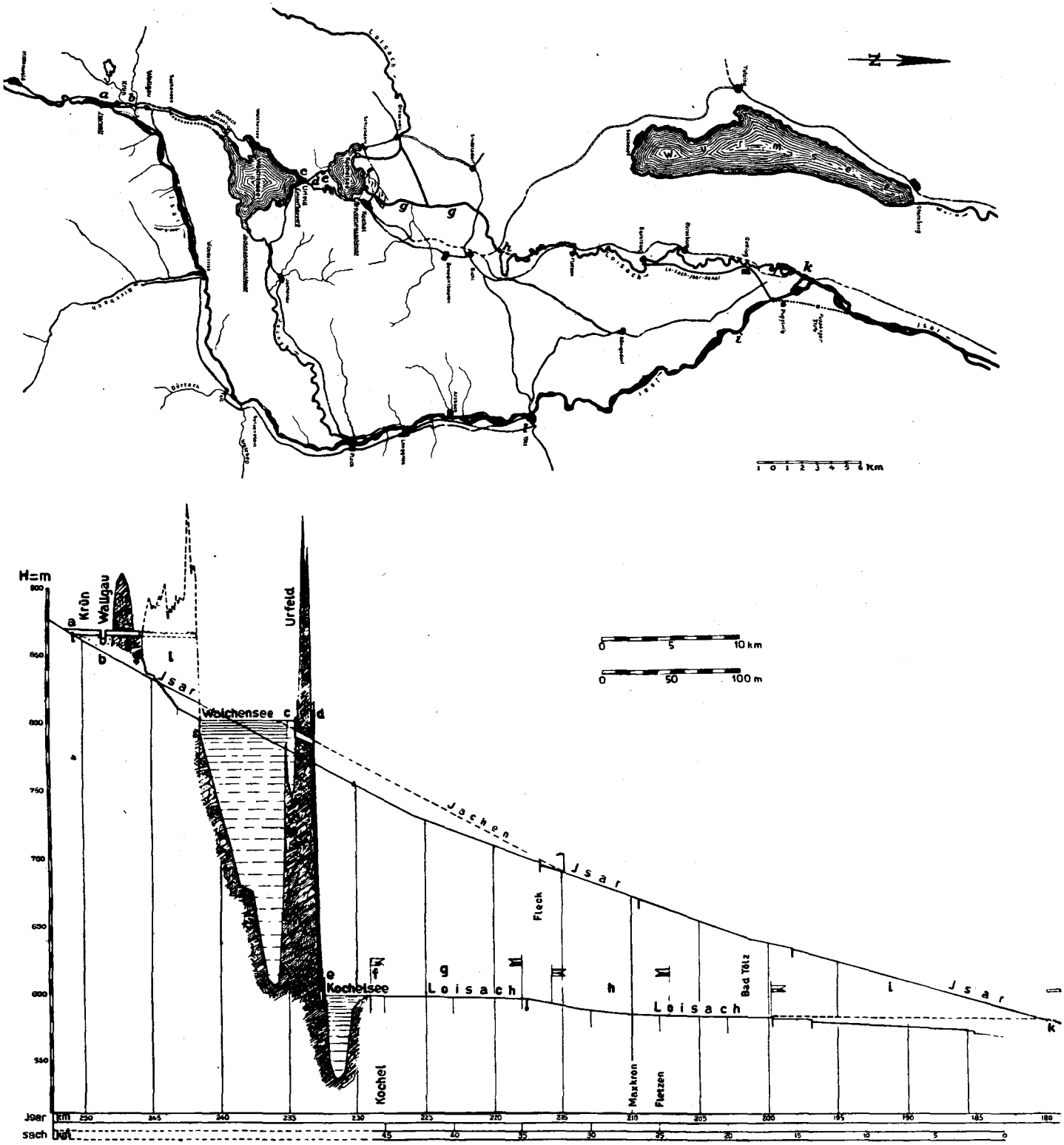

Fig. 2. Walchensee power station. General arrangement and altitude chart.

From the Isar weir (a) Isar water is conducted into the Walchensee by means of a syphon (b) and equalised there. Area of lake 17 km.^{2} (square kilometres), utilisable water volume of lake, at 4·5 m. reduction of water level, 75,000,000 cubic metres. A pressure tunnel leads from intake (c) to the gate house (d), pipeline hence to the power house (e). The variations of the water level, due to the daily consumption of water, are equalised in the Kochelsee. The power water is brought in through the control sluice (f) into the Loisach (g-h-i) and led back into the Isar at (k).

Available head between Walchensee and Kochelsee = 200 metres.

B—To face page 200.

(*e*) The total power utilisation scheme of a river must aim at the most efficient utilisation of all the storage possibilities. By their systematic development and organised co-operation the most economical total hydraulic efficiency of a river is obtained.

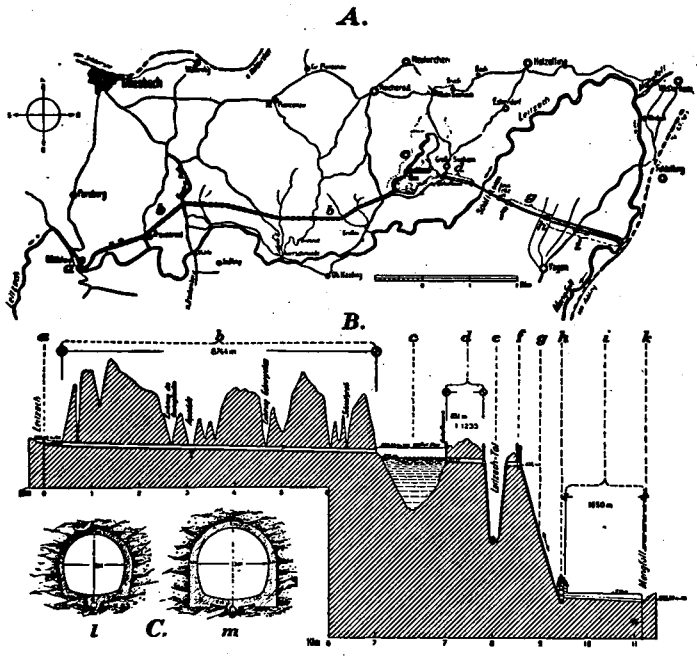

Fig. 4.
Leitzach power station.
A = General arrangement. B = Altitude chart. C = Tunnel section.

On the Leitzach, a tributary of the Isar, in the Bavarian Highlands, an effective head of 120 m. is utilised in one step by a canal, 11 km. long, for the intake and discharge of the power water, cutting off one of the windings of the river. The power water is taken from the main river (a) through a tunnel, (b) 6,744 m. long, to a natural lake (c), whose water level can be lowered by 8 m. Between the lake and the gate-house (f) of the power station the pipe-line crosses a river valley 80 m. deep (e) by means of an iron syphon. From the gate-house the iron pipe line leads to the power house (h). The low water-level canal (i) between power house and main river serves for equalizing the extra water volumes used during overloads of the station.

This General Station has been built after the plans and under the supervision of the Civil Engineer Geh. Baurat Dr. Schmick, Munich.

The interests of single undertakings must be subordinated to the general scheme.

(*f*) In view of the variations of the quantities of river water available during the year all races and hydraulic machinery

must be designed to cope with the greatest possible productive quantity of water. (Calculated maximum quantity).

Professor Dr. Camerer of the Technical University, at Munich, has introduced the term " Flussnutzbarkeit " (the " yield " of a river). This represents the ratio between the average productive quantity of water and the mean yearly quantity of

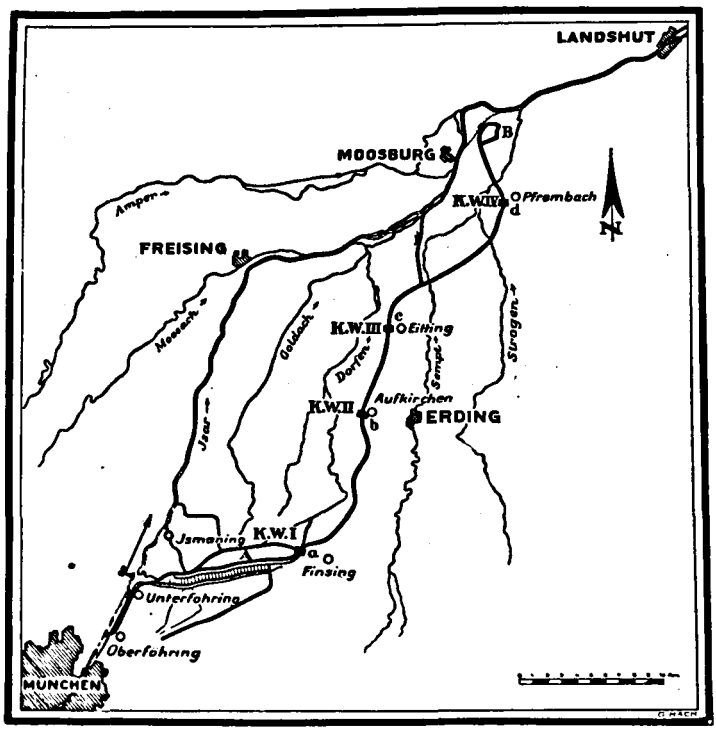

Fig. 5.

" Middle Isar " power station. General arrangement.

Above the first power step (a) a storage lake 29,000,000 cu. m. capacity (with 4·8 m. drop of level) for monthly, weekly and yearly supply storage is created by damming up an area comprising 7 square kilometres. Below the lowest power stop (d) a compensating pool B is built with a capacity of 3,000,000 cubic metres, to regulate the water flow during discharge under extra load.

water flowing down the river. The latter is calculated from the yearly average flow divided by the number of seconds in a year. New water powers must be developed with a maximum yield of power.

A plant up to or beyond the yearly mean quantity of water is

generally suitable, even up to quantities which may be available for 120-80 days of the year only. The term of " Werknutzbarkeit " (utilisation factor) indicates, in accordance with Prof. Camerer, the ratio between the average productive

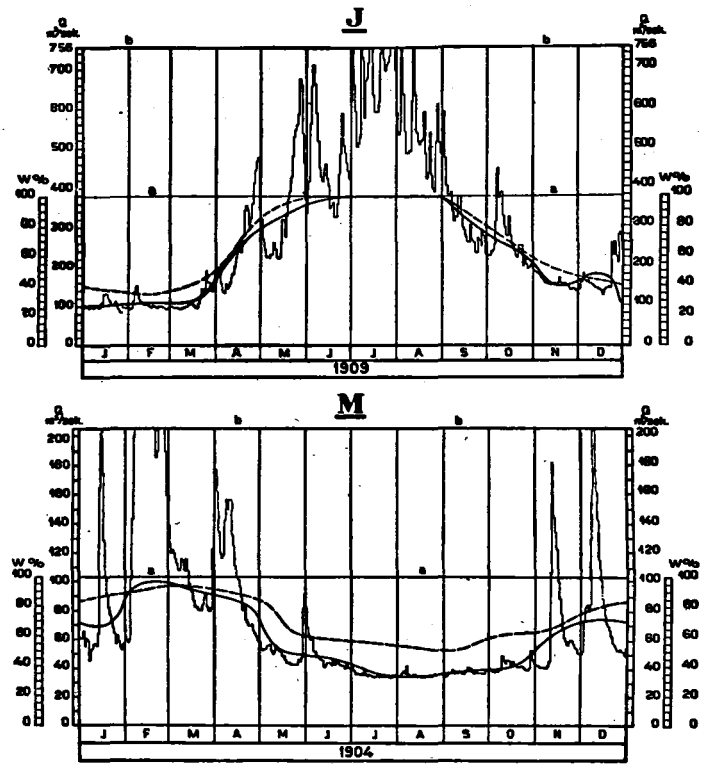

Fig. 6.

Diagrams of yearly flow.
J = Inn at Muehldorf M = Main at Schweinfurt.
a = Mean annual flow.
b = Mean of mean annual flow.
W = " Utilisation factor " in per cent.
= " Utilisation factor " during a drought year for development on mean annual flow, calculated from the mean of several years.
= " Utilisation factor " during the mean year for development on the mean annual flow.

quantity of water and the developed quantity of water. In conjunction with the estimated costs the " utilisation factor" assists in deciding upon the economical percentage of water to be utilised.

5. Water powers of different character, *e.g.*, storable or non-storable, water powers with summer floods (Alpine rivers) and those with winter floods (rivers from the secondary mountain chains) should co-operate for the equalisation of working conditions and for the increase of reliability.

6. The endeavour to build power stations cheaply, must not be made at the expense of public safety or of reliability.

The dams, canal dykes and other contractors' work must be built with the greatest care. To lead the water round the power house during breakdowns and repairs, proper conduits must be provided. Where sufficient experience is lacking on the effect of important constructional details of power plants, the dimensions and shape of details must be dependent on trials with models, carried out by specially trained engineers with greatest accuracy and conscientiousness in the laboratories of technical universities.

7. Damage to agricultural interests and to the soil or subsoil near the power house must be avoided at all costs during the construction of the power stations, especially by possible drainage of the ground water, in case of flooding through obstructions. Beyond this, it is advisable to improve the drainage of agricultural land during the construction of generating stations through the improvement of existing drainage or the supply of water from the power canal for irrigation purposes.

8. In case of a power canal connecting up to an existing or projected canal, the new conduit should be made navigable for tugs and barges by the selection of a suitable profile and a reduction of the water velocity to the admissible speed for shipping, by raising the bridges and the provision of space for locks, etc., to overcome the power plant steps.

9. Where the power water is fully utilised only during parts of the day and the remainder cannot be stored, a pumping plant should be installed, to lift the water into high reservoirs, where it is stored until it is wanted for extra power. Where low pressure plant without storage basins is connected electrically with high pressure plants with reservoirs, the surplus power of the low pressure plant can be applied to work the storage pumps of the high pressure plant.

TECHNICAL DETAILS OF THE HYDRAULIC POWER GENERATION IN GERMANY.

The generation of power from natural waterfalls is impossible in Germany. (The various waterfalls in the mountainous districts are unimportant as power sources during the low water periods.) The

watercourses, which are used for the generation of power, are crossed by a structure placed across the flow of the water to dam the water. If the structure is arranged is such a way that flood-water can pass without materially raising the natural high water mark, it is termed a weir, otherwise a dam or barrage. On many barrages

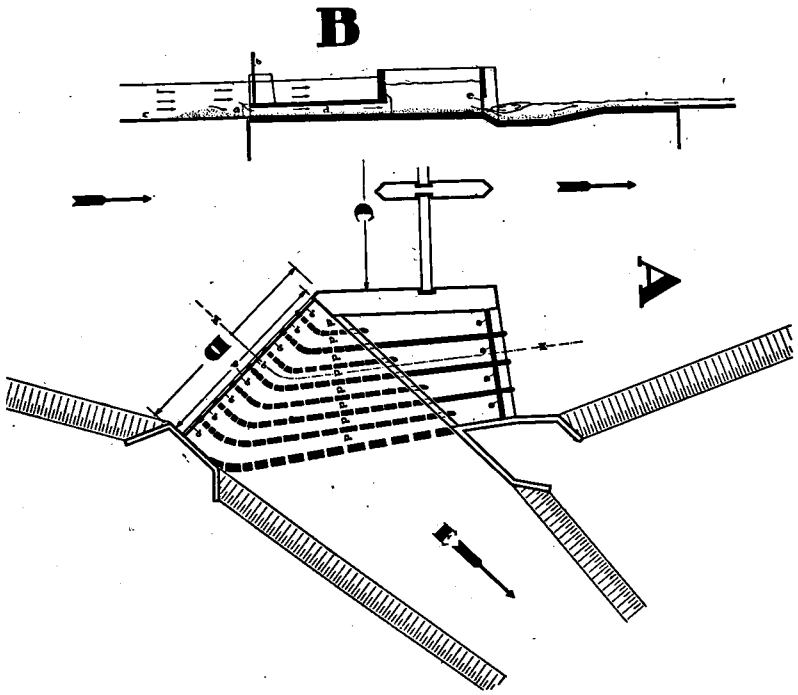

Fig. 7.

Pebble by-pass at the intake of the " Middle Isar " power stations. General arrangement A and longitudinal section B.
C = Sluice dam across the Isar.
D = Intake of the power canal E.

The sill a below the intake sluices b is 2 metres high from river bed c and contains the passages to the by-passes d, which underneath the power canal lead to the tailwater of the weir and can be controlled by the sluices e. When these are opened, water will rush through the by-passes with great velocity and remove the gravel deposited by the river against the sill.

the above-mentioned function is combined with the generation of power through utilisation of the water head at the barrage.

Whether a weir or barrage is to be built, depends on the formation of the valley at the crossing point of the river, on the state of the river bed and sides of the valley, on the character and purpose of

the valley on the upper side, on the extent of any floods, on the character of the river (whether it is a secondary mountain river with little deposit or an Alpine river carrying boulders and pebbles), but above all on the purpose of the damming (whether it is intended to store water or only to direct it to the side of the river bed).

A great number of barrages have already been built in Germany, chiefly in the valleys of rivers coming from the secondary mountain chains. The greatest height of dam is 60 metres.

The greatest storage capacity is that of the Eder Valley barrage namely 202,000,000 cubic metres. None of the large dams have

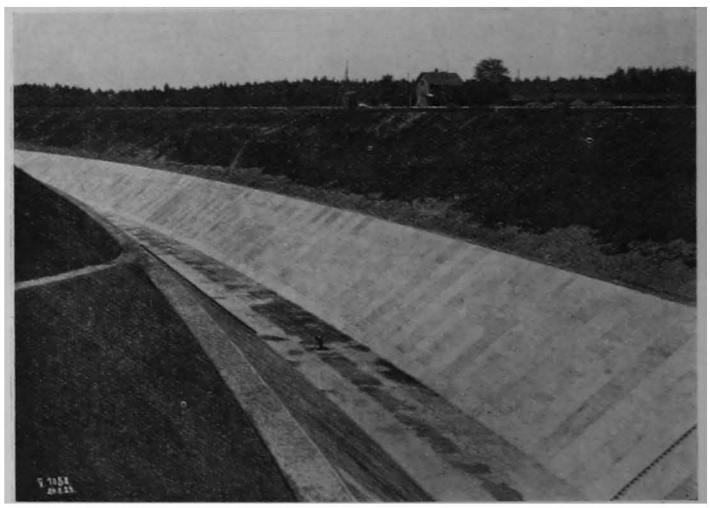

Fig. 8.

Canal of the Inn power station at Muehldorf.

Of 35 m. gross fall, 31 metres average effective head is gained with 23 km. length of canal, which is built for 300 cubic metres/sec. of power water. To secure the minimum loss of fall with smallest cross area, the canal bed, of 8 m. water depth, 28·75 m. width at water level and 8·75 m. at the bottom, has been lined with concrete.

been built solely for the utilisation of water power, but chiefly for protection against floods of the lower reaches, by the creation of storage lakes for the flood water, partly also for the supply of drinking water and as reservoirs for existing power stations and as reservoirs for navigation in case of drought.

Whilst on barrages across rivers coming from secondary mountain chains no danger exists of silting up, such an eventuality must be reckoned with in the case of rivers carrying boulders and gravel.

All German barrages have so far been erected in solid brickwork without causing troubles or difficulties.

The first German ferro-concrete barrage was erected on the Linach, near Voehenbach, in Baden (27m. high).

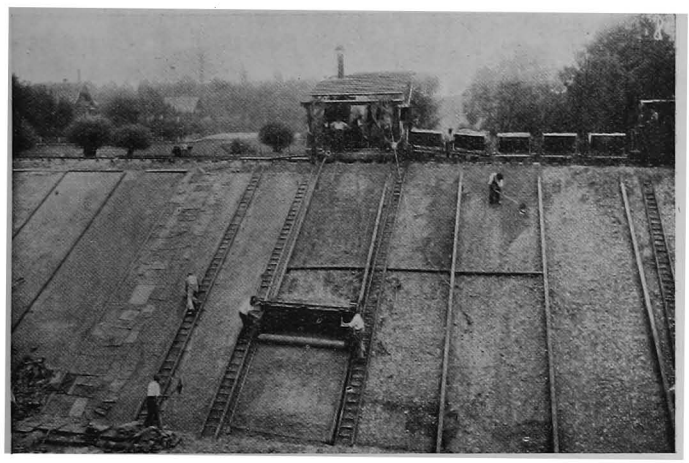

Fig. 9.

Concrete work on canal banks.

A concrete trough, carried on rollers, is moved along the incline by means of winches. The trough empties itself through a hole during the pulling-up; an adjustable scraper at the bottom of the trough spreads the concrete to required thickness. The concrete layers of 3 metres width are pressed down immediately by a steel roller, fixed at the front.

CROSS SECTION OF THE „MIDDLE JSAR" CANAL.

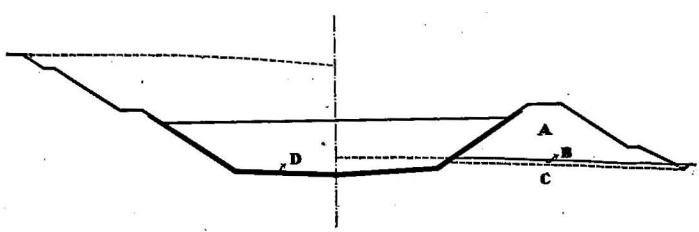

Fig. 10

The banks (A) are covered with clayey, gravelly material and padded down by the traffic with heavy transport material. (B) turf, soil and other unsuitable material is removed right down to firm ground before covering the banks. (C) Bottom and sides are lined with concrete (D) to smooth the surface and to increase the impermeability.

To enable weirs to cope with floods, a corresponding area of the dam side must be removable in time of high-water. This is attained by movable gates, which can be lifted partially or wholly according to the quantity of flood water. The most common moveable gates are sluices, but roller and segment shutters are also used.

If weirs are erected for the assistance of shipping on navigable rivers, water power is generated only from the head of water gained at the weir.

In all other cases weirs serve for the sole purpose of directing the power water from the main bed towards the bank into an artificial channel (tunnel, power race) which conducts the water to the generating station.

Weirs being the vital parts of hydraulic power stations, their foundations and the protection against corrosion below the fall receive the greatest attention. The construction of the weirs is often the most difficult and lengthy part of the contract, because their completion depends upon the state of the river. The total time of construction of a power station is frequently the time taken for the construction of the weir.

On weirs across rivers carrying pebbles, difficulties arise when the pebbles get carried into the power canal through the raising of the water level. The reduced velocity allows them to settle in the channel, whence they must be removed if they cannot be prevented from entering at all.

This is mostly done by dredging. To drain the deposit away from special settling pools without lowering the water-level, *i.e.*, during work, has proved unsuccessful because it is not possible to let the water pressure act simultaneously all over the bottom of the settling pools. In recent plants the pebbles, etc., are washed into the tail water through the pressure between high and low level by means of channels passing from the bed of the upper reach underneath the weir.

Trials with models have shown that the width of the intake can be reduced considerably if it is placed at an angle with the river instead of being parallel to it.

The power races are either open channels or tunnels, the latter with natural fall or under pressure. The loss of head in channels is kept down by selection of the smallest possible section and by lining the sides with concrete, 15-25 cm. thick and not necessarily watertight. The desired watertightness of channels is obtained through the deposits from the main river which close the pores of the concrete.

In recent times one has frequently used the formula $v = \lambda R^{0.7} J^{0.5}$

(v=velocity m/sec.) which shows certain practical advantages over the usually applied Ganguillet-Kutter formula. This formula for water velocity v, with the constant λ (constant factor for roughness), which is independent of the hydraulic radius R (the ratio between sectional area and wetted circumference) and the water-level fall J, corresponds well with measurements on existing plants.

Tunnels have been driven in Germany through moraine gravel with natural fall for a capacity up to 60 cubic metres/sec. and through rock (lime) as pressure tunnels up to 27 metres water pressure. The tunnels are lined with concrete and partly with ferro-concrete.

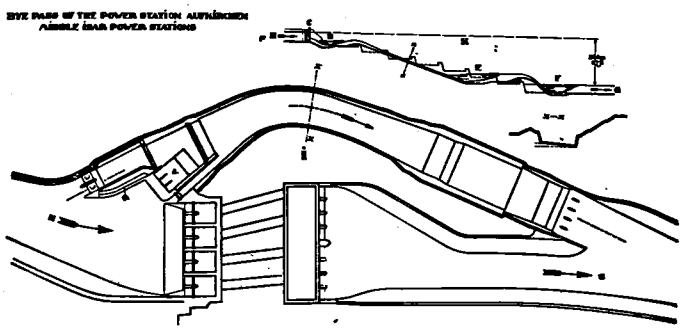

Fig. 11.

By-pass of the Aufkirchen power station (Middle Isar power stations). General arrangement J and longitudinal section K.
Water not absorbed by the turbines automatically flows from the high-level water H through the automatic lifters A and over the overflow B or through the submerged sluices C. Eddies with horizontal axes are formed at D, E and F, through the shape of the channel, to annihilate the force of the water, calming it before its entry into the low-level canal. To avoid vibration of the power house by the falling water in the by-pass, the channel for the latter is placed at some distance from the power house. The by-pass is able to cope with the total quantity of power water, in this case 125 cu. m./sec.

The water is led to the turbines without intermediate pipelines up to a fall of 20 metres by placing the runners in open chests or chambers, which form the volute casing with moveable iron hoods at the lower part, or have iron volute casings altogether. For higher falls, the power water is conducted through pipes from the gate house to the iron cased turbines. The pipes are generally made of iron, resting on numerous supports, but recently also self-supporting for spans of 20 metres and resting upon special joints on the ends.

Ferro-concrete pipes are used in special cases where the water

pressure is not high. Most generating stations must be provided with a reliable by-pass, capable of conducting the whole power water for long periods from the upper to the lower canal, in case of sudden changes to no-load, or for the unchecked supply to the lower turbine set (tandem stations) in case of stoppage or repair of the machinery. For a fall not exceeding 15 metres in one power step, waterfalls in one or several cascades with steps of ferro-concrete are suitable. (Meitingen power station of the Lech Electricity Works—A.G.). For higher heads it was proved unsatisfactory to use this form of construction on account of the excessive quantity of

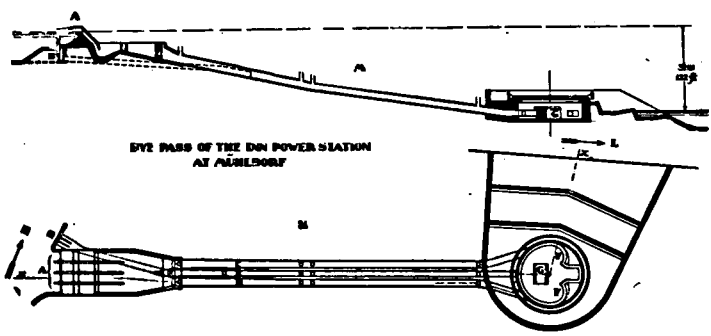

Fig. 12.

By-pass of the Inn power station at Muehldorf.
General arrangement K and length section M.

The water passes from the high water canal H through automatic lifters A into the iron pipes C and D, and through the bottom sluice B into the pipe E. The pipes lead into a circular whirling-pool, in which two spirals F and a strong concrete block G deflect and mix the water currents in such a way that the water runs quietly into the lower canal L over the rounded edges J of the pool. About one half of the maximum bulk of water of the station (300 cu. m./sec.) can be got rid of this way.

concrete required and the numerous points of attack offered to the water. Trials with models in this instance also have led to better and cheaper methods, namely, the annihilation of the hydraulic energy by the formation of eddies in the falling water through the shape of the bed.

Iron pipes are also often used for the by-pass in sizes of 2-3 metres diameter through which the water can run down with considerable speed according to the incline.

Only a small part of the energy is lost through pipe friction and the water leaves the pipes in these plants with an exceedingly high speed. Before entering the low level canal it is calmed in special whirlpools,

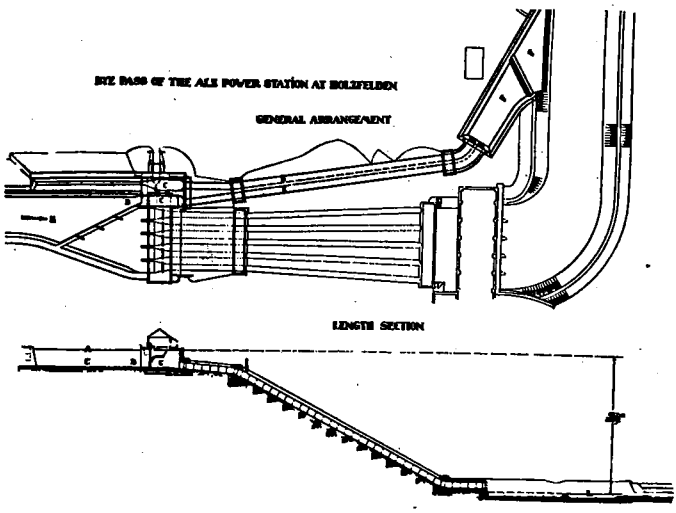

Fig. 13.

By-pass of the Alz power station at Holzfelden.

Overflow A or ground sluice B lead the water from high-level canal H to the collecting pool C, from which two iron tubes D and E lead downwards to run out horizontally over the lower water level L. The annihilation of the force of water takes place in the whirling pool F, which is lined with concrete and has a layer of heavy granite boulders at the bottom.

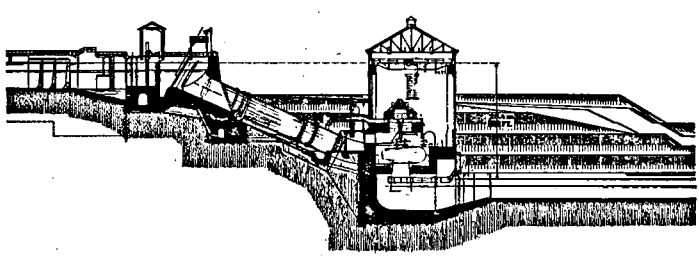

Fig. 14.

Longitudinal section of the Aufkirchen power station of the " Middle Isar " power stations.

With a mean power water quantity of ca. 100 cu. m./sec. the canal of the " Middle Isar " power stations is built for 125 cu. m./sec.

Each turbine (vertical shaft, hood generator) is calculated for 42 cu. m./sec. (effective head 25·3—26·4 m).

he iron draught pipes have a diameter of 5 metres.

whose action is augmented by special structures (Margarethenberg Power Station on the Alz) by special shape and intake for creating eddies (Inn Power Station, near Muehldorf) or by armouring the bed with rough granite boulders (Alz Power Station, Holzfelden). In the arrangement of all details the free course for any possible ice drifts must be reckoned with.

LENGTH SECTION OF THE POWER STATION PFROMBACH OF THE "MIDDLE ISAR" POWER STATIONS.

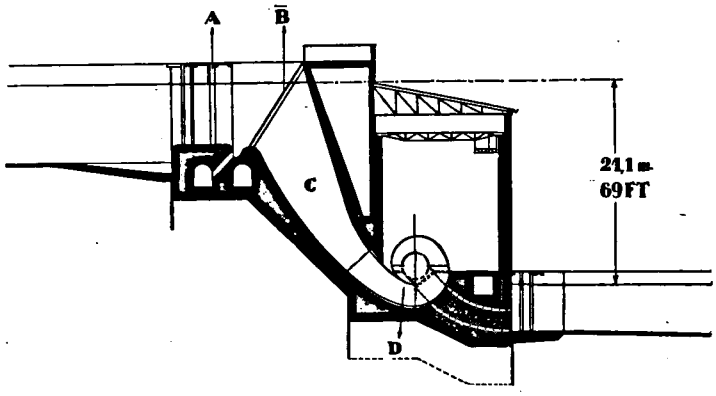

Fig. 15.
Longitudinal section of the Pfrombach power station of the "Middle Isar" power stations.
A = Turbine sluices.
B = Turbine rack.
C = Ferro-concrete pressure duct.
D = Iron volute casing of the horizontal turbines, centre line vertical to direction of water inlet.

Until a few years ago Germany had, barring a few small installations only turbines with horizontal shafts, in single up to quadruple sets with direct coupled generator. Since the vertical turbines with hood generators were introduced by other countries in nearly all modern plants on account of higher efficiency, Germany has followed suit. The vertical iron draft pipes require spacious escape chambers to obtain high efficiency of the turbines, and this entails deeper excavations, which latter may influence the cost and time of building. The power house itself must be kept higher to allow the use of an overhead crane for mounting and unmounting the long shafts, and for any other moving of machinery.

Quite recently, and on account of the cheaper and quicker contractor's work, horizontal turbines have been installed for heads of 20-22 metres. The upper level canal ends in this case in separate

turbine chambers, which at the lower part assume the shape of the volute casing and lead the power water to the turbines without intermediate pipes.

The turbine shaft is arranged vertical to the axis of the canal, to carry a series of separate single step turbines and a dynamo at each end, of which the one creates three-phase current for the overland wires, the other direct current for the railway. The shaft is divided between the various turbines by clutches so that each generator can be driven by any number of turbines.

RÉSUMÉ.

Quoique le nombre et la puissance des forces hydrauliques en Allemagne ne soient pas de première importance, on prête beaucoup d'attention à leur exploitation. Elle est soumise au contrôle public. On findique les conditions principales, sous lesquelles on accorde noce concession et ou communique en même temps quelques expériences es fait jusqu'à présent dans l'exploitation.

PROBLEMS RELATING TO RUN-OFF, STORAGE, AND THE ALLOCATION OF CATCHMENT AREAS IN GREAT BRITAIN AND IRELAND

W. J. E. BINNIE, M.A., M.Inst.C.E., F.G.S., Etc.

RUN-OFF.

A study of the run-off—or quantity of water discharged—from any drainage area throughout the year, is essential to enable the engineer to lay out a scheme for the development of power.

It is exceptional to find that gaugings have been taken of the flow of the stream, extending over a sufficient period to determine this point.

The bulk of the capital required for the development of electric energy from water power is spent on the hydraulic part of the installation, and although the success of the scheme depends almost entirely upon the reliability of the estimates which have been formed of the amount of water which will be available, this aspect of the matter is frequently overlooked in this country, and the advice of competent hydraulic engineers, whose whole time is devoted to the study of such problems, is not sought.

In Great Britain we are fortunate in having at our disposal a large number of rainfall records, and in order to determine the necessary storage capacity of a reservoir to maintain a certain discharge, the records of monthly rainfall are of service in estimating the approximate variations of monthly flow.

The loss by evaporation—or, more strictly speaking, the difference between rainfall and run-off—varies with each month of the year, and the relation which has been found to exist between the two, has been determined by actual gaugings, and forms a useful guide in cases where only the monthly rainfall records are available.

The actual variations in discharge are also influenced by the amount of natural ground storage which exists in the drainage area, *i.e.*, the extent of the permeable superficial deposits, or fissured rock, which absorb water during periods of rainfall, and discharge it during periods of dry weather.

Lakes also play an important part in tending to maintain the flow in dry weather and in reducing the flood discharge.

In applying this method of estimation from rainfall in Great Britain it is, therefore, necessary to bear in mind that, although there may be no rainfall during a certain month, a stream rarely runs dry, its flow depending largely upon the character of geological formations and superficial deposits.

In cases where there is no opportunity for the construction of a storage reservoir, the minimum dry weather flow of the stream is all that can be depended upon at certain periods of the year and, therefore, gaugings in dry weather, even if few in number, are of supreme importance.

Each individual stream differs with regard to its minimum discharge. For instance, the latter will generally be found to be high from a granite drainage area, owing to the existence of superficial deposits of a permeable character and fissures in the granite; whereas the minimum flow from an impermeable area—such as clay—will be very small.

The size of the drainage area is also of importance in determining the minimum run-off, which increases with the extent of that area.

This is probably due to two factors.

(1) It takes a greater difference in time for water flowing from areas near the upper limits of the drainage area to reach the stream at the lower limit, than it does for water flowing from areas near the lower limit. Hence there is a balancing effect on the variations of flow and this increases with the extent of the drainage area as the run-off, due to rainfall on distant portions of the area will pass a point on the lower limits simultaneously with a low run-off after dry weather on adjacent portions.

(2) Water which passes into fissures or permeable deposits on the upper portion of the drainage area, finds its way back to the stream in its lower reaches in the form of springs.

As an illustration of the effect of the size of the drainage area in balancing fluctuations in flow of the stream, it is necessary to compare two drainage areas having approximately the same geological character.

The river Alwen has a drainage area of 10 square miles, and the river Severn at Worcester a drainage area of 1,960 square miles, there being no great difference in the geological character of the drainage areas.

Assuming that no storage exists, and that hydraulic power plant capable of dealing with two-thirds of the average annual run-off

of each river were established, the gaugings show that it would be possible, in an average year, to develop 61 per cent. of the discharge into power in the case of the Alwen, and 80 per cent. in the case of the Severn; and if auxiliary plant were established to maintain the output when the river fell below that discharge, the plant would have to be called upon for 211 days in the case of the Alwen, and 173 days in the case of the Severn.

The comparison would be still more striking if a plant were established capable of dealing with only one-third of the average annual run-off, the corresponding figures being: water power utilised, Alwen 74 per cent., Severn 95 per cent., and auxiliary plant called upon to make up deficiencies on 158 days for the Alwen and sixty-six days for the Severn in an average year.

The mean gradient of the slopes of the hills bounding the stream affects the variations in run-off, as the steeper the slopes, the more rapidly will the rain flow from the ground.

The actual effect of forests in influencing the annual run-off is a debatable point, but the effect on the variations of that run-off is well marked. Forests retard the rate of flow, whereas land drainage facilitates the more rapid discharge of water to the stream.

CONDUITS.

It is not unusual to find a suitable site for a storage reservoir where the natural drainage area is limited in extent, but where it is possible to divert the discharge from adjacent areas into that reservoir by means of weirs and conduits.

As the flood discharge of a stream may reach several hundred times its average flow, it would be an expensive matter to construct such conduits so as to convey the maximum flood discharge, and some economic discharging capacity has to be determined.

The variation in the discharge of streams whose drainage areas vary widely in extent, and in the amount of average annual rainfall which falls on those areas, is similar, and by the aid of diagrams based on gaugings, it is possible to determine the economical carrying capacity of the conduit.

RESERVOIR STORAGE.

Owing to the wide range of variations in annual rainfall, opportunities very seldom exist of constructing a reservoir of such capacity as will balance the run-off over a long series of years, and it has become the established practice for waterworks engineers in Great Britain to provide such storage as will balance only the run-off during the driest three consecutive years.

The average annual rainfall during that period amounts to about

80 per-cent. of the true average annual rainfall, and a simple formula was derived by the late Mr. Thomas Hawksley for estimating the number of days' storage of the average daily run-off which should be provided, *viz.*, $D = \frac{1000}{\sqrt{F}}$ where F is the mean annual rainfall of the driest three consecutive years, and D the number of days' storage.

This formula has been criticised and other formulæ put forward, but the author has proved by actual test in many cases that it gives a result which is very near the truth.

It sometimes happens that storage can be economically provided which will balance the run-off during a longer series of years, but more frequently it is not economical to construct a reservoir of that capacity, especially when large streams are to be impounded.

The late Dr. Deacon carried the investigations a stage further, and published a diagram in his article on " Water Supply " in the Encyclopædia Britannica, showing the discharge which can be maintained by reservoirs of varying capacity.

This diagram covers a wide range of annual rainfall, and the author has found it of great service. Its application is, however, limited to cases where the ground storage is negligible.

When considering the best utilisation of storage reservoirs for power purposes, there are points other than the maintainable yield to be considered, as the actual proportion of the average annual run-off which can be obtained from a reservoir of given capacity will be governed by the conditions under which the power demand is to be supplied.

When the demand is constant throughout the year, as will be the case where an undertaking has been entered into to supply a fixed output per diem, that output will be limited, in the absence of some auxiliary power station, to the energy which can be derived from the proportion of the average annual run-off which the reservoir is able to maintain during the driest years.

Under such circumstances a considerable proportion of the average annual run-off will be wasted by overflow from the reservoir in all but the driest years.

If, however, market conditions are such as to permit of making the best use of the variations in run-off, this loss can be avoided to a considerable extent, a larger output being utilised in the wetter than in the drier months.

For an ordinary power scheme supplying energy for industries,

lighting, tramways, etc., it will probably be found most economical to make the best possible use of the average annual run-off, and to provide auxiliary power to make up the deficit during periods of low rainfall.

ALLOCATION OF WATER SUPPLIES.

Sources of water are allocated in a haphazard fashion in Great Britain, as Parliamentary Committees are only called upon to consider the merits of the particular schemes before them.

The author has known more than one instance where unnecessary powers have been granted by a Committee, simply because they had no opportunity of reviewing the position in all its bearings, and were kept in ignorance of the fact that it was in the power of another authority to supply what water was required.

Powers have also been granted which have assigned to some water authority a valuable source of supply which would have served for a larger population, a very serious matter when the difficulty of finding water for our industrial areas is considered.

It would frequently be to the public advantage if water boards were formed for supplying water to several authorities, as, other things being equal, water can be supplied more cheaply by a large scheme than by a multiplicity of small schemes.

It is an unfortunate fact, however, that it is a difficult task to persuade authorities to combine when going for a new source of supply.

The present procedure for obtaining the necessary powers is also cumbersome and expensive, and if opposition has not been met in the first House, the merits of the scheme are considered *de novo* by a Committee of the other House.

This has frequently led to the opposition in the second House being removed by prior agreement on clauses, and this has proved a very expensive handicap to the undertaking.

A private Water Supply Bill should be a non-party measure, and there seems to be no reason why it should not be dealt with once and for all by a Joint Committee of the two Houses.

The Water Power Resources Committee of the Board of Trade considered the question in all its bearings, and came to the conclusion that some rational system of allocation of water resources should be adopted, based on a review of the water resources of the whole country and the needs of the community.

They further reported in favour of the setting up of expert water commissioners, who would hold enquiries subject to the confirmation of Parliament in case of opposition, and who would collect all the

statistics to enable them to take a much wider view of particular projects than is possible with the existing procedure.

At present no obligations are placed on the promoters to collect and record for the use of some central authority, statistics with regard to rainfall and run-off, with the consequence that very few reliable records are available.

Unfortunately, the recommendations of the Water Power Resources Committee have not yet met with the support of the representatives of Local Authorities, whilst the Ministry of Health appears to regard with some apprehension the setting up of such a body as that recommended, and is now collecting statistics and reviewing schemes before the Committee stage is reached.

Their powers, however, are not sufficiently wide to enable them to compel water authorities to supply the necessary statistics, nor to simplify the procedure. They have also no means, other than persuasion, of bringing about that combination for the purpose of water supply, which may be desirable.

It is hoped, however, that their reports will be of real informatory value to Committees, and so enable them to take a wider view of the particular question before them.

COMPENSATION WATER.

The Water Power Resources Committee dealt at some length with the present procedure of Parliament when fixing the amount of compensation water which has to be discharged down a stream from which water is to be abstracted.

When schemes are placed before a Committee, the promoters inform that Committee of their estimate of the average rainfall and of the drainage area. Agreement on this point is generally reached, and it has been the custom to fix the compensation water as some proportion—usually one-third or one-fourth—of the run-off during the three consecutive driest years.

Such a procedure is illogical, and leads to results which may be unduly onerous to the promoters or the riparian owners.

In a number of cases, no injury would be inflicted on riparian owners if the minimum flow of the stream in dry weather were preserved to them.

The minimum flow of the stream is, however, not dependent upon rainfall, but on the natural ground storage and size of the drainage area, and hence it is not unusual to find streams where the average rainfall on the drainage area is high, but in which the minimum discharge is low. On the other hand, streams where the average rainfall on the drainage area is low, may have a high minimum discharge.

The compensation water when fixed on the basis of rainfall, would work out at a much larger discharge in the former than in the latter case, and hence it may amount to many times the natural flow of the stream in dry weather in the former case, and may not reach that flow in the latter case.

The Water Power Resources Committee, therefore, recommended that compensation water should be fixed only after the actual variation in flow of a stream is known, and its exact relation to the minimum flow determined for each particular case in accordance also with the nature of other interests concerned.

The value of a source when developed for power purposes would be severely handicapped and might be rendered uneconomical for development if the ordinary practice now followed by Parliament were adopted with regard to compensation water.

When water is abstracted from the upper portion of a valley and discharged again into the river from the power house at a lower level, it should generally be possible to make such arrangements with the riparian or mill owners as will avoid the discharge of compensation water.

When, however, water is taken from one drainage area and diverted into another, it is difficult to satisfy all the interests concerned, and compensation water would almost certainly have to be discharged, with the consequent loss of power.

Most of the schemes which can be economically developed in Great Britain, are situated in the Highlands of Scotland, or the mountainous regions of Wales, where there would be no conflict of interests between the development of water power and public water supply, and where industrial interests are very small.

The fishing interests are all that will be interfered with, and these are usually the most difficult to satisfy, and the time is approaching when it will be necessary for Parliament to consider whether they should be allowed to stand in the way of the industrial development of water power in this country.

RÉSUMÉ.

L'auteur montre l'importance d'une évaluation approximative des variations de l'écoulement à la surface lorsqu'on envisage la quantité d'énergie que peut fournir une source.

Il attire l'attention sur le petit nombre de renseignements dont on dispose sur les écoulements mesurés et fait remarquer qu'en Grande-Bretagne il existe beaucoup de données relatives à la chute de pluie par mois, données dont on peut déduire les variations mensuelles d'écoulement.

Il passe en revue les facteurs qui influent sur le débit d'un cours d'eau en temps sec, notamment l'accumulation naturelle des eaux dans le sol, l'étendue de la surface de drainage, l'inclinaison des pentes, l'afforestation et le drainage, et fait ressortir l'importance de la détermination par jaugeage direct du débit minimum lorsqu'il n'est pas pratique d'établir des réservoirs.

L'importance de la détermination de la capacité de débit économique des conduites de captage lorsque l'eau est détournée d'une zone de drainage dans une autre est examinée.

La question des réservoirs d'emmagasinage est considérée ensuite, avec référence à la formule empirique de M. Hawksley et à l'abaque du Dr. Deacon donnant les débits que peuvent fournir des réservoirs de différentes capacités pour différentes chutes annuelles de pluie sur la zone de drainage.

Il étudie ensuite la question de l'utilisation d'un réservoir comme source de force motrice de manière à tirer le meilleur parti possible des fluctuations annuelles de l'écoulement à la surface, et il arrive à la conclusion que dans certaines circonstances il est économique de fournir de l'énergie à titre auxiliaire.

Il passe en revue les formalités actuelles, gênantes, coûteuses et inefficaces, pour obtenir les pouvoirs nécessaires, les recommandations du *Water Power Resources Committee* à cet égard, et les mesures que prend en ce moment le Ministère de l'Hygiène, et il soutient que l'examen des projets de loi particuliers par des comités distincts des deux Chambres devrait être remplacé par un seul examen devant un comité unique représentant les deux Chambres.

Il examine la procédure actuelle suivie devant les comités parlementaires pour déterminer la quantité d'eau de compensation à donner à une rivière ou à un fleuve auquel on soustrait de l'eau, et arrive à la conclusion qu'elle mène à des résultats illogiques.

Il montre l'importance de l'eau de compensation en égard au développement économique d'un projet d'installation hydraulique, et suggère que le moment est venu d'envisager la question dans son ensemble si l'on veut utiliser en grand la force hydraulique dont dispose la Grande-Bretagne.

FACTORS OF EFFICIENCY IN HYDRO-ELECTRIC DEVELOPMENT

LT.-COL. C. M. NORRIE, D.S.O., B.Sc., M.INST.C.E.

The demands for hydro-electric development of ever growing magnitude during the past thirty years, have resulted in an ever-increasing application of methods and designs embodying greater efficiency in the various branches of engineering involved. The radical improvements introduced in this natural evolution have centred principally round the actual machinery, but in the glamour of the increasing economy in its design and construction, and of the marked advances in its mechanical efficiency, it may be that other aspects of equal or even greater importance have not received sufficient consideration.

The necessity for the highest mechanical efficiency within the commercial limits of cost of power production, is obviously of the greatest importance. In this respect the ability of hydraulic machinery to maintain continuously its guarantees is of perhaps greater economic value, than an initial fulfilment of high duty followed by a declining performance in after years. The assessment of the monetary value of mechanical efficiency is no very difficult matter, and together with considerations of reliability, conformity with all particular requirements and economy in cost, constitutes the usual basis on which suitable machinery is selected.

Efficiency, viewed in a broader sense, can be considered from a national and from a commercial standpoint as measures of approach to certain ideals. These ideals are, in many cases, not easy of exact definition, as the constituent factors depend so often on incomplete data or on the unforeseen contingencies of construction, and only become reliable estimations later, when the completed installations are in operation.

NATIONAL EFFICIENCY.

From a national standpoint, it is desirable that each water power site should be developed to the maximum extent possible. Any pre-determination of this maximum, however, must have regard to the river systems in one locality as a whole, the fundamental

consideration being the best utilisation of all national water resources for both immediate and future demands. Unless such a policy is insisted on by governing authorities, the possibilities of national industrial prosperity will be affected adversely in the future.

The ideal of national efficiency may be considered as the fullest development of the two factors constituting a water power site—the gross head and the highest proportion possible of the average discharge. The economic aspect of the problem, however, furnishes a third factor of paramount importance, and upon it depends the full realisation of the above.

On a particular catchment area it may be possible from an engineering point of view to utilise the maximum possible of the average discharge and the maximum head available, but it frequently happens that the high cost of power production from such an ideal development renders the proposal impossible. It is obvious, therefore, that in such cases the full utilisation must be viewed in the light of commercial expediency, and that the degree of utilisation must be limited to economic proportions, in the absence of any financial or other aid from outside sources towards a realisation of the best national efficiency.

The development embodying the highest national efficiency may not necessarily be the cheapest, but so long as the costs of power production are competitive, it should be the duty of the generating authority to utilise to the maximum possible any water power resource within such competitive limits.

The pros and cons of state or private development enterprise are not discussed here. These questions must necessarily be influenced by national or local conditions of demand, and by the nature of the available resources of power. The function which the State should exercise in either form of enterprise, is that of guardian of those national resources and as such it is probable that it will envisage a wider perspective of the possibilities of development than may be viewed by the private concessionaire, whose attention is focussed more on the immediate market and its profits than on any approach to a national ideal.

Examining the position more closely, it will be seen that the condition of the immediate power market can, in certain cases, impose limitations on ultimate development. When the existing power demands and those of the near future are such that development by stages only is economical, and if the initial stage must be burdened by the unproductive capital cost of enlarged permanent works, as provision for an ultimate increase of output within a

reasonable sinking fund period, then the problem demands the closest study, so as to determine the economic limit of final development as restricted by the initial financial requirements. The only commercial solution may lie in a neglect of part of the available water or head, if by so limiting the ultimate completed scheme, a profitable start can be made with the first stage of development.

Whilst emphasising the necessity of national efficiency, it cannot be too strongly urged that the State in its attitude towards private enterprise, cannot reasonably insist on ideals for the future benefit of the country, without recognising the commercial aspects of the present situation. It is submitted, therefore, that in localities of prospective demand, where the exigencies of construction demanded by a policy aiming at national efficiency, necessitate financial burdens at any stage of a scheme, a State contribution towards the interest on the extra capital involved, during its unproductive period, is a logical sequence following the adoption by the State of such a policy.

As an alternative, the State may itself construct such heavy permanent works as will ensure the maximum conditions of river discharge, and may recoup itself by selling water for power purposes at prices based on the ultimate full utilisation.

Among the essentials for the enforcement of national efficiency is the framing of legislation, tending to decrease the capital cost of obtaining concessions, land and wayleaves and of compensating existing riparian rights. Of importance also is the removal of all anomalies of taxation and rating, which press more heavily on water power than on fuel power schemes, where assessments are based on the capital costs of construction.

A national organisation for the collection and recording of all data regarding power sites has been instituted by most countries interested in the efficient allocation and use of water, either for supply or power purposes. In Great Britain there is as yet no permanent authority responsible for the collection of the necessary observations. In this country, therefore, there can be little check on the efficiency of water power proposals, and what there is may easily lose application, by reason of the temporary constitution of the Parliamentary committees appointed to investigate them, which have not the advantage of guidance by any permanent authority responsible for a definite policy, regarding both the allocation of the national water resources and the efficient utilisation of these. This matter has been the subject of many writings and

recommendations,[1] and in time, alterations of existing procedure may be effected. The state of affairs may serve, however, as a warning to countries where the demands for water, for both domestic and industrial purposes, are only beginning to be exercised.

COMMERCIAL EFFICIENCY.

The commercial efficiency of a water power development may be defined as the measure of its suitability to produce energy at the cheapest cost in the distribution area after all legislative requirements have been met. Each project presents an individual problem from the generating and transmission point of view, but a study of this feature alone, however efficient it may appear, does not give a true perspective of the economic situation. The special market conditions either existing or to be created, and the suitability of any water power as the sole or as a contributary source of generation to meet the particular demands, must also be considered. It is no exaggeration to state that a great number of the attempts to exploit hydro-electric concessions fail, owing to a lack of appreciation of this commercial aspect.

A matter of importance in commercial power development is the load factor which, although defined in various ways may be considered here generally, as a measure of the efficiency of the demand for energy.

The load factor is naturally dependent on the peculiarities of the existing or prospective market, but, whilst accepting the general limitations of these, the aim of the power supply authority will be to encourage such conditions of service as will lead to general improvement in the load factor. Obviously, if consumers can benefit by any reduction in energy prices thereby, they will more readily accommodate their requirements.

The cost of water produced energy is affected to a greater extent by load factor than is the cost of energy generated from fuel, and hence the usefulness of water power development is particularly dependent on the maintenance of an economic load factor, and its prospects are enhanced if improved conditions can be introduced.

In localities where water forms the basic source of power, the continuance of a low load factor must eventually become a matter for serious consideration, first, because it entails a waste in the absence of sufficient storage of the limited resources of power and, secondly, because the competitive instinct will force the cheapening of energy costs. The introduction of high load factor industries

[1] Water Power Resources Committees Reports, 1919-21.

and of more continuous domestic consumption, the interlinking of stations and the centralising of generation to meet load fluctuations at particular stations, selected because of their suitability to supply these variations, and the establishment of systems of charging for energy which encourage high load factor, are all tried methods of suiting the demand to the supply or *vice versa*.

In any one country or locality the development of the basic power resource—either water or fuel—individually or combined with the other as auxiliary—has established economic standards of power costs which cannot be exceeded without industrial reorganisation.

In any comparison between the generation of energy from water and from the most used fuel—coal, an arresting feature is, that whereas modern hydraulic machinery is capable of recovering from 85 per cent. to 90 per cent. of the total available energy, the most up-to-date coal power plants convert as a maximum only about 19 per cent. of the potential energy of the fuel, whilst small and older plants give results as poor as 5 per cent. The possibility of greater improvements of a far-reaching effect, in the latter form of power generation, must be envisaged in any economic forecast and it should be recognised in such that extensive water power development, excepting under specially favourable conditions of capital cost and of market, will show relatively, a decreasing advantage where such already exists.

On the other hand, water power development is independent of the oft-recurring abnormal conditions in cost and supply of coal, and by virtue of this advantage plays an important part in considerations of industrial expediency, as well as in national and international politics.

Again, the use of water power is the only considerable alternative, capable of achieving a conservation of the national coal resources.

However important it may be to husband the latter it is not unreasonable to expect that immediate economies in coal consumption, consequent on the probable introduction of low temperature carbonisation methods and the centralisation of generation, will be effected, and that in any locality where the basic source of power is coal, it will primarily be found cheaper to conserve fuel by direct saving, even to the extent of discarding old and installing new plant in existing stations, than by substituting water power. Exceptions to this general statement can obviously be advanced, where the costs of particular water power developments and transmission are exceedingly low, and where the total output can be utilised continuously at high load factor.

Where water forms the basic source of power the problem is reversed, and whilst giving credit for every advance in power production from coal or any other fuel, the relative costs of energy permit of the latter developments only as auxiliaries. The economic ratio of utilisation of the auxiliary will, in each case, form an individual study, but broadly, the fundamental principles governing the most efficient proportioning are the variations of discharge as affecting supply of energy, the respective costs of energy at the point of distribution and the load factor of the system. The advantage of the auxiliary fuel plant is two-fold, in that it supplements the daily or seasonal deficiencies in uncontrolled river flow, and also acts as a partial standby in case of accidents on the transmission lines from the water generating source. Seldom will it be found economical to install an auxiliary fuel plant, with a water power development depending on river flow fully controlled by storage. In reality, such a plant will constitute a permanent increase of the total continuous capacity and as such, its adoption can be justified only on the basis that its individual energy production costs are approximately competitive.

TECHNICAL EFFICIENCY.

The technical efficiency of water power generation depends chiefly on economy in the layout and design of the construction works entailed, and in the employment of the best contracting experience for their execution, cost and time of construction being the ruling factors. In general, the proportion of capital cost expended on the construction work of dams, canals, pipe lines, power house and structures other than the mechanical and electrical equipment, may amount to between 60 per cent. and 85 per cent. of the total cost in any one scheme. Rigid economy in the outlay on these major works is, therefore, of relatively greater importance than in the remaining expenditure on the factory made portions. Extras will obviously be more likely to occur in the former, as the unforeseen contingencies are infinitely greater, and the opportunities for wasteful administration and design are more numerous.

The ideal of layout aims at the most economical delivery of discharge and conservation of head at the power house, under conditions which will enable the best types of machinery to be adopted, and the highest mechanical efficiencies of output and speed regulation to be obtained during all stages of development. It is a matter of difficulty to lay down any general principles for proximity to this ideal and, therefore, with no claim to completeness, but

rather as an invitation which may elicit experienced opinions, attention is drawn here to a few general points which influence economical results.

It often occurs that the most experienced engineer is set a difficult task, in having to evolve a layout with insufficient knowledge of the actual regime of the river flow. The lack of data on this essential feature, and the over or under estimation of the permanent works required have been frequent causes of disappointment in the past. Although not always appreciated by financiers, the expense of exhaustive and continued preliminary investigations generally leads to economy in the end.

In some schemes the initial stages of construction have been carried so far as to include complete settings and draft tubes for future turbine units. No improvements in turbine or draft tube design having been anticipated, the latter units have had to be installed at considerably higher cost than would have been entailed, had modern turbines of higher speed been adopted, whilst it has been impossible to realise the full benefit of higher mechanical efficiencies. The recent great advances in specific speed and high efficiency attained by turbine builders, and the possibilities of still greater improvements, should be given every opportunity of achievement when extensions are being anticipated. This may be a matter of conjecture in many cases, but a close study of the trend of modern turbine development will give some guidance as to the forms which will permit of cheapest conversions to the best use later on.

Another feature deserving of more detailed consideration in many cases is the layout, as it affects the speed of the turbo-generator unit. In the larger stations this question is given careful study when the general layout and dimensions of pipe lines and units are decided, but in many schemes the conditions which are imposed on the machinery designers involve unnecessary additional expense.

The old relations which were assumed to exist between head and specific speed are no longer tenable. These relations were based on past experience, but were misleading, in that an adoption of limiting values of specific speed for particular heads without any consideration of the corresponding draft heads, presented a doubtful standard of tabulation. In this respect many instances of cavitation and vibration, especially at part loads, have occurred, not because the specific speed value has been too high for the head, but because with the type of turbine and draft tube adopted, the specific speed has been too high for the particular draft head in

conjunction with the total head available. It will be realised, therefore, that the insistence on or the assumed necessity for some particular setting of the turbine may involve uneconomical conditions of machinery design which, with little difference to the layout, can possibly be avoided.

One of the essentials of good service is close speed regulation, and to obtain the best conditions for its attainment, the designs for the canal, forebay, pipe line, turbine and generator must be considered together. In schemes where synchronous byepass or relief valves are installed, the nature of the load and the frequency of large load variations should be considered, as it is possible under some conditions to obtain close speed regulation only at a sacrifice of overall efficiency, owing to the high proportion of water waste through the byepass. In such cases it may be advantageous to increase the flywheel effect or the pipe dimensions, or to install a surge tank of some description.

The introduction of the differential surge tank is a striking instance of successful design to meet the modern demand for high overall efficiency. Its use in certain schemes has enabled the achievement of results which would otherwise have been impossible.

In drawing attention to these features, it will be realised that one of the essentials of success lies in close collaboration between all the specialised designers of the successive steps of power production, and in a free opportunity being given to each to advise as to how features outside his own scope of influence may best be constructed, to attain the main object in view. As an instance of the latter the recent advances in draft tube design, assisting towards economy through higher speeds and towards greater mechanical efficiency, show that progressive overall improvement can be attained by the interchange of experience and research results, between the turbine designer and the hydraulic engineer. On the other hand, the former can, in turn, materially assist the generator maker. The demands for flywheel effect made on the latter often necessitate extra expenditure, which might be more economically met by modification in adjacent designs, for example, in the pipe line or in the turbine governing provisions. Without the essential collaboration, each is striving for and possibly achieving individual efficiency, but there is no assurance that the combined results are within the most economical limits.

In whatever manner this desirable co-operation be achieved, the fact remains that the principal burden of responsibility lies primarily with the engineer in charge of the hydraulic layout. In general,

he is responsible for the bulk of the capital expenditure, and the commercial success of many a scheme depends on his ability to adapt efficiently the natural conditions of the site, and on his experience in co-ordinating to the best advantage the proposals for generating machinery—functions which, if indifferently exercised, may seriously diminish the commercial value of the enterprise, in spite of the best mechanical efficiencies, and economy in the actual power house equipment.

RÉSUMÉ.

L'auteur montre que dans le développement de l'industrie hydroélectrique les idées, en ce qui consume le rendement, se sont généralement concentrées autour des progrès marqués réalisés dans la construction et le rendement des machines, mais que certains autres aspects de la question méritent la même considération.

Il discute la question de l'efficacité nationale de développement, et insiste sur la nécessité d'utiliser au maximum les sites de force hydraulique.

Il montre, cependant, l'impossibilité commerciale de toujours réaliser cette condition, en raison du coût élevé de production qui en résulte si les étapes initiales de la construction doivent être grevées de lourdes dépenses de première installation en ouvrages permanents destinés seulement au développement maximum ultérieur. Si l'État insiste sur l'exécution de tels ouvrages au-delà des exigences industrielles, il devrait aussi prêter son assistance financière.

Pour réaliser cette efficacité nationale il faudrait une législation visant à réduire les frais de la procédure parlementaire, de l'acquisition des terrains et droits de circulation, et à supprimer les anomalies de l'impôt, qui pèse plus lourdement sur les entreprises de force hydraulique que sur celles qui exploitent l'énergie calorique.

L'absence de toute organisation nationale pour recueillir des données sur les sites hydrauliques de la Grande-Bretagne est l'objet de certains commentaires.

L'efficacité commerciale est définie comme étant la mesure de l'aptitude à produire de l'énergie au plus bas prix après satisfaction de toutes les exigences de la loi. Mention est faite du facteur de charge en tant qu'affectant le coût de l'énergie dérivée de l'eau, et une comparaison établie ensuite entre l'énergie dérivée de la houille et l'énergie hydraulique.

Tandis que les turbines modernes convertissent de 85 à 90 pour cent. de l'énergie hydraulique disponible, la machine thermique la plus moderne alimentée au charbon ne récupère qu'environ 19 pour cent. de l'énergie potentielle du combustible. Des perfectionnements dans ce dernier mode de production d'énergie enléveront à la force hydraulique son avantage là où elle le possède déjà.

La conservation des ressources houillères se réalisera probablement par économie directe, plutôt que par substitution de l'énergie hydraulique dans les régions carbonifères.

L'auteur discute le rendement technique de l'installation hydraulique et attire l'attention sur la haute proportion des frais de premier établissement

nécessitée par les travaux de construction de canaux, barrages, etc., et sur la nécessité d'une rigide économie dans leur conception et leur exécution.

Quelques points d'intérêt général sont mentionnés quant à leur influence sur l'économie des résultats.

Le mémoire finit en soulignant la nécessité d'une étroite collaboration entre les différents groupes de spécialistes, et d'une coordination appropriée par l'ingénieur hydraulique responsable de la majeure partie des dépenses.

WATER STORAGE CONDITIONS IN INDIA

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1. PHYSICAL FEATURES.

India embodies a great diversity of topographical features in its area of about 1,500,000 square miles. The North is walled in by the mighty Himalayas, with Mount Everest, the highest peak in the world, 29,000 feet above the sea level. Between the Himalayas and the Vindhyan and Aravelli ranges of hills, which traverse as a belt across mid-Hindostan, lies the great Indo-Gangetic plain, which is entirely of alluvial formation. The portion of India from the Aravelli Hills to Mysore, is called the Deccan trap area and consists of high plateaux and uplands, with intervening valleys, and is criss-crossed with drainages in all directions. These river courses, owing to the heights from which they drop, have scoured out deep channels, which flow torrentially in the rains and run dry after the cessation of the monsoon in October—in India the monsoon is confined practically to four months, from the 15th of June to 15th of October—when the land becomes parched and dry. This is why this portion of India is so sparsely populated. The Southern portion, pertaining to the Crystalline tract, comprises the high Ghauts on the west, reaching up to Cape of Comorin and the entire Madras Presidency.

2. RAINFALL.

Over this vast area the incidence of rainfall is very uneven and irregular. The Eastern portion—Assam and its adjoining country —is the wettest in India, having a rainfall of over 150 inches per annum, whereas the Western portion is almost dry and rainless, the rainfall in Sind and Rajputana being scarcely 10 inches in the year. This accounts for the aridity and barrenness of the region. The rainfall over the Western Ghauts, owing to their standing as a high barrier against the Arabian sea currents, ranges from 100 to 150 inches, but descending eastward it diminishes to 30 inches, till on the east coast it again rises to about 50 inches. The rainfall on the

Deccan trap area varies from 25 to 40 inches, but is generally unevenly distributed, and is in deficit every third or fourth year, leading to famine conditions. This tract is in a chronic state of drought. Southern India is favoured by two monsoons—the south-west and the north-east, but in spite of this the average rainfall does not exceed 35 inches.

3. IRRIGATION.

From this brief resumé of the physical conditions of India it will be realised that, though politically one country, India is not homogeneous in the matter of physiographic characteristics. It is this absence of homogeneity that accounts for the variations in the methods of applying water for irrigation in different parts of India. A great portion of the north alluvial tract, *viz.*, the Punjab and the United Provinces, being blessed with numerous perennial rivers, is covered with a network of canal systems, the most magnificent in the world, which between them irrigate about 20,000,000 acres. There are no large irrigation works in Bengal and Assam, though canal irrigation is carried out on a restricted scale. Madras also has a few big-sized canals, taking off from raised weirs, but the greater portion of India, about three-quarters of the total, depends for irrigation on storage works. In other words, the monsoon run-off has first to be stored behind dams and then let out in small quantities as necessity for irrigation is felt after the cessation of the rains. The configuration of land in the Central and Southern tracts lends itself very well to the construction of storage reservoirs with their separate distributary systems. There are wide basins and valleys in the hilly regions, drained by rivers and streams with rocky beds and narrow canyons, where dams can be economically constructed and below which are open plains with gentle slopes affording easy command for the canals. Ideal conditions for irrigation on a limited scale are obtainable all over this region, and though numerous storage works have already been constructed, there are no signs of the exhaustion of suitable sites.

4. SPECIAL INDICATION FOR STORAGE WORKS IN THE DECCAN TRAP AND CRYSTALLINE AREAS.

As the Deccan trap and Crystalline areas are specially liable to famine, owing to the small and unevenly distributed rainfall and to the early drying up of the river beds, the only way to improve conditions is to multiply storage works. As the water table is too far below the surface and there are no springs, recourse must be had

to storing the monsoon yield. Storage of water is necessary also on other grounds, as rapid denudation of land is going on in all the valleys and uplands and the fine top soil is being washed down to the sea, whilst large areas are being encroached upon by ravines and are becoming unfit for cultivation. The havoc is going on in such a stupendous scale that even the multiplication of storage basins will not stop it. If, however, the programme of construction is pursued steadily it will be possible, within 40 or 50 years, to obviate loss and damage to the most valuable portions which are threatened with ruin. The storage basins will not only reclaim large stretches of land in their beds and on their margins but, by controlling the floods, will lessen the erosive action of the rivers.

5. DEVELOPMENT OF WATER POWER BY COMBINING IRRIGATION AND POWER SCHEMES.

The average rainfall over the whole of India is worked out to be 37 inches. This is equivalent to a precipitation of 128 billion (*i.e.*, million million *not* thousand million, as the term is now often used) cubic feet of water. If 40 per cent. of this runs off it works out to 50 billion cubic feet per annum—serving one-fifth of this for irrigation, present and future, 40 billion cubic feet can be made available for the generation of water power if suitable sites for storage dams can be found. I have already said there is no dearth of sites, especially in the hilly regions of the Deccan trap area. Surveys were carried out by different Provinces under the auspices of the Hydro-Electric Survey Department of India, but they had to be undertaken by already overworked Irrigation Officers. They had scarcely touched the fringe of the problem when the Hydro-Electric Department was closed owing to financial stringency, but the work done was recorded in the Triennial Reports, Superintendent, Government Printing, Calcutta. The total output of hydro-electric power in India at present, including the plant under erection, is 268,780 k.W., equivalent to about 360,000 W.H.P. (*vide* Mr. J. W. Meares' Report for 1919-21). It is difficult to say what proportion of 40 billion cu. feet of water could be utilised for the generation of power and what head would be available, but a conjectural estimate is 40,000,000 water horse power.

Only a properly conducted investigation can verify if this figure is at all within the pale of practical politics. As the possibility of the exhaustion of coal and petrol is exercising all the far-seeing captains of industry, it is time that the Government of India paid more serious attention to the question of the development of water

power. The Government may hesitate to invest large capital sums in water power schemes only, until the need for power is more urgent, but if the advantage of developing power with irrigation is demonstrated this hesitation may give place to enthusiasm. There should be absolutely no objection to the combining of power and irrigation if the whole subject is rightly understood and intelligently worked out. This combination will, no doubt, be subject to one drawback—in slack seasons of irrigation sufficient water will not be available for power purposes and few irrigation engineers will agree to deplete their storages and cripple their schemes in order to promote water power enterprises. This difficulty can be got over by small standby steam plants for the minimum requirements of the slack season, or such combined schemes may be promoted as will not suffer by temporary closures. The advantage gained by using the same water twice over will far outweigh any small locking up of capital necessitated either by maintaining a small steam plant or by temporary closure of the industry.

The large number of storage works in India primarily constructed for irrigation needs, possess a potential value as power resources. Their possibilities are great and, in the industrial evolution of this great Empire their development should not be forgotten.

S. No.	Name of work.	Storage capacity in m.c.ft.	Irrigable area in acres.	Completed or otherwise.	Cost in lacs of rupees	Extr'm' height of dam in feet.	Remarks.
			MADRAS PRESIDENCY.				
1	Periyar Lake	13,300	173,000	Completed	100	158	Water power contemplated.
2	Rushikulya	—	106,000	—	—	—	
3	Toludur	2,400	26,800	Nearly completed.	—	—	
4	Nagavalli	—	23,814	—	—	—	
5	Mopad Lake	—	12,500	—	—	—	
6	Kistna Project	163,586	—	Projected	834	154	
7	Cauvery	80,000	400,000	do.	400	—	
			BOMBAY PRESIDENCY.				
1	Anobra Valley Power Project	13,000	—	Completed	—	190	For water power.
2	Kayna Project	112,600	—	Projected	750	300	Power Project.
3	Nika Mula Project	16,500	—	Under construction	—	—	
4	Lake Hill	8,671	—	Projected	—	260	
5	Lonavla Lake	360	—	—	—	—	Storages utilised for creation of power in connection with Tata Hydro-electric scheme
6	Walvhan Lake	2,560	—	—	—	—	
7	Shirwata Lake	6,920	—	—	—	—	
8	Sukkur Barrage	—	4,000,000	Put in hand	200	—	
9	Lake Fife	4,900	16,800	Completed	79	106	
10	Ekruk Tank	3,330	16,990	do.	7·8	76	
11	Mukti Tank	342	—	do.	2·7	65	
12	Mhaswad	3,070	27,800	do.	9·5	80	
13	Chankapur	1,197	10,000	do.	5	120	

S. No.	Name of work.	Storage capacity in m.c.ft.	Irrigable area in acres.	Completed or otherwise.	Cost in lacs of rupees	Extr'm height of dam in feet.	Remarks.
			BOMBAY PRESIDENCY.				
14	Gokak	701	—	—	5·5	—	
15	Lake Beale	9,000	220,000	do.	100	92	
16	Pravara	13,000	—	Under construction	127	270	
17	Nira Right Bank Canal Project	24,000	117,000	—	—	180	Comprising two reservoirs, Lakes Whiting and Bhatgar.
18	Ashti Tank	1,550	11,780	Under construction	9·7	58	
19	Waghad Tank	624	—	—	4·2	96	
			UNITED PROVINCES.				
1	Paricha Weir and Canals	3,000	150,000	Completed	83	—	
2	Gangao and Bariarpur Dams	4,000	125,000	do.	60	—	
3	Dhukwan Weir	4,000	90,000	do.	—	57	
4	Mirzapur Dam	5,000	67,000	do.		65	
			PUNJAB.				
1	Sutlej Valley Project	110,000	1,500,000	Under construction	990	360	
			CENTRAL PROVINCES.				
1	Mahanaddi Reservoir	8,230	400,000	Under construction	116	—	
2	Wainganga Dam & Canal	570	79,000	Completed	48	—	
3	Asola Mendha	—	60,000	do.	18	—	
4	Ramtek Tank	4,000	48,000	do.	29	—	
5	Tandula Project	9,000	200,000	—	100	—	
6	Kharung Tank	—	80,000	—	—	—	
			RAJPUTANA.				
1	Bitra Tank	—	4,200	Completed	9·2	42	
2	Dhontera Tank	—	3,220	do.	4·3	—	
3	Ramgarh Dam	—	2,689	—	5	90	
4	Tori Sagar	—	2,057	—	6·2	—	
			MYSORE STATE.				
1	Markanave Reservoir	32,350	45,000	Complete	40	142	
2	Krishnaraja Sagra Dam	41,500	125,000	Under construction	—	127	
Wk			BARODA STATE.				
1	Orsang Project	—	12,500	—	—	—	
			GWALIOR STATE.				
1	Sindh Project	37,000	500,000	Projected	100	275	
2	Parbatti Project	18,000	180,000	Under construction	129	140	Comprises four dams
3	Rampura Res.	1,200	14,000	Completed	6	57	
4	Sankh-Asan Project	12,300	65,000	do.	56	85	Comprises four dams
5	Baisly Project	—	15,000	Under construction	5	35	
6	Morar Project	500	5,000	do.	4	35	
7	Anda Project	—	20,000	do.	16	30	

RÉSUMÉ.

L'auteur expose brièvement les caractères physiques et la distribution du régime des pluies aux Indes. Les besoins de l'irrigation ont nécessité la construction de divers réservoirs pour l'emmagasinage des eaux et l'on insiste pour que l'on mette à profit ces sources potentielles de force hydraulique déjà existantes comme aussi celles à édifier dans l'avenir pour leur utilisation au mieux, à la fois pour l'irrigation et pour la production d'énergie.

THE COEXISTENCE OF HYDRO-ELECTRIC AND STEAM-DRIVEN GENERATING STATIONS AS AFFECTING THE ECONOMY OF PRODUCTION AND THE NECESSITIES OF STORAGE AND RESERVE

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I. THE INTEGRATING FUNCTION OF HYDRO-ELECTRIC DEFICIENCIES.

For a long time, the distribution of electric energy has acquired in all civilised countries the character of a public service, having an importance slightly smaller than the provision of drinking water in the large cities.

This character is particularly prominent in such countries that are poor, or not provided with coal, and where, owing to such a deficiency, manufacturers have been brought, in almost all cases, to replace steam engines with electric motors (so that it can really be said that here, electric energy is the bread of industries), and where, in other fields as well, the place that electricity has attained, has become such, that its consumption may be considered the most significant index of national progress.

Among other European countries, Switzerland and Italy, both provided with great quantities of hydraulic energy, are in this condition.

In these countries therefore, more than elsewhere, distribution of electric power must serve the purpose of making the largest possible quantity of electric current available for the public at the minimum possible cost.

Not always, however, does the unit cost of hydraulic energy that can be obtained from a watershed, decrease when its development is pushed to the maximum. Indeed, the reverse can be demonstrated, and has, in fact, often happened; in other words, by limiting the development, energy can be obtained under better conditions. This gave rise to a contrast which had some importance and which provided politicians with no little food for thought, so long as electrical enterprise was the field of individual capital; but that

ceased to be when the capital to be invested became so big as to require the support of large corporations.

In this field, also, corporations have shown up as an instrument of progress. The freedom and latitude that is allowed to the managers (much more than that which a private individual, thinking only of his capital, may be expected to have) has brought into the first rank, or has treated as the independent variable of the problem, the *quantity of energy to be produced*, so that the second element, the *cost of production*, has been relegated to the second rank and has become a function of the variable. From that day the work of electrical engineers and of business men has been to solve the problem in such a way that the minimum value of the function (*price*) should correspond to each of the increasing values of the independent variable (*consumption*).

I do not wish it to be thought that I mean, or urge, that hydro-electric energy be generated *at any price*; this would be an impracticable economic absurdity. I only want to say that, within the limits of economic convenience, as compared with steam generation, the decrease of cost of hydraulic production has lost a large part of its importance.

Now, if one does not take into account the technical improvements of the steam turbine, the cost of electricity generated by steam has increased since the war in a measure probably larger, certainly not smaller, than the cost of hydro-electric energy; on the other hand, not even these improvements, still in the experimental stage, could set off the characteristic advantages of the hydraulic plants, first of all the simplicity of the machinery and the small amount of sinking funds necessary to cover the capital outlaid; and, therefore, there is still a large margin to be taken advantage of, even without taking into account such reasons as economic independence from foreign countries that strongly favour hydro-electric development.

On the other hand, in many cases, the aid of thermal generation during the low water period may contribute to the decrease of the average cost, because it allows a greater utilisation of the water-shed. Finally, it is not true that our hydraulic resources have already been impoverished in respect of the most important and most economical plants. This is a story greatly credited by people who do not know the facts, with the result (I will not say the purpose) of depicting Italian electrical industries as mere grabbers. Indeed, people emphasise the burden imposed on this industry by the monopoly of existing companies, who are alleged to have taken

the cream of all the hydraulic patrimony of the nation and left for the future only a few and costly plants.

Nothing could be less correct, both for the quantity of energy that can still be produced from the waters of the Alps, and for the unit cost.

As to the quantity, even if a detailed valuation is not available, competent engineers have estimated that in the Italian Alps, within the new boundaries, two million kilowatts can still be developed, while the power at present developed is only a little over one million kilowatts.

As to the price, there are now under construction or under consideration some large new plants, which, even allowing for the creation of large artificial reservoirs, will give the kilowatt-hour at a capital cost not larger than 50 or 60 centesimi at the present value of the Lira. These figures, owing to the devaluation of the Lira as compared with gold, are only $\frac{1}{4}$ or $\frac{1}{5}$ of pre-war values. Therefore, they unquestionably show that the residual hydraulic wealth of our country has no smaller intrinsic value than the part that has already been developed. Thus the panic of politicians, and the scares of sceptics are without foundation, at least for many years to come; and the so-called monopoly (which is really a very large "polipoly," owing to the great number of independent companies engaged in the electrical industry) may be confidently accepted, inasmuch as it exists everywhere and, in our country, has made electrical energy available at prices that are among the lowest in the world.

These, therefore, are the reasons why the aim of large electrical enterprises has been the maximum development of our hydraulic energy, which consequently must be carefully studied and methodically developed.

When in 1919 Italian legislators established the principle that among several applications for franchise, preference should be given to that which would make for the largest and most rational utilisation of a watershed, they gave their approval to the character and the purpose of electrical industry in national life.

But engineers had to face two contradictory elements that complicated the problem. On one hand the extreme variability of the rainfall, and consequent dependence on nature's whim for hydraulic possibilities; on the other hand an almost absolute regularity in the law that controls the consumption of electrical energy.

Speaking from an industrial point of view, atmospheric precipitation and the regime that is thus given to our Italian rivers, could

not be less suitable for such an important industry as the production and the sale of energy, and this holds good especially for the valleys that have no glaciers.

As a matter of fact, while in the Alps the variation of flow roughly follows the sinusoidal curve of the average temperature, *i.e.*, is maximum during the summer and minimum during the winter, in the northern Apennines the regime of the water is so capricious as to appear surprising, until one remembers the extreme capriciousness of the rainfall itself.

A recent report of the astronomical observatory of Milan demonstrates this truth incontestably. From the figures pertaining to a series of 157 years, from 1764 to 1920, it is seen that the rainfall during the same month of different years reached some very high maxima (not very different from one month to another, *i.e.*, from 376 to 208 millimetres), while on the other hand the minimum is practically zero in every month (see appendix A*). A relative constancy can only be found in the yearly rainfall; although here also, as compared to the average of about 1,000 millimetres per annum, some considerable variations above and below can be found. These circumstances explain everything.

One can understand that the torrents of the Apennines can provide absolutely no electrical energy for the national market, without some means that allow of integrating the deficiencies of the low water period (this is absolutely necessary), and possibly also allow of conservation of the excess of precipitation of the periods of abundance (this may be useful).

As the northern Apennines have their low water period mostly during the summer months, when the rivers of the Alps, on the contrary, get plenty of water from the melting of the snows, the integration of the deficiencies in the torrents of the Apennines has been effected for some years, through electrical interconnections with the Alpine plants. But there are also the winter deficiencies, which are sometimes important, and these can only be met by reservoirs, or by thermo-electric stations.

On the other hand, not even the Alpine stations are able to give that constant production which would be desirable for the electrical industries, and which is necessary to meet the demand. Indeed, for the Alpine plants one may safely say that the reverse holds good, for while the consumption is higher during the winter than during the summer, the hydraulic availability follows an exactly opposite law. Thus the Alpine plants are also faced with a problem

*See page 248.

of yearly integration caused by the deficiency during the winter period, and it has been thought to make up for the deficiency by reservoirs.

But, if we really want to use the average hydraulic availability of our valleys, reservoirs cannot be deemed sufficient. Let us again consider the figures of the average rainfall at Milan, as they may be taken as an example to make our point of view clear. If we want completely to utilise 1,000 millimetres of average rainfall in a certain watershed, it is not enough that the generating plants be able completely to use the maximum rainfall of 1,578 millimetres during the years in which such rainfall occurs; it is also necessary that customers be willing to adapt themselves to the enormous variation between 640 and 1,578 millimetres. As such conditions will generally be impossible, and as, on the contrary, it will usually be necessary to assume the consumption as constant, one of the two following cases must obtain; either the reservoirs must have sufficient volume to assure the average flow at any time, or else thermal aid will be necessary.

It is well known that the volume of the necessary reservoirs increases with the widening of the required regulation, *i.e.*, from a *daily* regulation (to shift from night to day the consumption of the available flow) to a *weekly* regulation (to use the Sunday flow during working days), and finally to a *yearly* regulation (to make up for the ordinary shortage of water during summer or winter), and yet higher to a *decennial* or even to a *secular* regulation, to take precautions for extraordinary droughts.

Now, it is out of the question for us to build in our Alps reservoirs sufficient to regulate the average flow for a long period of years; on the contrary, it is often difficult to regulate the flow within the modest limits of twelve months, and therefore, in spite of the reservoirs, one must frequently allow for there still being an excess of summer energy. It is probably easier to attain that result in the Apennines on account of their different geological nature; but there, the usefulness of artificial reservoirs is considerably smaller, because such reservoirs are at moderate heights, and therefore allow only small falls.

Nor is it wise to harbour too many illusions as to the possibility of integrating the hydraulic deficiencies of one watershed with the surplus of another, located at a certain distance from the former. First of all, the balance between watersheds of the same type, as for instance that of two Alpine watersheds, is almost impossible because the meteorological phenomena are only slightly different,

even over very vast expanses of land. Another apparently very appealing idea has for some years been quite successful in Italy, namely, the compensation of Alpine deficiencies (which exclusively occur in winter) with the simultaneous surplus of the Apennines, where the low water period should be during summer. But experience has shown that it is not possible to rely on the northern Apennines, because not even their winter regime has the relatively constant character which alone would allow the compensation to be brought from the field of ideas to the field of industrial facts.

Therefore, there is no other choice, if all possible advantages are to be taken of the resources of our Alps, than to resort to the steam plant.

In conclusion, we may say that when an electrical company decides to dispose of, say, a thousand million kilowatt-hours as a yearly average, even if the plants be provided with reservoirs, these reservoirs will either have such a large volume in order to guarantee the average for a very long period of years, or else, if the volume of the reservoirs be only sufficient for the yearly regulation, the company will undoubtedly have to make use of thermal stations.

In the latter case, which in our country can be considered as normal, the capacity of the thermal station and its output can be considered in proportion to the complete difference between the year of minimum and the year of maximum rainfall, and in such a way complete advantage will be taken of the watershed. But it is clear that if the thermal station is only to provide for the integration of hydraulic deficiencies up to their *average* value, all the excess during the years of abundance will be disposed of only with difficulty.

II. THE FUNCTION OF RESERVE.

Having thus examined the integrating function performed by thermal stations in a system which is really to solve a duty of national importance, a great deal more could be said of other advantages that thermal stations might bring to this service.

Briefly, I would point out the function of reserve that the thermal station may perform in order to guarantee the continuity of the service, in spite of the accidents to which, unfortunately, hydro-electric power plants are subject.

It is not necessary to mention the recent disaster of Gleno (Dec. 2nd, 1923), caused by the failure of a multiple arch dam, as in this case the reason was very likely due to negligence during construction. I would rather mention the other causes, unfortunately frequent ones, which during recent years have put out of service for

periods varying from one week to several months, some important Italian hydro-electric plants.

Appendix B* shows that such cases of interruption rather frequently affect whole hydro-electric plants. Thus, it follows that a company, making use of only one or two hydraulic stations, cannot give the necessary reliability to the service. And if the system supplies important public services, as, for instance, the service of railway traction, the guarantee of a thermal station, of sufficient proportions, will generally be deemed necessary.

SULLA COESISTENZA DI CENTRALI GENERATRICI IDRAULICHE E TERMICHE CON SPECIALE RIGUARDO ALL'ECONOMIA DELLA PRODUZIONE E ALLA NECESSITA' DELL'INTEGRAZIONE E DELLA RISERVA.

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1°. LA FUNZIONE INTEGRATRICE DELLE DEFICIENZE IDROELETTRICHE.

La distribuzione di energia elettrica ha da tempo acquistato in tutti i paesi civili il carattere di un servizio pubblico di importanza appena inferiore alla provvista di acqua potabile nelle grandi metropoli. Questo carattere è particolarmente marcato nei paesi poveri o privi di carbone, dove, a motivo di tale deficienza, le industrie manifatturiere sono state indotte, per la quasi totalità, a sostituire le motrici termiche coi motori elettrici (talchè è proprio il caso di dire che qui la energia elettrica costituisce il pane delle industrie) e dove, anche in altri campi, il posto conquistato dall'elettricità è diventato tale da farne considerare il consumo come uno dei più significativi indici del progresso nazionale.

Sono in queste condizioni, fra altri paesi europei, la Svizzera e l'Italia, entrambi dotati di grandi quantitativi di energia idraulica. In questi paesi dunque, più che altrove, la distribuzione di energia elettrica deve avere lo scopo di *mettere a disposizione del pubblico la maggior quantità possibile di energia elettrica al minor prezzo possibile.*

Non sempre però il costo unitario dell'energia idraulica ottenibile da un determinato bacino imbrifero diminuisce quando se ne spinga al massimo lo sfruttamento. Anzi frequentemente è accaduto, ed è facilmente dimostrabile il contrario; e cioè che, limitando lo sfruttamento si ottiene energia a miglior mercato. Di qui un contrasto che ha avuto qualche importanza, destando perfino preoccupazioni eccessive negli uomini politici, fino a quando le imprese elettriche poterono costituire il campo d'azione di un patrimonio individuale; ma che cessò di esistere quando i capitali da immobilizzare crebbero a tal punto da esigere lo sforzo di potenti società anonime.

Anche in questo campo la Società Anonima si è dimostrata strumento di progresso. L'obiettività e la larghezza di vedute che essa consente ai dirigenti, ben maggiore di quella che si può pretendere dal privato che gestisca esclusivamente capitali proprii, ha permesso di mettere al primo piano, cioè di considerare come la variabile indipendente dal problema, *la quantità di*

*See page 249.

energia da produrre, cosicchè il secondo elemento, *il costo di produzione*, è passato in seconda linea, diventando una funzione della variabile. Da quel giorno l'obbligo dei tecnici e degli industriali fu quello di risolvere il problema in modo che a ciascuno dei valori crescenti della variabile indipendente (*consumo*) corrisponda il minimo valore della funzione (*prezzo*).

Non vorrei essere frainteso; non è già che si possa, nè, peggio, che io sproni a produrre energia idroelettrica *a qualunque prezzo*; questa sarebbe una assurdità economica inattuabile. Voglio soltanto dire che, entro i limiti della convenienza economica in confronto con la produzione a vapore, la diminuzione del costo di produzione idraulica ha perduto molta parte della sua importanza. Ora, astraendo dai perfezionamenti tecnici delle turbine a vapore il costo della elettricità prodotta termicamente è aumentato nel postguerra in misura forse maggiore, non certo inferiore, al costo del'energia idroelettrica; d'altro lato nemmeno gli accennati perfezionamenti, ancora in via di esperimento, potrebbero tener testa ai pregi caratteristici degli impianti idraulici, primi fra tutti la semplicità dei macchinari, e la piccolezza delle quote necessarie per l'ammortamento effettivo del capitale immobilizzato; sicché c'è ancora un largo margine da sfruttare, anche non contando le ragioni di indipendenza economica dall'estero che militano potentemente a favore degli impianti idroelettrici.

D'altra parte, in molti casi il sussidio della produzione termica durante la magra può contribuire alla diminuzione del costo medio; perchè consente una maggior utilizzazione del bacino. Infine non è vero che le nostre risorse idrauliche siano ormai impoverite degli impianti più importanti e più economici. E' questa una leggenda molto creduta da chi non conosce a fondo la materia, e che ha per risultato (non oso dire lo scopo) di dipingere coi foschi colori dell'accaparratore le imprese elettriche italiane. Si dice e si ripete infatti che il monopolio di queste imprese, già per sè stesso poco simpatico, è ancora più gravoso, appunto perchè le società esistenti hanno scremato tutto il patrimonio idraulico della nazione, lasciando per il futuro, e quindi per l'eventuale concorrenza, solamente pochi impianti e costosi.

Nulla di meno esatto, tanto per la quantità dell'energia ancora producibile idraulicamente nelle Alpi, quanto per il costo unitario relativo.

Per la quantità, pur mancando di valutazioni dettagliate, le stime dei competenti fanno ritenere che si possano certamente creare nelle Alpi italiane entro i nuovi confini, nuovi impianti per oltre due milioni di kilowatt (si tenga conto che appena poco più di un milione sono quelli generati ora).

E quanto al prezzo, sono attualmente in costruzione ed in progetto grandiosi impianti, i quali pur prevedendo la creazione di serbatoi artificiali daranno il kilowattora a un costo capitale non superiore a 50 o 60 centesimi della lira attuale. Queste cifre equivalgono al quarto o al quinto dell'anteguerra, data la svalutazione della lira rispetto all'oro; esse dimostrano perciò in modo indiscutibile che la residua ricchezza idraulica italiana non ha affatto un pregio intrinseco inferiore a quella già sfruttata. Il clamore dei politicanti e i timori delle anime innocenti non hanno dunque ragione di essere, almeno per molti anni ancora; e il così detto monopolio (che poi sarebbe un *polipolio* immenso, vista la molteplicità delle aziende indipendenti che esercitano l'industria elettrica) può ben essere accettato, dal momento che esiste dovunque e da noi ha costantemente permesso al paese di fornirsi di energia a prezzi che sono relativamente fra i più bassi del mondo.

Ecco dunque le ragioni per cui l'obiettivo delle grandi intraprese elettriche è diventato quello di sfruttare al massimo le nostre energie idrauliche, le quali per conseguenza devono essere accuratamente studiate e metodicamente sviluppate.

Il legislatore italiano, quando nel 1919 fissò il principio di preferire fra molte quella domanda di concessione che raggiungesse la più vasta e razionale utilizzazione di un determinato bacino imbrifero, ha voluto rendere omaggio al carattere ed agli scopi della industria elettrica nella vita nazionale.

Ma gli uomini dell'arte si trovarono tosto di fronte a due elementi contradditori che complicano il problema. Da un lato l'estrema variabilità delle precipitazioni, ergo delle disponibilità idrauliche, le quali non tollerano finora l'intervento della volontà umana; dall'altra, per contrasto, una quasi assoluta permanenza nella legge che regola il consumo di energia elettrica.

Industrialmente parlando, le precipitazioni atmosferiche ed il regime che ne consegue per i corsi d'acqua italiani, non potrebbero essere meno adatte a fondarvi sopra un'industria così importante, come la produzione e vendita di energia, specialmente per le vallate prive di ghiacciai.

Mentre infatti nelle nostre Alpi la variazione della portata segue grossolanamente la curva sinusoidale della temperatura media, vale a dire è massima nel periodo estivo e minima nell'invernale, negli Appennini settentrionali il regime idrologico è così capriccioso, da riuscire sorprendente per chi non pensi alla stravagante capricciosità delle precipitazioni.

Una recente pubblicazione dell'Osservatorio Astronomico di Milano dimostra questa verità fino all'evidenza. Dalle cifre relative ad una serie di 157 anni — dal 1764 al 1920— risulta che le precipitazioni verificatesi nello stesso mese dei diversi anni presentano dei massimi altissimi tutti poco diversi da un mese all'altro (376 e 208) mentre invece il minimo è praticamente zero in tutti i mesi (vedi allegato). Soltanto nella precipitazione annuale c'è una relativa costanza, per quanto anche qui si riscontrino, rispetto alla media di circa 1000 millimetri annui, delle notevoli oscillazioni in più ed in meno.

In tali condizioni di cose tutto si comprende e tutto si spiega.

Si comprende da un lato che i torrenti appenninici non si prestino assolutamente alla creazione di energia elettrica adatta al fabbisogno nazionale, senza ricorrere a qualche espediente, che integri le deficienze nei periodi di siccità (questo è assolutamente *necessario*) e possibilmente risparmi e conservi l'eccedenza di precipitazione nei periodi di abbondanza (questo può soltanto essere *utile*).

Poichè i periodi di siccità negli Appennini settentrionali si verificano più sensibilmente nei mesi estivi, nei quali invece i fiumi alpini sono gonfi d'acqua per lo scioglimento dei ghiacciai, l'integrazione delle deficienze nord appenniniche si sta facendo da qualche anno mediante collegamenti elettrici con gli impianti alpini. Ma ci sono anche deficienze invernali, e qualche volta gravi, e queste non si possono fronteggiare che con i serbatoi o con le centrali termiche.

D'altro lato si comprende che neanche gli impianti idroelettrici alpini possano dare quella produzione costante che sarebbe desiderata dalle imprese elettriche ed è necessaria a fronteggiare il consumo. Anzi per gli impianti alpini si è certi a priori del contrario, perchè mentre il consumo è maggiore d'inverno che d'estate (stimo inutile dirne le ragioni, ovvie per i competenti ai quali queste poche osservazioni sono dirette) la disponibilità idraulica

segue una legge esattamente antipodica. Dunque, anche per gli impianti alpini c'è un problema di integrazione annuale causato dalla deficienza nella produzione invernale; ed a questa si è pensato far fronte coi serbatoi.

Ma se veramente si vuole sfruttare la disponibilità media idraulica delle nostre vallate, non possono bastare i serbatoi. Riprendiamo le cifre della precipitazione media annuale di Milano, perchè si prestano utilmente ad esemplificare, e perciò a chiarire le idee.

Volendo in un determinato bacino utilizzare completamente 1000 millimetri di precipitazione media, non basta che gli impianti generatori siano in grado di sfruttare completamente la precipitazione massima di 1578 millimetri negli anni in cui si manifesta, ma occorre che i compratori di energia elettrica si adattino alla enorme oscillazione fra 640 e 1578 millimetri. Non essendo possibile generalizzare tale ipotesi, e dovendo ammettere invece che il consumo sia almeno costante, delle due l'una: o i serbatoi abbiano un volume sufficiente ad assicurare in ogni tempo la portata media; oppure si ricorra alla integrazione termica. Ora è notorio che il volume del serbatoio occorrente cresce con l'ampliarsi della regolazione desiderata; vale a dire passando dalla regolazione *diurna* (per differire dalla notte al giorno il consumo della portata disponibile) alla *settimanale* (per utilizzare nei giorni feriali la disponibilità idraulica della domenica) e poi alla *annuale* (per sopperire alle magre ordinarie jemali o estive) alle *decennali*, e più su fino alle *secolari* (per fronteggiare le straordinarie siccità).

Ebbene, si può escludere senz'altro che nelle nostre Alpi sia possibile creare serbatoi capaci di regolare la portata media per un lungo periodo di anni; anzi è spesso difficile regolare la portata entro i modesti confini di 12 mesi, e si deve perciò frequentemente tollerare che ad onta del serbatoio vi sia eccedenza di energia estiva. Quel risultato è forse più facilmentè raggiungibile negli Appennini, per la loro diversa natura geologica; ma quivi l'utilità degli invasi artificiali è molto minore, perchè essi si trovano ad altitudini modeste e perciò ammettono a valle piccole cadute.

Neanche si possono coltivare eccessive illusioni sulla possibilità di integrare le deficienze idrologiche di un bacino con le esuberanze di un altro più o meno lontano. Già la compensazione è assai improbabile, si può dire impossibile, fra bacini dello stesso tipo, ad esempio fra due bacini alpini, perchè le vicende meteorologiche sono poco dissimili anche sopra zone molto vaste. Ecco perchè in Italia ha avuto fortuna per qualche anno una diversa idea, in apparenza molto seducente: voglio dire la compensazione delle deficienze alpine, esclusivamente invernali, con le simultanee esuberanze degli Appennini i quali dovrebbero avere magre estive. Ma l'esperienza ha mostrato che sugli Appennini settentrionali non si può fare assegnamento di sorta, perchè neanche il regime idrologico invernale ha quel carattere di costanza, sia pure relativa, che solo potrebbe permettere di trasportare la compensazione dal campo delle idee a quello dei fatti industriali.

Non c'è dunque altra via da scegliere, se si vogliono sfruttare al massimo le disponibilità idrauliche alpine, rendendole atte alle vendita, che ricorrere alla centrale termica.

In riassunto, quando una impresa elettrica annuncia di disporre per es., di un miliardo di kilowattore *in media* all'anno, anche se gli impianti relativi sono muniti di serbatoi, delle due l'una: o questi serbatoi hanno un volume così grande *da garantire* la media anche in un lunghissimo periodo di anni,

oppure, se il volume dei serbatoi sia appena sufficiente alla regolazione annuale, quella impresa deve necessariamente disporre di centrali termiche.

In quest'ultimo caso, che è si può dire la norma da noi, la potenza della centrale termica e la sua produzione possono proporzionarsi alla intera differenza fra l'anno di minima e l'anno di massima precipitazione, nel quale modo si realizza lo sfruttamento completo del bacino imbrifero ; ma è manifesto che se la centrale termica provvedesse solamente alla integrazione delle deficienze idrologiche fino al loro valore *medio*, tutta l'eccedenza negli anni di abbondanza, non potrebbe trovare che difficile collocamento.

II°. LA FUNZIONE DI RISERVA.

Così esaminata a grandi linee la funzione *integrativa* delle centrali termiche *in un sistema che si proponga di assolvere ad un compito di portata veramente nazionale*, molte cose resterebbero a dire circa i vantaggi che le centrali termiche arrecherebbero al servizio.

Non credo necessario dilungarmi. Basterà accennare per tutti alla funzione di riserva che la centrale termica può disimpegnare per garantire la continuità contro gli accidenti ai quali pur troppo vanno soggetti gli impianti generatori idroelettrici.

Non voglio soffermarmi al recente disastro del Gleno (2 Dicembre 1923) causato dalla rottura di una diga ad archi multipli, perchè il fatto è con ogni probabilità imputabile a negligenza costruttiva. Alludo invece alle altre cause, purtroppo frequenti, che nel corso degli ultimi anni misero fuori servizio per periodi variabili fra una settimana e parecchi mesi, alcuni importanti impianti idroelettrici italiani.

L'allegato B dimostra che simili casi di sospensione di funzionamento di interi impianti idroelettrici sono piuttosto frequenti. Ne deriva che una azienda la quale disponga di una o due centrali idrauliche non può dare al servizio quel grado di sicurezza che sarebbe necessario. Quando poi la rete alimenti importanti servizi pubblici quali ad esempio la trazione elettrica ferroviaria, si ritiene indispensabile dai più la garanzia di una centrale termica sufficientemente proporzionata.

ALLEGATO A.
(APPENDIX A)
MILANO-PERIODO 1764–1920.
PIOGGIE MENSILI E ANNUALI.

MESI.	Valore.		
	massimo.	minimo.	medio.
Gennaio	208	0	61,2
Febbraio	261	0	58,6
Marzo	264	0	71,6
Aprile	282	0,4	88
Maggio	339	13,5	101
Giugno	270	2,9	82
Luglio	233	0	72,4
Agosto	338	2,4	80,7
Settembre	343	0	88,6
Ottobre	376	4,8	122
Novembre	349	5,6	109
Dicembre	323	0	77
Anno	1578	639,4	1010

ALLEGATO B.
(APPENDIX B)

ELENCO DI ALCUNE SOSPENSIONI VERIFICATESI IN IMPIANTI DI PRODUZIONE IDROELETTRICA.

Data di inizio.	Nome dell'impianto.	Corso d'acqua utilizzato.	Causa della sospensione	Durata della sospensione
21 Agosto, 1911	Grossotto	Adda	alluvione; rottura del canale	53 giorni
9 Gennaio 1919	Piedimulera	Anza	frana del bacino di carico	22 giorni
5 Febbraio 1919	Pont S. Martin	Lys	rottura tubazione forzata	18 mesi
27 Sett. 1919	Piedimulera	Anza	allagamento della centrale	20 giorni
26 Ottobre 1919	Calusco	Adda	frana del canale	10 mesi
22 Sett. 1920	Varzo	Diveria	frana del canale	2 mesi
10 Aprile 1921	Selvanizza	Cedra-Enza	franamento della camera di carico	8 mesi
13 Gennaio 1923	Grossotto	Adda	rottura della tubazione forzata	parziale di 4 mesi
4 Maggio 1923	Cedegolo	Poglia	rottura della tubazione forzata	totale di 20 giorni—parziale di 5 mesi
18 Maggio 1923	Villadossola	Ovesca	riparazione generale del canale	3 mesi
5 Luglio 1923	Rivasco	Toce	rottura della tubazione forzata	26 giorni
? Agosto 1923	Temù	Lago d'Avio	infiltrazione nella galleria	10 giorni
19 Agosto 1923	S. Damiano	Maira	rottura saracinesca sulla tubazione forzata	62 giorni
1 Dicembre 1923	Gleno	Povo	rottura della diga del serbatoio di stagione	fermo dal 1 Dicembre
23 Dicembre 1923	Roasco	Roasco	frana del canale	29 giorni
25 Gennaio 1924	Piedimulera	Anza	frana del canale	oltre un mese

RÉSUMÉ.

Le service de la distribution de l'énergie électrique a pour but de mettre à la disposition du public la plus grande quantité possible d'énergie au plus bas prix possible. A cette fonction ont paru particulièrement adaptées les sociétés anonymes, en raison de l'ampleur des moyens dont elles peuvent disposer.

Au fur et à mesure de l'augmentation de la consommation, elles doivent y pourvoir par de nouvelles centrales, en choisissant les plus économiques parmi les nombreuses installations qui sont encore possibles, et en suivant le critérium de l'exploitation intégrale des cours d'eau.

Mais, à cause de la très grande irrégularité des précipitations atmosphériques, on ne peut obtenir l'exploitation complète des ressources hydrauliques qu'en ayant recours à des expédients pouvant suppléer aux insuffisances des périodes de sécheresse.

Les interconnexions électriques entre des bassins ayant des caractéristiques différentes et la création de réservoirs n'arrivent qu'en partie à résoudre le problème. Aux insuffisances de l'énergie des Apennins qui ont lieu en été, on peut suppléer par l'excédant d'énergie des Alpes qui se produit dans la même saison. Mais pendant l'hiver les fleuves des Apennins ne peuvent apporter qu'un secours sans importance aux manques des fleuves des Alpes.

D'ailleurs, il n'est pas possible en général de construire sur les Alpes des réservoirs capables de régler la portée moyenne pendant plusieurs années, ce qui serait nécessaire pour exploiter complètement les précipitations, lesquelles révèlent de très grandes variations dans les valeurs mensuelles et montrent, même dans les valeurs annuelles, des écarts très remarquables par rapport à cette constance que l'on trouve seulement dans les moyennes décennales ou séculaires.

Pour se garantir de ces variations et assurer un service satisfaisant, il devient indispensable de recourir à la centrale thermique, dont la puissance doit être proportionnée à la valeur maximum des dites variations et non à leur valeur moyenne.

En plus de la fonction de suppléer aux insuffisances hydrauliques, la centrale thermique a une autre fonction non moins importante ; celle de réserve proprement dite contre les interruptions de service auxquelles sont inévitablement exposées les installations hydroélectriques, par suite des imperfections de tout ouvrage humain ou des surprises de la nature.

En conclusion, dans le but d'intégrer les manques d'énergie hydraulique, comme d'assurer le fonctionnement d'importants services d'intérêt public, la centrale thermique est, même en Italie, un complément nécessaire de toute grande distribution d'énergie électrique.

LE PROJET D'UTILISATION DU DNIEPRE

PROF. I. ALEXANDROW

Les conditions naturelles excessivement avantageuses de la Russie méridionale, forment une base pour sa transformation, non seulement en un des centres principaux de la vie industrielle du pays, mais aussi en un centre agricole très important. Les richesses minières, situées dans sa partie Est et centrale, les grandes ressources d' énergie hydraulique et la possibilité de son utilisation pour l'amélioration de terrains très étendus, présentent des éléments dont l'exploitation combinée, peut transformer cette partie du territoire énorme de l'Union des Républiques des Soviets en une des régions les plus florissantes du monde entier.

D'après les données de 1920, les réserves de houille dans le bassin du Donetz sont évaluées à 59.613.000,000 de tonnes, dont 35.613.000.000 de tonnes réelles et 24.000.000.000 de tonnes probables. 32 pour cent de ces réserves se rapportent aux charbons et 68 pour cent aux anthracites.

Les réserves de minerais de fer se partagent comme suit : le Krivoï-Rog au nombre de 261.000.000 de tonnes (Fe—42—62 pour cent), de Kertsch—900.000.000 de tonnes (Fe—34—42 pour cent) Korsak-Moguila—0,326 million de tonnes (Fe—66,3—67,4 pour cent) et du bassin du Donetz—0,360 million de tonnes (Fe—35—40 pour cent).

Les dernières recherches démontrent la probabilité de réserves beaucoup plus grandes au Krivoï-Rog (jusqu'à 650.000.000 de tonnes avec une contenance de fer supérieure à 50 pour cent et jusqu'à 26.229.000.000 de tonnes avec une contenance de 25 à 50 pour cent). Les réserves de Kertsch d'aprés les nouvelles données, sont estimées à environ 7.000.000.000 de tonnes. On a aussi des données précises relatives aux réserves de minerais de fer dans la région de Korsak-Moguila—Orechow. Les réserves de manganèse près de Nicopol sont évaluées à 50.000.000 de tonnes.

La présence dans cette région de spath-fluors et d'une série de matériaux de construction, offre toutes les conditions nécessaires pour e développement d'une grosse industrie minière et métallurgique.

Déjà avant la guerre cette région était reconnue comme un centre industriel important. L'extraction de charbon a atteint son maximum en 1916 (environ 30.000.000 de tonnes). La métallurgie de la région a donné en 1905 plus de 3.000.000 de tonnes de fonte.

La présence d'un réseau de chemins de fer très développé, l'apparition d'une série d'usines métallurgiques et de constructions métalliques, chimiques, d'aciéries, de verreries, etc., montrent que le capital privé a tenu compte des conditions favorables de cette région, en plaçant plusieurs centaines de millions de roubles dans ces entreprises industrielles.

La nationalisation de l'industrie, en écartant tous les inconvénients du système capitaliste, offre au pays de nouvelles perspectives de développer l'industrie rationnellement. Le Gouvernement des Soviets, quoique étant encore dans une période de situation économique très difficile, a mis à l'ordre du jour l'étude des mesures les plus rationnelles pour l'exploitation des richesses naturelles du pays, en combinaison avec les possibilités qui résultent du nouvel ordre social, et en mettant à la base de ces mesures l'application maximum de l'utilisation de l'énergie. Sous ce rapport la Russie méridionale présente les circonstances les plus favorables. L'extraction des différentes espèces de charbon laisse comme résidu une quantité considerable de déchets, sous forme de charbon menu, qui ne supporte pas économiquement un transport sur une plus ou moins grande distance. La présence de certaines espèces de charbon, dont la qualité souffre des mêmes défauts, mais qui peuvent être utilisées sur place représentent de grandes ressources pour la production de l'énergie électrique. Enfin les grandes ressources des forces hydrauliques du Dnièpre, dont la chute concentrée sur le parcours Ekatérinoslaw—Alexandrowsk permet de créer une source d'énergie en ne construisant qu'une grande usine hydro-électrique, dont la combinaison avec l'usine thermique, donne le moyen d'augmenter considérablement le degré d'utilisation de la première—telles sont les ressources d'énergie sur la base desquelles on peut reconstruire toute la vie économique de la Russie méridionale.

La construction de l'usine hydro-électrique est le centre des travaux, projetés dans ce but. Le bassin du Dnièpre, de sa source jusqu'à la mer Noire, présente d'après les données de certains auteurs, une surface de 510,534 km.^{2}, et même plus grande d'après d'autres. La précipitation varie sur son parcours (pour Smolensk—645,4 mm., pour Kherson—316,3 mm.). Le volume total des eaux de précipitation est estimé à 273,219 $\times 10^6$ mètres cub. La chute du

fleuve dans les différentes sections est : le Haut-Dnièpre—121,5 mètres, la Pripiate—70,4 mètres, la Desna—121,5 mètres et le Bas-Dniéper—91,8 mètres. La chute moyenne est évaluée à 196 mètres. Avec le coefficient d'écoulement de 0,35, ces donnée permettent d'obtenir une puissance totale du fleuve de 3,963,000 C.V.

La masse principale de cette puissance est concentrée entre Ekaterinoslaw et Alexandrowsk, où la chute est de 37 mètres, et l'endroit des deux barrages projetés, dont un est situé près de Nicopol (5,9 mètres) et l'autre près du village de Gornostaewka (7,2 mètres). La puissance théorique du Bas-Dnièpre est évaluée pour l'année moyenne à 2,020,000 C.V., et le rendement moyen annuel—13.000.000 kWh.

Le Dnièpre présente pour la navigation des conditions peu favorables ; le bief supérieur jusqu'à Ekaterinoslaw ne laisse circuler pendant l'étiage que des bateaux ayant un tirant d'eau inférieur à 1,07 mètres, dans les rapides la navigation n'existe presque pas, et sur la section Alexandrowsk—Kherson on peut admettre à l'étiage les bateaux ayant un tirant d'eau de 2 mètres. L'utilisation des forces hydrauliques du Dnièpre se combine avec l'amélioration des conditions de navigabilité et il s'agit de transformer la section Alexandrowsk—Kherson en une voie d'eau—accessible pour les bateaux de mer ayant un tirant d'eau de 4—4,5 mètres, et la voie de Briansk, de Pinsk et d'Orcha—en une bonne voie navigable pour les bateaux ayant un tirant d'eau de 2,2 mètres sur la section Pripiate—Kiew—Ekaterinoslaw et de 1,5 mètres sur le Haut-Dnièpre et sur la Desna.

La section Ekaterinoslaw—Alexandrowsk sera canalisée et à l'endroit de l'usine hydro-électrique un système d'écluses est à construire pour le passage des bateaux avec tirant d'eau jusqu'à 4,2 mètres.

La région des rapides du Dnièpre qui s'étend sur une distance de 90 km., traverse les embranchements des Carpathes et consiste de plusieurs groupes d'échelles, où le courant est serré entre les rives rocheuses.

Les observations hydrométriques, faites depuis 1877, permettent de déterminer le débit sur cette section, qui varie de 20,395 jusqu'à 195 mètres cubes par seconde. D'après ces données le débit moyen imnimum est de 1,265 mètres cub. avec l'écoulement annuel de 39.996.7 millions de mètres cubes.

Les changements les plus caractérisiques des débits sont indiqués ci-après :

	Maximum.	Minimum.	Moyen.
Débits maximum par an ...	20.395 met³/sec	2.749 met³/sec	7.847 met³/sec
„ moyens „ „ ...	2.942 „	1.010 „	1.632 „
„ minima „ „ ...	845 „	194 „	386 „

Le renouvellement des périodes annuelles dans le régime du fleuve est représenté sur le dessin (Figure 1).

Fig. 1.

La question de l'utilisation du Dnièpre avait déjà fait l'objet de projets différents établis par plusieurs ingénieurs. La solution de cette question consistait dans la construction de plusieurs barrages sur l'étendue de la section des rapides. En ce moment on achève, sous la direction de l'auteur de ce rapport et d'après sa proposition,

les études d'un seul barrage à l'aval des rapides avec une chute maximum de 36,83 mètres et une chute minimum de 30,83 mètres.

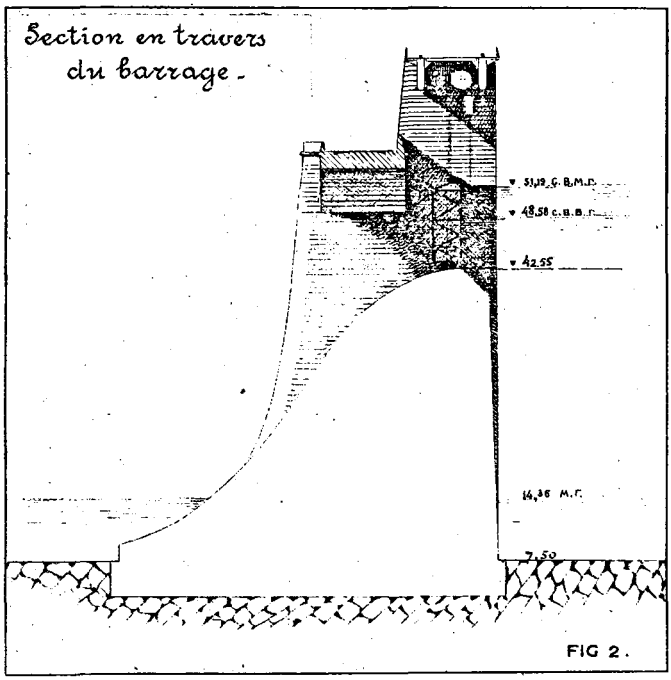

Fig. 2.

Le type de barrage choisi est représenté sur les Fig. 2 et 3 et il est caracterisé par les données suivantes :

1.	Côte de la crête de la partie massive du barrage ..	43,25	mèt.
2.	,, du niveau du bief supérieur pendant l'étiage	51,19	,,
3.	,, du niveau du bief supérieur pendant le débit maximum	48,58	,,
4.	,, du niveau du bief inférieur pendant l'étiage..	14,36	,,
5.	,, hauteur de vannes .. .. (utile—7,95 m.)	8,50	,,
6.	Nombre de travées du barrage	1 28	,,
7.	Ouverture d'une travée	24	,,
8.	,, totale du barrage	624	,,
9.	Longueur totale du barrage entre les parements de devant des culées	732	,,

La disposition générale des bâtiments projetés est indiquée sur la Fig. 4. Comme on peut en juger par le schéma, le barrage est situé sur une ligne droite qui traverse deux iles ; l'usine est située sur une rive du fleuve, les écluses—sur l'autre.

L'usine fait un angle de 145° avec l'axe du barrage et comprend 13 groupes électrogènes complets, de 50,000 H.P. chacun, ce qui donne une puissance totale de 650.000 H.P. sur l'arbre des turbines. Les alternateurs d'une puissance de 35.000 kW. doivent fournir le courant triphasé à la tension de 11.000 volts avec une fréquence de 50 périodes par seconde.

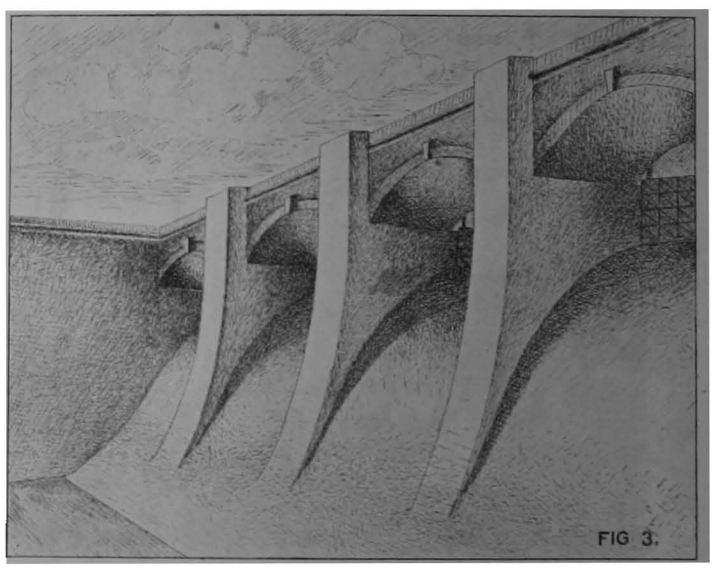

Fig. 3.

L'eau est amenée aux machines par des tuyaux de 5 mètres de diamètre, fermés par deux vannes, dont la première est placée à l'entrée, la deuxième à l'endroit de son passage dans l'appareil dirigeant du système Jonson. L'eau de la conduite d'amenée entre dans l'appareil de guidage hélicoïdal de la turbine système Francis, et ensuite dans le tuyau d'aspiration du type hydrocone du système Moody. La coupe en travers de l'usine hydro-électrique est représentée sur la Fig. 5. Dans un bâtiment spécial situé près de l'usine seront disposés les transformateurs et les interrupteurs de courant.

Les turbines sont calculées pour une chute de 36,83 mèt, leur vitesse est de 120 tours par minute et le rendement 0,90. Le coefficient de rapidité est admis à 292, le débit normal est de 113,1 met^3. sec. Le diamètre de la roue motrice est de 3,48 mèt., le diamètre de l'ouverture d'échappement est de 4,5 met., la hauteur de l'entrée dans la turbine est de 1,70 met., l'angle de l'appareil de guidage est de 22°30″, l'angle des aubes de la roue motrice est de 42°.

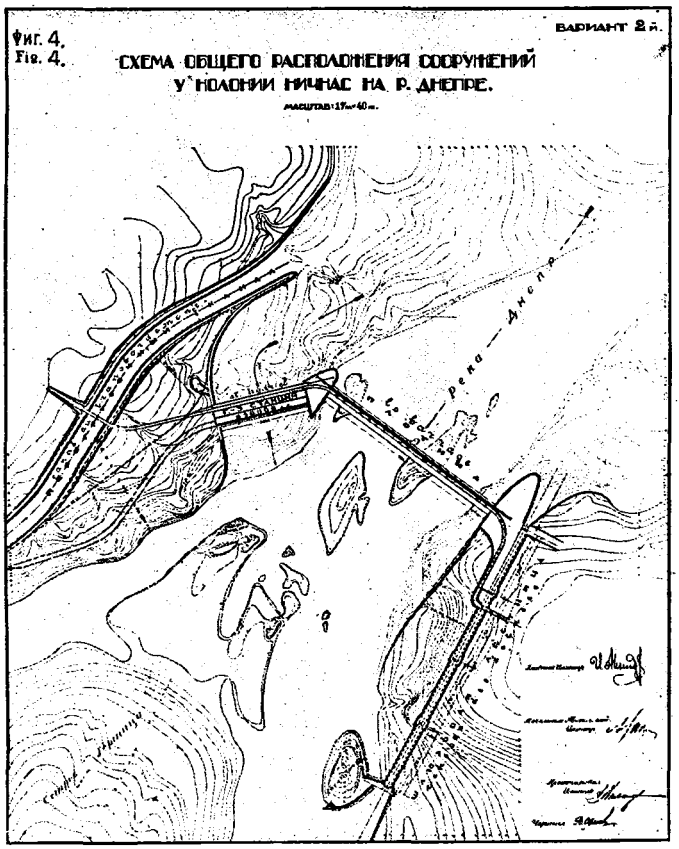

Fig. 4.

Schéma (2 ème variante) de la situation générale des ouvrages près de la colonie Kitschkas.

Echelle : 1 cm. = 40 m.

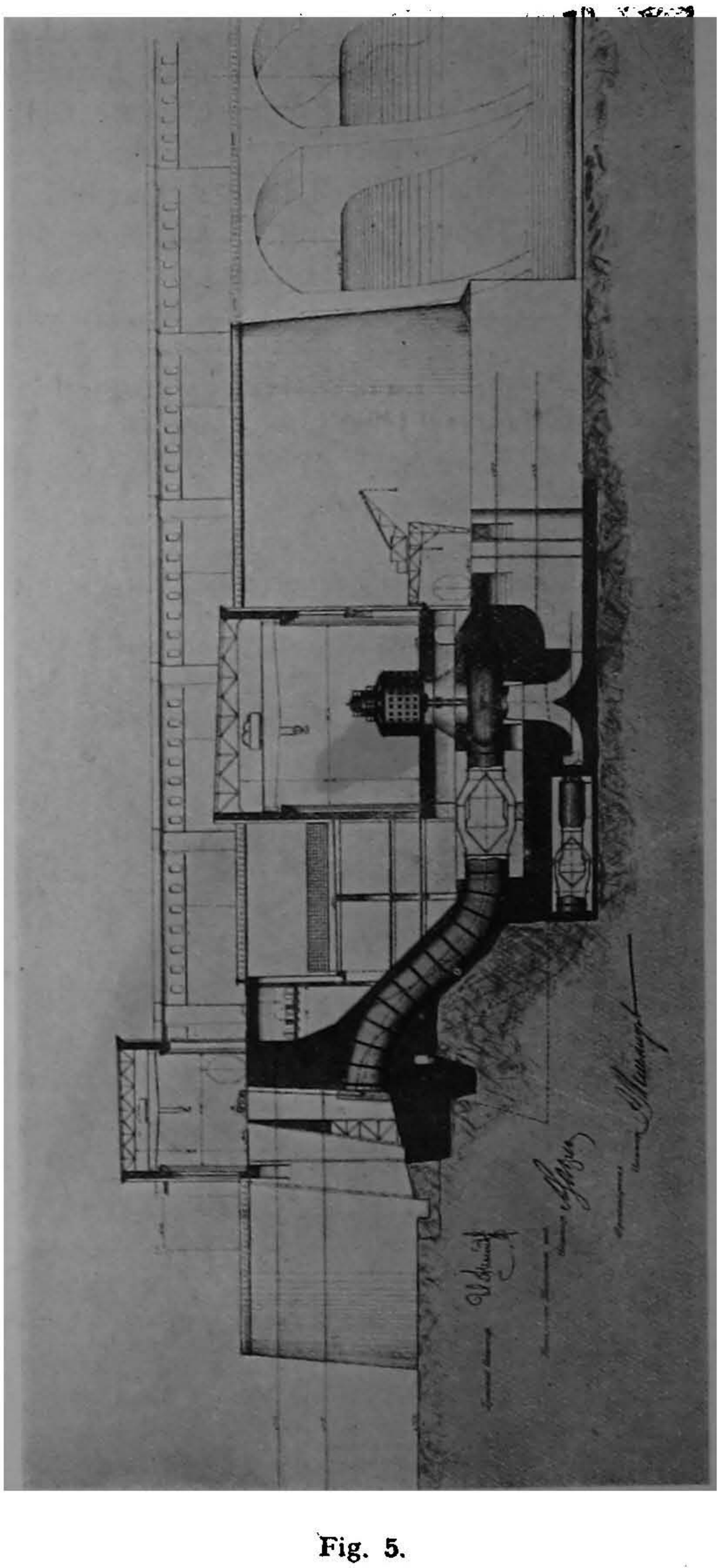

Fig. 5.

Projet préliminaire 2 ème variante de la station hydro-électrique de 650.000 H.P. R. Dnièpre de la colonie Kitschkas.

Echelle : 1 cm. = 2 m.

Comme la puissance de l'usine sera utilisée successivement l'installation des machines de la première série n'est projetée que pour une puissance de 300.000 H.P., tandis que les travaux hydrauliques seront exécutés pour la puissance totale prévue.

L'usine projetée doit donner une impulsion puissante à l'économie industrielle et commerciale de la région, d'après les calculs préalables les consommateurs principaux de l'énergie obtenue doivent être les centres industriels, comme par exemple ; Ekaterinoslaw, Nicopol, Krivoï-Rog, Alexandrowsk, etc. L'usine hydro-électrique sur le Dnièpre dans l'avenir travaillera parallèlement avec la station thermique, prévue dans la région de Grischino, elle pourra aussi fournir l'énergie dans la région de Kherson. La quantité d'énergie utilisée peut atteindre 2.000.000.000 kW./heures par an et dans la combinaison avec les stations thermiques—jusqu'à 2.300.000.000. kW./heures. Grâce à la construction de l'usine hydro-électrique et à l'établissement du barrage, la ville d'Alexandrowsk peut devenir un gros centre industriel.

La possibilité d'avoir l'énergie électrique à bon marché et la situation favorable de la ville entre les gisements de minerais de fer et les houillères permettent d'espérer la création, dans ses environs, d'une grande usine métallurgique. La construction de la ligne de chemins de fer Démourino—Alexandrowsk—Marganez rapproche le charbon de ce dernier point, surtout, si cette ligne est construite d'après le type de " super-magistrales." L'amélioration des conditions de navigation sur la section Ekaterinoslaw—Alexandrowsk donne les moyens pour l'organisation dans cette dernière ville, d'un point important de transbordement entre les biefs supérieur et inférieur du Dnièpre avec la concentration des scieries pour la préparation des bois descendant le fleuve. Le changement du Dnièpre inférieur en voie d'eau, accessible aux bateaux de mer, transformeront Alexandrowsk en un point d'embarquement sur ces bateaux des blés à exporter, des minerais et des charbons. La mécanisation des travaux de transbordement, ajoutée aux conditions naturelles favorables pour l'établissement du bassin supérieur près du port futur de cabotage, laissent croire, qu'il sera plus avantageux d'exécuter de cette manière la plus grande partie des manipulations liées au trafic et de limiter le passage direct des bateaux du bief supérieur au bief inférieur. Voilà pourquoi on prévoit des écluses capables de laisser passer seulement jusqu'à 15.000.000 de tonnes. Les données principales, relatives aux écluses projetées, sont indiquées ci-dessous :

Nombre de sas	4
Chute d'une écluse	9,2 mt.
Chute totale	36,8 ,,
Longueur utile d'un sas ..	235,5 ,,
Largeur utile d'un sas.. ..	17 ,,
Profondeur d'eau au busc ..	4,9 ,,

Pour desservir les manœuvres de transbordement on prévoit ; la construction du port fluvial dans le bief supérieur et d'un bassin à l'entrée de l'écluse du bief supérieur, l'agrandissement du port d'Alexandrowsk et la création d'un port dans le bief inférieur, près de la colonie de Kantzerowka et la construction du bassin à charbons dans la partie sud de l'île de Khortiza.

Eu égard à la nécessité de relier Krivoï-Rog au bassin du Donetz d'une façon efficace et plus intime, on prévoit la construction d'une nouvelle ligne de chemins de fer du type de " super-magistrale " avec une rampe de 0,006 et un rayon de courbe de 1.000 mètres. Cette magistrale permettera de diminuer considérablement le coût du transport des charbons aussi bien pour la future usine métallurgique que pour l'exportation.

Avec le programme prévu pour le développement de la métallurgie, le trafic calculé entre Krivoï-Rog et le bassin du Donetz peut dépasser dès le début, trois millions de tonnes par kilomètre de voie. La transformation indiquée plus haut du Dnièpre inférieur en une voie d'eau accessible aux bateaux de mer et la construction des barrages et des écluses près de la ville de Nicopol et du village Gornostaiewka permettront d'améliorer plus de 150.000 hectares de terrains marécageux par le procédé d'endiguement et de construction de canaux de dessèchement. De plus en élevant le niveau d'eau et en faisant l'irrigation artificielle, on peut irriguer jusqu'à 750.000 hectares de terrains sur la rive gauche du Dnièpre qui souffrent en ce moment de manque d'eau.

Comme suite à la canalisation du Dnièpre inférieur, on examine la question de l'amélioration du port de Kherson et de son outillage.

Le vaste projet de construction examiné ci-dessus, nécessitera certainement de grandes dépenses, mais en même temps il offre de larges perspectives pour le développement de toutes les branches de la vie économique du Sud de la Russie. Malgré la situation économique difficile de la Russie moderne, il n'y a pas de raison de douter que dans un avenir prochain, elle ne puisse commencer la réalisation de ces problèmes grandioses, même en ne comptant que sur ses propres moyens. La participation de capitaux étrangers, dans des

conditions acceptables pour la Russie des Soviets, permettra, certainement, de réaliser ces projets dans un délai plus rapproché.

Les calculs préalables du coût des travaux projetés en première ligne, d'après les prix d'avant guerre, donnent le montant de dépenses nécessaires :

Barrage et écluses	env.	33.000.000	roubles.
Usines hydro-électriques	,,	21.000.000	,,
Transport d'énergie	,,	8.000.000	,,
Acquisition des terrains, etc. ..	,,	6.000.000	,,
		68.000.000	roubles.
Chemin de fer Demourino-Marganèse		20.600.000	,,
Total		88.600.000	,,

Pour une durée d'exploitation de 6,000 heures par an de la première section de l'usine la quantité d'énergie électrique livrée peut être estimée à 1,200,000,000 de kW/heures et son prix à l'usine, en évaluant le montant de toutes les dépenses à 12 pour cent, du capital engagé, serait $\frac{60.000.000.000}{1.200.000.000}$ =0,5 kop. kW./heure, si on met le coût total du barrage et de l'acquisition sur le prix du courant électrique. Si les frais de l'installation du barrage et de l'acquisition sont affectés en partie à l'amélioration de la navigabilité, le prix de revient serait moins élevé. Le montant total des travaux d'exécution du projet complet est évalué comme suit :

Installation des machines pour la puissance complète de l'usine	30.000.000	roubles.
Canalisation du Dniepre inférieur.. ..	12.000.000	,,
Dragage	10.000.000	,,
Reconstruction du port d'Alexandrowsk..	15.000.000	,,
,, ,, ,, de Kherson ..	12.000.000	,,
Dessèchement des marais du Dniepre ..	40.000.000	,,
Irrigation de 600,000 hectares en élevant le niveau de l'eau..	150.000.000	,,

Si l'on tient compte de l'état des usines métallurgiques du Sud de la Russie et des besoins en fonte et en acier dans les prochaines années, on peut admettre que la construction de nouvelles usines métallurgiques modernes doit être mise à l'ordre du jour. En raison de la production de l'énergie à bas prix, ces usines devront appliquer largement l'énergie électrique pour la préparation de la fonte et des aciers. L'état de l'outillage des usines d'Ekaterinoslaw

réclame aussi de nouvelles dépenses pour le renouvellement des installations électriques. Tout porte à croire que la centrale hydro-électrique trouvera rapidement des consommateurs, les calculs préalables montrent que les besoins peuvent être estimés approximativement à :

Région d'Alexandrowsk (nouvelle usine métallurgique comprise)	60.000	H.P.
„ d'Ekaterinoslaw	40.000	„
„ de Krivoï-Rog	10.000	„
„ de Nicopol (nouvelle usine de ferro-manganèse comprise)	124.000	„
Electrification des chemins de fer	50.000	„
En tout ..	284.000	„
pertes ..	28.000	„
Total ..	312.000	H.P.

Ainsi on peut prévoir que la puissance de la première partie de l'usine sera utilisée dans l'espace de quelques années après l'achèvement de sa construction.

RÉSUMÉ.

The author, in the above report, reviews first the considerable natural resources of South Russia in coal and iron ore, mentioning at the same time its possibilities as an important agricultural centre. In 1916 South Russia produced 30,000,000 tons of coal and in 1905 its pig-iron production reached 3,000,000 tons. A well-developed railway system, several large steel works, chemical factories, etc., show that before the war a large amount of private capital was invested to further the development of that district.

Notwithstanding its present most difficult economic position, the Soviet Government has decided to develop the natural resources of the country and particularly the production and utilisation of electrical energy.

One of the most important schemes is the development of the large hydraulic power of the river Dnieper, whose total available power is estimated at about 4,000,000 H.P., at the same time its navigability, which is rather poor, would be considerably improved.

Many projects have been made from time to time, for the utilisation of the water power of the Dnieper, by means of a series of barrages to be erected in the stretch of the rapids ; the author is now completing the design of a single barrage for the rapids, which would give a maximum fall of 36·83 metres (120 ft. 6 in.) and a minimum fall of 30·83 metres (101 ft.) ; details of the barrage are given, and its design is shown in Figs. 2 and 3, the layout of the buildings in Fig. 4 and a section of the plant in Fig. 5.

A first section of the plant, consisting of 6 units of 50,000 H.P. each is first anticipated, the plant when completed to consist of 13 units of a total capacity

of 650,000 H.P. The power would be used in the industrial centres such as : Ekaterinoslaw, Nicopol, Krivoï-Rog, Alexandrowsk, etc., as well as for the electrification of the railways. Information is also given about the new lock to be erected at Alexandrowsk which would connect the upper Dnieper with the lower Dnieper. The latter would be navigable to sea-going vessels and Alexandrowsk would thus become an important export port for wheat, coal and iron. In addition, large tracts of lands could be drained and others irrigated, increasing the area available for cultivation. Some figures are given as to the cost of the barrage and the first section of the plant, for its completion, as well as for the improvement of the harbours of Alexandrowsk and Kkerson, the drainage of the Dnieper marshes, the irrigation of 600,000 hectares of land, etc. All the figures are based on pre-war prices. Mention is made of the fact that if it was possible to interest foreign capital, the scheme could be realised much more quickly than if the Soviet Government has to rely on its own financial resources.

SOME FEATURES OF MODERN HYDRO-ELECTRIC DEVELOPMENTS

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I.—THE GENERATION OF POWER

Among the essential factors which constitute a modern hydro-electric development, probably the most important are flexibility in all the elements to enable them to fulfil the requirements of the demand, and the fullest posible utilisation of the water power available. Hydraulic power is sought out, and projects are drafted, to attain these two ends as far as the natural conditions permit and, where they are adverse, supplementary works are carried out. For instance, the lack of natural reservoirs leads to the provision of at least daily storage by arranging lengths of horizontal canal, tunnels and canals under pressure, taking advantage of dips in the ground traversed by the canal to form lateral basins, increasing the size of the head-race as much as the conditions of the ground will allow, and similar measures all of which tend to augment the storage of water so that it can be drawn upon as required.

The dams of these installations should alter the course of the solid matter carried in suspension with the water utilised, as little as possible from its original direction. To this end, an unbroken wall should be avoided and sluices or means for emptying the basin rapidly must be provided, both in the case of high reservoir dams and in that of spillway dams. The diverse systems of automatic sluices which are being adopted in practice, and the modern types of balanced gates evolved by the Americans, provide great safety in this section of the work, which was somewhat precarious in the past, and they have filled a serious want.

It is not customary to pay enough attention to the removal of extraneous solid matter carried with the stream. This affects the working of a hydro-electric installation in a very marked degree and often occasions unsatisfactory running. In our

rivers, at altitudes less than 1,000 metres, we rarely have to combat ice in the winter which is the chief enemy in more northerly latitudes, but on the other hand we have to fight against the continual obstruction of the strainer racks with vegetable matter, which grows with incredible rapidity owing to certain favourable climatic conditions, and is carried down in quantities with the water, completely obstructing the racks and producing considerable water pressure. It is desirable that manufacturers should create practical and inexpensive types of movable racks to cope with these cases.

One problem which frequently occurs in the hydraulic section of hydro-electric engineering, is that of the tunnels or conduits under pressure running through solid rock, which have given surprisingly bad results and have attracted the attention of technical specialists. It will suffice to mention among others, the cracks in the aqueduct of Catskill cut in rock, working with a head of 350 feet,[1] and in that of Lake Ritom in Switzerland. As a result of examination,—tallying with my own experience, since I have suffered to some extent in the same way,—it would appear that the elasticity of the rock must be taken carefully into account when preparing the plans for similar work; for sometimes its compressibility is greater than shown by a superficial inspection, and as a consequence, longitudinal capillary cracks are produced as the lining gives way under the stress. Considering this problem theoretically, and assuming such conduits to have elastic walls of an indefinitely great thickness, leads, in my opinion, to results which are too optimistic and against which one has to take precautions.

Experience has established in a most conclusive manner the advantages of reinforced concrete for pressure pipe-lines. It results in saving in many cases and is easy to construct, being capable of withstanding water heads up to 100 metres if treated to make it impermeable. The cost of maintenance is less than with metal pipes, since with the latter, even when the water is pure, and if re-painting be not done frequently (which creates many difficulties in the operation of the plant), there is certain to be scaling and pocking which makes a margin of extra thickness indispensable when getting out the designs. It is possible to work spans up to 30 metres with straight metal lines of 2 metres

[1] Proc. American Soc. Civ. Eng. "Elastic Stresses in the rock surrounding pressure tunnels." April, 1923, and Discussion, August, 1923.

diameter and moderate thickness, without supplementary supports. This is an advantageous manner of dealing with cases where the hydraulic pressure necessitates a thickness of metal which approaches that required by the mechanical stresses.

The gates or sluices of penstocks are parts which require great care in operation. The usual sluice and butterfly types employed up to the present in large conduits are often unsuitable, and it is desirable to replace them with modern balanced types, simplified so that they are not too costly for plants of medium importance.

Modern hydro-electric developments are characterised by the ever-increasing output of the generators, which reaches 70,000 H.P. at the turbine shaft per unit, and 65,000 kVA. at the terminals of the generator in the latest installations at Niagara. This tendency, though fully justified in countries generously endowed with water power, as is the case with North America and Scandinavia, is not similarly applicable to Spain, where the natural conditions do not provide such concentrations of power. In countries like Spain, the natural resources should be developed in medium and even small falls, by means of units which are simple in their construction and automatic in their working, with long-distance gear to allow each section of a drainage area to be developed independently, and direct-coupled to one central station on completion. This would avoid having to carry out extravagant projects, difficult to prepare and launch upon the financial market, especially when the demand is not sufficient to absorb the full capacity of the power station when it is ready. Automatic sub-stations for electric-traction service, and some small experimental hydro-electric power stations in the United States, have shewn the possibility of obtaining an efficient service on these lines. The three-phase induction generator, in use for a long time past, and foretold by the famous Steinmetz, who pointed out its advantages (among them, the ease in coupling to the main lines), is peculiarly suited for such installations when the system can amply supply the wattless exciting current which they absorb.

Vertical shaft generating units are frequent in modern power-stations; their advantages from the mechanical point of view are unquestionable, the insecurity due to the bottom support having disappeared with the use of the thrust-bearing system with a film of oil. The angular speeds are increasing and the size of

the machines decreasing, hence, forced ventilation and lubrication are unavoidable. The increase of speed makes the problem of the mechanical strength under runaway conditions a most important consideration, since these may be taken as double the normal speed in modern types of turbines.

What should be the factor of mechanical safety for the overspeed of a set? Ought a runaway test to be specified at the maker's works? These questions become of special interest when dealing with generators for automatic power stations, where the lack of attendance makes cases of overspeed more likely to occur. It would be necessary to provide the turbines of such stations with an arrangement to close the gates when the increase of speed is caused by the interposition of extraneous material among them.

Forced ventilation is a complication in the installation of generators and in the layout of power stations. Further, it endangers the electrical insulation because it is not always possible to have the air as pure and dry as would be convenient, unless expensive filtering apparatus, which it is usual to do without, be provided. The dust adheres strongly to the insulation, making it brittle as well as decreasing its insulating properties.

The great impedances with which modern electric generators are provided, and the use of reactances in the connecting circuits, reduce the effects of instantaneous short-circuits to less than 5 times the normal current; none the less, the mechanical stresses to which the outside coils of the windings are subjected are severe. These parts of the machines even when properly arranged, *i.e.* with a solid wedging, have to withstand strong vibrations which weaken insulation in time. For this reason it is advisable to specify a test voltage for the complete winding which should not be less than three times the normal voltage between phases and a re-test should be made periodically during service especially after heavy short-circuits. In connection with this point one may ask what ought to be the margin of mechanical safety under short circuit, and whether the corresponding test should be specified to take place at the maker's works.

The safety of the service requires that it should not be sacrificed to efficiency when designing a generator. Its power in kVA. ought to be ample in relation to that of the prime mover, as well as its characteristic of magnetic saturation, so that under the most unfavourable working conditions a variation of

voltage can be obtained not less than 15 per cent. of the normal value. The protection of the generator against the incidents of operation must be provided at the terminals themselves Arrangements for checking the temperature of the different parts of the machine most exposed to heating are indispensable, since concentrations of heat which are not registered on thermometers placed on the surface must occur in the winding.

II.—TRANSMISSION

In this section I propose to deal only with overhead lines, suspended insulators, and the three-phase system.

It is the established practice with main transmission lines at potentials which exceed 80,000 volts, to make use of single towers supporting two circuits of three conductors, arranged in the form of an isosceles triangle and having one or two earth wires. Only lines of small importance, or at unusual voltages above 150,000 volts, are provided with single circuits. The double circuit on the same posts doubtless offers many advantages in operation but introduces certain restrictions regarding the arrangement of, and distances between, the conductors, and above all the first cost is markedly increased. The carrying load does not require to be large at the commencement of the operation, but future increase must be foreseen, especially in districts where one attempts to promote industrial development by electrification. My experience, dating from the beginning of the present century and based upon the successful achievement of many lines working up to 130,000 volts, confirms me in the belief that a single circuit line can operate to-day with unusual constancy, provided that a great factor of safety be adopted in its erection and in the design of its mechanical and electrical features. The single circuit line installed in the undertaking of the Catalana de Gas y Electricidad S.A. of Barcelona, being 225 kilometres in length and equipped for 130,000 volts at the supply end, transmitting power to the industrial region of Catalonia, has not given the slightest trouble during the five years which have elapsed since it was put into operation.

A support, flexible in the direction of the line, is highly to be recommended even for lines with rigid insulators, and much more so with suspension-type insulators where the lengths of the strings assist the flexion of the posts in relieving the strain of the conductors, and in balancing the stresses—without introducing

dangerous mechanical oscillations—in the stretch of line between two anchoring points where the load of all the conductors of a series of spans is totally or partially taken. These towers or flexible steel frames, can be designed so that their weight is in the neighbourhood of a ton for lines above 100,000 volts carrying 20,000 kW.

It is quite in accordance with this point of view to employ wooden poles for these extra high voltage lines, which the Americans, who have taught us so much about these matters, at present use up to 220,000 volts, but on the basis naturally of not taking the wood into account as an insulator, that is, avoiding all possibility of it becoming a path between one of the poles of the system and earth. Concerning the foundations of metal posts, the views of Europe differs from those of America in that it is not usual to omit the masonry or concrete setting, which I believe to be indispensable for stability and for conserving the tower foot by avoiding the rusting of the iron, which is very active in certain places, at the point where the legs of the structure are received. Both methods, with and without foundations, can be reconciled by joining the corner pieces of the support structures to reinforced concrete anchors, but this is complicated and does not procure much saving of cost.

The insulator adopted for main transmission lines, consisting of a single shell, cap and coupling, united or cemented to the porcelain, has given rise to not a few surprises and investigations, which in my opinion have not completely accounted for the phenomena or anomalies observed therein. I consider that the type has not yet been designed which means unreserved reliance in regard to its lasting dielectric stability, although one must recognise the great value of the investigations of J. J. Pick, Professor Ryan and others, in their researches in connection with the design of the 220,000 volt lines of the California Companies. Although progress has been made in accordance with the demands of the industry in the ceramics of the insulator, producing a porcelain which is compact, sufficiently homogeneous, and scarcely porous at all, by the successful application of microscopic analysis, one cannot see much advance in respect of shape. The type used to-day is identical with the one first used in the Ontario installation during the first decade of the century, save for a slight increase in the dimensions. On the contrary, there has been a retrograde tendency towards the use of the Hewlett

insulator with crossed loops, which had been abandoned, a tendency which appears mistaken in view of the unsatisfactory distribution of the electric field between each electrode.

With the modifications in detail brought about in the structure and execution of joints between the metallic parts and the porcelain and the scrupulous care taken in manufacture, types have been produced which are practically stable, although they have been under test but a little time as yet, not long enough to form a definite opinion as to their reliability. Unfortunately many circumstances come into play which are difficult to reproduce in the laboratory, and practical means do not exist for checking the state of each unit of a string of suspension insulators with any degree of accuracy. Furthermore, the theoretical distribution of the fall of potential, has not been throughout confirmed, since complete strings which are periodically dismounted for submitting their distinct units to tests, give erratic results when out of their working position, notwithstanding in operation those nearest to the conductor are subject to the greatest voltage.

I think that the string type of insulator ought to be modified so that the distribution of potential takes place more evenly in each unit, following the process of thought which determined the design of modern rigid insulators, provided with a huge mass of porcelain and surfaces adapted to the trajectories of the lines of force. The employment of metal shields, or other means for increasing the capacity of the last units of a string, and in general, anything which contributes to gradual distribution of the fall of potential between the conductor and earth, must be effective; and I would mention therefore the use of metal rings having a diameter somewhat greater than the shell on the outside units, a cheap device which I have employed with markedly good results. The solution of the problem will probably be found in entirely eliminating the use of jointing cement, a tendency which has commenced in Europe with the appearance of diverse types of suspension insulators, placed upon the market by various porcelain manufacturers.

The overhead earthed wire used in the majority of main transmission lines as a means of protection, has been the subject of much discussion, and its efficiency is doubted at the present time by many well-known electrical specialists, so much so, that in designing a line of this kind the question arises as to its adoption.

Opinions and even statistics exist which support all tendencies and prejudices, varying from attributing to the earthed wire so great an efficiency that its presence in a transmission line of 2,000 volts decreased the surges by 40 per cent.,[1] to believing that it constitutes an economic waste in lines on wooden posts and of doubtful advantage in all others.[2] The nature and the extent of this paper prevent me from going more deeply into this interesting question, and I must limit myself to giving a brief account of my own experience.

I used earthed wire for the first time in 1905 on a transmission line of 52,000 volts and 125 kilometres in length, which were unusual conditions at that period, so much so, that the reduced dimensions of the insulators which were at that time available from European manufacturers (about half those of types which would be used now) made me establish, as a precaution on that line, an earthed wire of four millimetres diameter, basing my selection upon data from American sources and the somewhat empirical ideas which were professed at that time.

The result was entirely satisfactory. The line, with insulators which would now seem insufficient to any expert, has operated successfully. Mechanically the earthed wire took up the stress, and electrically it appeared to protect the lines effectively, in spite of the fact that devices provided in the stations for protection, were rather deficient according to the technical requirements of power transmission at that time. Through the occurrence of an accident, I discovered for the first time the possibility of reaching dangerous potentials in those parts of a line imperfectly connected to earth (namely, the support and the earthed wire) a phenomenon later analysed theoretically and quantitively by various specialists, among them R. Rudenberg.[3]

I have since employed earthed wires in lines of many voltages either with steel or wooden poles, and finally in the one already mentioned of 130,000 volts and 225 kilometres, providing economical elastic structures in the direction of the line and ensuring its mechanical stability by means of the earthed wire. The result has always been so successful, that I am at the present time equipping a 22,000 volts wood pole line, with an earthed wire,

[1] W. Petersen: "Der Schutzwert von Blitzseilen." Elektrotechnische Zeitschrift. 1 Januar, 1914

[2] E. E. F. Creighton: "Questions on the Economic Value of the Overhead Ground Wire." Journal Am. Inst. E.E. January, 1922.

[3] "Elektriche Schaltvorgánge." Springer, Berlin, 1923, page 154.

where troubles due to atmospheric causes and peculiar to the system, are much more frequent than in other lines in the same district with higher working voltages. I believe therefore, the effects imputed to the earthed wire of increasing the capacity between the working lines and earth (limiting as a consequence surges of electrostatic origin, damping the travelling waves in the electro-magnetic field by its presence, etc., etc.), have been confirmed in operation, and therefore it is advantageous to provide this protective wire until it can be replaced by exposure to direct atmospheric strokes, this is a contingency repeatedly observed which must be taken into account when determining its situation on the pole, clearances and diameter.

In selecting the *working conductor*, aluminium is justified for high voltages, since the diameter is increased without affecting the cost and keeps the voltage below the critical corona voltage. Copper is better known, however, and is preferred in Europe when the conditions of power and voltage allow it to be used. Because of the corona effect mentioned, neither material is suitable for lines transmitting some 10,000 kilowatts with voltages above 100,000 in altitudes of 500 to 1,000 metres, if the diameter is less than 12 millimetres, least of all copper, owing to its greater specific section. This constitutes a disadvantage when branching off from the main lines to feeding points or stations of small load, without reducing the voltage at the tapping point. Bi-metallic (copper-clad) conductors have been proposed, but they are costly and lack the flexibility of a cable, which adds so much to the mechanical resistance of a suspended conductor stretched in line. It would be desirable for this reason to consider a tubular conductor, composed of a flexible steel core and a stranded outer conductor; this would have the advantage, from the electrical point of view, of reducing the skin effect, which has been calculated recently with practical application by H. B. Dwight.[1]

III.—TRANSFORMATION.

The transformer is the most important element in the transmission of power at extra high tension. By stepping the voltage up and down it makes an installation industrially economical; situated in what may be described as the most strategic points of the system, we find the disturbances concentrating upon it, and it serves as a buffer and protection between the different parts. Present day tendencies are directed towards

[1] Journal Am. I.E.E. March, 1922. August, 1923.

increasing capacities and dimensions. In American Plants, 22,000 kVA. (Niagara) have been reached with single-phase units; in Europe, 60,000 kVA. with a three-phase water-cooled unit, and 15,000 kVA. with a self-cooled unit.

The general type adopted to-day has concentric circular windings, reinforced coils at the beginning of the windings, coils held in position sometimes by means of springs, connections preferentially arranged star-delta, neutral point directly connected to earth, (sometimes through a resistance) conservator tank for the exclusions of air, and bushings with vegetable insulating materials or else oil of great viscosity as the principal dielectric element. In America, single-phase transformers grouped in banks to form three-phase units are frequently used, an arrangement providing great security when very high voltages are employed, but complicated, expensive and disadvantageous when compared with three-core transformers connected star-star, on account of the third harmonic derived from the variation of magnetic permeability of the iron sheets. In Europe, preference is given to the three-phase transformer with three cores, sometimes using the zig-zag connection (interconnected star) in one set of the windings, that is, connecting in series parts of the windings on distinct cores, an arrangement presenting many drawbacks which have rightly excluded it from American practice, although it increases the number of combinations of voltages obtainable. A happy innovation was introduced by the General Electric Company of America in the arrangement of the extra high tension windings of transformers built for systems working at 220,000 volts in California, in which they connected the feeding circuit at its middle point, splitting it up into two halves about two cores and joining both extremes above and below, to earth, by which a good distribution of potential is obtained between winding and core and one extra high tension terminal is dispensed with. This arrangement has latterly been applied in Europe to three-phase transformers of larger capacity.

From the operating point of view, one should make some observations about the modern type of transformer of large kVA. rating and very high tension. The separating walls between the cores constitute weak points in three-phase units; their complete elimination would be preferable even if this means increasing the size and detracting from the electrical qualities. The exclusion of wood for the purpose of supporting or wedging the winding, is also to be desired because it offers but little security

even when carefully treated. The artificial insulating materials manufactured of paper and bakelite under pressure, used on all sides to-day in different varieties, and endowed with special names by their producers, spring upon the users not a few surprises, and the failures found in them confirm the hypotheses either of pyro-electric causes, to which is attributed the perforation of solid dielectrics under voltage; or it may be thermic instability and electric conductivity produced by the want of homogeneity in the material, in certain parts of which thermic and electrical energy is accumulated by an effect analogous to the self-excitation of an electric generator, and thus the perforation is produced.[1] This suggests the disuse of materials of rigid structure in thick sheets, and the substitution of superimposed thin laminations with which it is possible to secure greater uniformity.

An essential element of the extra high tension transformer is the terminal bushing, where a very high fall of potential is concentrated in a small space. Both the kind called the condenser type and that using viscous oil have given good results in practice, although the former requires scrupulous care in manufacture to assure a regular distribution of the electrical field without concentrations of flux. The external regular variation of the gradient is a most essential condition, so that no corona effect may occur under working voltages, since, according to my own observation such an effect under the oil is not inoffensive but produces in time partial carbonisation of the oil, and one can see solid black particles adhering together in a fibrous form, deposited in places where the corona is produced and marking the lines of the electric field. Perhaps the nature of the surface of the terminal, and not only its form or mathematical distribution of the electric field, has a very marked influence in the formation of corona effects in accordance with the modern electronic theory of the nature of electricity, and the practical demonstration made with paints which diminish the ionisation tensions on the surfaces which they cover.[2] The experiments and researches of L. Dreyfus regarding the air, published recently,[3] help in the

[1] J. L. R. Hayden and C. P. Steinmetz: "Insulation Failure—A Pyro-Electric Effect." Electrical World. October 21, 1922.

[2] E. W. Wagner: "The Physical Nature of the Electrical Breakdown of Slide Dielectrics." Journal of the A.I.E.E. December, 1922.

[3] "Ueber den gesetzmässingen Zusammenhang zwischen der Glimmspannung in Luft und der Verteilung des elektrischen Feldes, bei beliebig geformten Elektroden." Bull. "Schweiz. Electrotechnischer Verein." No. 12, 1923.

investigation of these phenomena although they refer to the shape of electrodes and emissory surfaces.

The *oil for transformers* and extra high tension apparatus gives rise to not a few anxieties for the manager of a hydro-electric undertaking; since the technical data available do not supply him at the present time with any trustworthy guide which will help him to determine its condition on delivery or its state in operation, except the degree of humidity physically deduced from its dielectric strength. Without doubt, the question is a difficult one, since chemists do not agree regarding the composition which good transformer oil should have, and have not devised simple methods of test or analysis which can be applied practically. The physical tests are also quite misleading; the diversity of prescriptions, some contradictory, appearing in the official regulations bear witness to the rule-of-thumb methods which hold sway in this matter.

The test of the dielectric strength of an oil, simple to carry out with the practical means industrially employed at the present time, gives very variable results, depending as is well known upon many circumstances. Hayden and Eddy, who have carried out the most numerous and complete experiments regarding the dielectric strength of oils,[1] have found variations up to forty-eight per cent. between the extreme values of oil under the same test conditions. Friese[2] obtains results which reach 230 kV./cm., far beyond anything obtained in practice.

Various circumstances and principally the form of the electric field (shape of the electrodes), and perhaps the nature and degree of cleanliness of the surfaces, have a marked influence on the results of these tests for one and the same kind of oil. The microscope, used by many investigators, explains to some extent the diversity of results obtained as due to the formation, between the electrodes, of bridges made up of filamentous material with a greater dielectric constant, which is present in the form of impurities in the oil subjected to the electrical tests.[3]

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[1] "Three Thousand Tests on the Dielectric Strength of Oil." Journal Am.I.E.E. July, 1922.

[2] "Ueber Durchschlag-festigkeit von Isolieroelen." Wissenschaftliche Veroeffentlichungen aus dem Siemens-Konzern I. 2, S. 41.

[3] F. Schröter: "Reinigung und Durchschlag-festigkeit von Transformatorenoel." Archiv für Elektrotechnik. XII. Bd. 10 Mörz, 1923.

Current practice points to the decisive influence which heat exercises on the chemical stability of an oil; for this reason the values of temperature and time must be carefully taken into account when carrying out drying operations, and any method which might cause excess of the proper values must be avoided. The usual method of filtering now practised is not free from disadvantage, because the particles of textile material of the paper are drawn into the oil and for this reason cleaning by centrifugal force is preferable. The tests by depositing sediment or " Sludge method " established in the English specifications, subjecting the oil to temperatures of 150 degrees C. during forty-five to fifty hours, do not give conclusive results according to my experience, regarding the relative value of oils.

In short, the question of the properties which transformer oil ought to exhibit, requires further research and experience.

The reliability of the transformer under short-circuit is another important item for good operation. The circular, concentric arrangement of the coils, their symmetry and the great impedances with which they are now designed, contribute towards decreasing the instantaneous currents of short-circuits and counteract the mechanical effects. In general, lateral fixings with insulated tie-bars, wedges or other devices, are the source of damage from electrostatic discharges; the bottom supports and means for compressing the coils axially to compensate the contraction which is attendant upon operation, are similarly arrangements which require serious attention. Fortunately, the great mechanical forces in a horizontal direction due to the repulsion of windings and in a vertical direction owing to lack of symmetry (calculated theoretically to amount to many hundreds of tons in transformers of 10,000 kVA. upwards), generally do not happen in practice, and one experiences, under the usual operation, excepting in the event of very rare and extraordinary occurrences, but few alterations of shape in the windings of well made transformers.

The question of *surges* in large hydro-electric systems and the protection of transformers against them, has been the technical field in which eminent engineers and physicists have exercised with preference their mathematical abilities, and even if they have made those of us who are on the practical side anxious on certain occasions with their pessimistic prophecies, it is to them that we owe the explanation of not a few phenomena and valuable fundamental and simple ideas regarding their causes, such as the transients which take place in an oscillatory form on a system

and their laws, the presence of stationary and travelling waves, their reflection and propagation in the working circuits with impedance and capacity, the phenomena of resonance in localised oscillatory circuits, etc., etc. In transformers it has been a usual practice to provide for the reinforcement of the insulation on the outside coils, a precaution which the occurrence of breakdowns in those of small output has justified. In large units for extra high tensions one often encounters similar failures in the interior part of the windings, and this seems to contradict the existence of steep wave front, or to belie the damping effect of the self-induction of the windings or choke coils. It is possible also that one deals in such cases with waves of greater frequency than that belonging fundamentally to the system, with resonance in some oscillatory circuit at the point of failure.

In any case there is no doubt that one is faced with complex phenomena, and to protect oneself against them from the operating point of view, the wish arises to provide reinforced insulation and to test with current from an external circuit source at much higher voltages, perhaps not less than two and a half times the normal operative voltage between the two windings or between the higher tension and earth.

The connection to earth of the neutral point of the high tension windings connected in star, without the intervention of any element whatever, is a protection with which I have experienced the greatest satisfaction over a period of twenty years. The connection of resistances in the circuit to earth only causes troubles without bringing any appreciable advantages in operation. Regarding the use of reactance coils or transformers, which join the neutral point or the poles of the system to earth, in order to damp down the current on a possible short-circuit and lessen the corresponding surge, many types with different properties have appeared since W. Petersen in 1918 proposed the reactance coil in resonance with the capacity between the system and earth. The discussion continues among European technical experts, without arriving at any definite agreement about the efficiency or preferable type. Data regarding its results in practice either do not exist or have not been published, except the observations made in America on the system of the Alabama Power Co.[1] with a Petersen coil installed under the care of the General Electric Co., from which it would appear, except for

[1] J. M. Oliver and W. W. Eberhardt: "Operating Performance of a Petersen Earth Coil." Journal of the A.I.E.E. September, 1923.

certain anomalies, that it possesses a protecting effect. From the foregoing, it would seem advisable to wait until practice has given its final verdict regarding the employment of such means, before using them in place of the direct connection to earth, the efficacy of which appears to-day to be beyond all doubt.

RÉSUMÉ.

L'auteur de ce rapport examine et passe brièvement en revue les questions concernant la *Production, la Transmission* et la *Transformation* de l'énergie, dans les installations hydro-électriques modernes avec transmission de force. Cet examen est fait d'une manière qualitative et quelque peu subjective, en basant ses remarques sur l'expérience acquise dans l'établissement de nombreuses installations réalisées en Espagne durant ces 25 dernières années; la plus récente étant l'entreprise de la " Catalana " de Gas y Electricidad S.A. de Barcelone, ayant actuellement en service une puissance de 50.000 H.P, et 225 kilomètres de lignes à haute tension à 130.000 volts.

Sous le titre de *Production* il examine la disposition adoptée par les différentes usines afin d'obtenir la flexibilité voulue et un bon rendement hydraulique; la position des barrages; la captation des eaux; les conduites sous pression en béton armé; les tuyauteries et les vannes. Il traite de la dimension des unités génératrices modernes et de l'aménagement des moyennes et basses chutes, recommandant dans ce cas les génératrices asynchrones. Il examine le type d'arbre vertical actuellement en vogue; les vitesses toujours croissantes; la vitesse d'emballement et son facteur de sécurité; la ventilation forcée; l'influence des court-circuits et leur marge de securité; la puissance, les limites de variation de voltage, la protection et la mesure de la température des génératrices.

Sous le titre *Transmission*, il signale la construction générale d'une ligne de transmission aérienne triphasée moderne à très haute tension; il suggère qu'un circuit unique avec pylones libres de se courber dans la direction du parcours est sûr même pour des poteaux en bois; il recommande des fondations en béton pour les poteaux métalliques; il discute le type actuel d'isolateur suspendu en porcelaine et suggère une modification de sa forme afin d'obtenir une meilleure stabilité diélectrique et l'élimination du ciment dans les joints. Il donne les résultats de son expérience personnelle satisfaisante dans l'emploi des fils de mise à la terre, ayant vérifié en pratique les avantages anticipés par la théorie. Il mentionne les conducteurs tubulaires pour la transmission économique de la force au dessous de 10.000 kW. avec des tensions supérieures à 100.000 volts.

Sous le titre de *Transformation*, il cite la part importante jouée par le transformateur dans les entreprises et l'accroissement constant de leurs dimensions; la construction générale et la manière de les connecter; groupes triphasés formés d'unités monophasées, la préférence en Europe pour les unités triphasées; la nouvelle disposition des enroulements de transformateurs dans les toutes dernières installations de Californie. Il discute les détails de construction des transformateurs au double point de vue du fonctionnement et de la sécurité, tels que, les parois isolantes en papier et en bakelite et leurs accidents, ainsi que la question des bornes. Finalement il porte son attention sur les propriétés des huiles de transformateur, les méthodes d'essai et le degré de sécurité sous l'influence des effluves et des court-circuits.

CANALISATION AND UTILISATION OF WATER POWER ON THE RIVER GUADALQUIVIR

CARLOS MENDOZA

In this paper a report is given of the project of canalisation and utilisation of the power of the river Guadalquivir, in order to indicate the considerations that have arisen in the treatment of this project to harness the power available between Cordoba and Sevilla.

The " Mengemor " Electricity Co., Ltd., founded in 1904, has constructed and put into operation successively, several Hydro-Electrical plants on the river Guadalquivir and its tributaries above Cordoba.

The State, in its turn, formulated a plan for hydraulic works in the river basin, with the object of regulating the water flow (especially of the river Guadalquivir) and of establishing extensive irrigated areas for which the climate and country offer especially advantageous conditions.

In accordance with this plan, they intended to construct in the river basin several dams of great height that would be able to store a volume of some 700,000,000 cubic metres.

The canalisation of the river, making it navigable above the port of Sevilla to Cordoba, was not included in the scheme, no doubt owing to the idea that the realisation of this long-felt want would be economically impossible. The river has a flow as low as 8 cubic metres per second at the port of Sevilla, while the maximum reaches the considerable amount of 8,000 cubic metres per second. The river gradient approximates to 1 in 1,000, which causes a considerable water velocity. The available fall between Cordoba and Sevilla is 100 metres approximately.

Throughout the length of this valley the river winds, varying its course from time to time and especially if any serious obstacle is placed in its way. For this reason the only dams that now exist are very low (1 to 3 metres being the limit) and constructed so long ago that they are inefficient and make but poor use of the available power.

The "Mengemor" Co., having a growing demand for power, intend to apply the results of a careful study of features of the Gualdaquivir. They intend to erect Stoney sluices, which have already been employed with good results in two installations on the same river (one of them on the Mengibar and the other on the Carpio). This would provide an adequate solution for utilising the 100 metres fall which exists between Cordoba and Sevilla. They, therefore, presented to the Ministerio de Fomento on the 14th of March, 1914, a *Project for the Canalisation and Utilisation of Power of the River Guadalquivir* between Cordoba and Sevilla, in which they had collated all statistics and details concerning the utilisation of power, together with the State plans for irrigation and the construction of large dams; they have, in this, technically and financially solved the problem of the canalisation of the river.

The projected plan, in its fundamental principles, may be said to be the creation of a series of reservoirs at different levels obtained by the eleven projected sluice gate dams, for the development of water power, each dam being provided with locks for the passage of barges.

The characteristics of these eleven dams, and the power of the generating stations is given in the following statement. (See also map).

Places.	Dams.		Hydro-electrical Installations.	
	No. of Locks.	Total drainage. Km.²	Height of head at low water in M.	Potential installed H.P.
Acala del Rio ...	9	135·00	8·00	6,400
Cantillana	9	135·00	5·25	3,900
Alcolea del Rio ...	9	135·00	5·75	4,800
Pena de la Sal. ...	9	135·00	8·00	6,900
Lora del Rio	9	135·00	11·50	9,700
Penaflor	8	120·00	6·50	5,400
Palma del Rio ...	7	105·00	5·75	3,300
Posadas	6	90·00	8·25	4,800
Guadiato	6	90·00	9·75	5,500
Villarrubia	6	90·00	9·25	5,200
Cordoba	6	90·00	10·00	5,900
			Total available H.P.	61,800

Each sluice will be 54 metres in length and 8 metres wide, with a minimum depth of 2 metres.

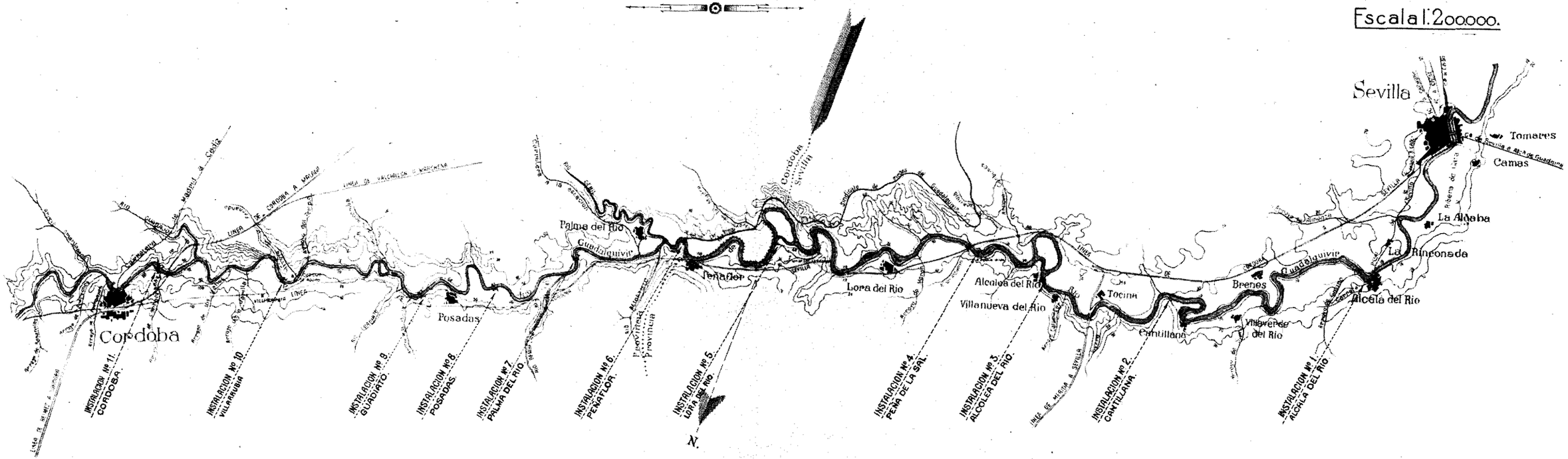
The type of barge will be of 525 tons displacement with 1·50 metres draught, 53 metres in length, and with a beam of 7·50 metres.

Plano General de la Canalizacion y Aprovechamiento de Energia del Rio Guadalquivir

entre

Cordoba y Sevilla.

Escala 1:200000.



The valley will be partially blocked transversely at each dam by two earth dams, whose highest level will be fixed at a greater height than the most exceptional floods which from time to time inundate the plain. Also, the piers of the central sluice dams will be utilised to support the necessary bridges for a public road between the two banks. This will keep the roadway above the highest flood level.

The fertile mud of the river will be deposited over the valley, the level of which in course of time will be raised.

The course of the river in this way will become more fixed, being obliged to pass by these eleven fixed points (the dams).

These hydro-electric plants form the financial basis of the great work of canalisation, and, thanks to the wealth they represent, it will be possible to carry this work through.

The regime of this river is actually so torrential that its power (61,800 H.P.) will not be available for more than six months during the year, being reduced on some days during the period of low water to little more than 8,000 H.P.

From the public service point of view, it is of the greatest importance that the construction of the large reservoirs projected by the State be carried into effect, since from the water outlet pipes of these large dams it will be possible to obtain hydraulic power during the time of irrigation which coincides with the low water period; this power, combined with that from the flow of water in the river, not utilised for irrigation, if placed at the disposal of the concessionaires, will completely ensure the regular supply of the 61,800 H.P. of installed power.

In view of the preceding statements, it will be seen that the conditions are perfectly adapted for carrying out the work.

The " Mengemor " Co. has asked the Ministerio de Fomento for a concession for these eleven hydro-electric plants, treating this part of the scheme as being independent of the great work of the canalisation of the river and of the large State works for irrigation, although they may technically appear to be connected with one another.

Added to this application for an administrative concession, there is the offer of a partnership in the completed work which the authors of the project have drawn up, and of which we are able to quote the most interesting points.

A. The State is to contribute to the completion of the works included in the project of canalisation of the Guadalquivir to the following extent only :—

(1) The cost of construction of the locks and entrance and exit

channels, as projected, forming part of installation No. 5, which will be used for navigation.

(2) The apparatus and accessories for the above.

(3) The protection and preservation of the banks of the river at the sluice dams.

(4) The piers and earthworks of such bridges as may be established over the dams, the transverse breakwaters across the valley and means of access to the bridge designed for public use.

B. The concessionaires to be responsible for the work of the foundation and erection of the dams, locks and accessories, the power stations and their machinery, and also the protection of the river banks under the arch of each dam on the side opposite to that in which they build the locks.

The concessionaires to bear the cost of the necessary expropriation for the execution of the work and sites for the plant.

C. The work on the eleven installations of the dams which is planned to be successively executed following the geographical order from installation No. 1 at Alcala down the river to Cordoba. This order is not to be altered without the authorisation of the Ministerio de Fomento.

D. The cost of the maintenance of all works that directly affect industrial undertakings is to be at the charge of the concessionaires, while the State is to maintain the works that it pays for, such as the maintenance of deep water for navigation.

E. The concessionaires must supply free to the State such electrical power as is necessary for the operation of the locks for the passing of boats.

F. All the works in category A, which are paid for by the State, are to be its property, and it will itself take charge of the maintenance and utilisation of the navigable channel that will result from the simultaneous execution of its own works and those of the concessionaires.

A representative of the Government in each installation is to be in regular charge of the relations between different undertakings in matters of mutual interest, according to the regulations of special Bye-laws that may be dictated by the Ministerio de Fomonto, and by mutual agreement of the Government and concessionaires.

G. The concessionaires have the right to take part in the adjudication of concessions for hydro-electric plants that are made possible by the regulating dams that may be constructed in the basin of the river by the State, or by the construction of works for irrigation which improve the volume of water in the river at low water.

They are also to have the right to a proportion of the concession if they promote the execution of any such dams to the extent of 50 per cent. of the estimated cost of the works, provided that they conform exactly with the first clause of the law in force regarding canals and dams issued 7th July, 1911.

In every case it is understood that all the works of the power station and the machinery of such installation are to be chargeable to the concessionaires.

H. If, before commencing the work, the concessionaires have offered to the State some of the help indicated on the preceding lines, for the construction of dams in the basin, and if they put into operation installations from which no benefit can be derived, because the State has not executed the corresponding works, then they are to be paid as compensation, 5½ per cent. interest on the capital invested.

To profit by this privilege, the concessionaires must fulfil the conditions contained in clause 2a of the law of Safeguarding of National Industries, 2nd March, 1917.

This assistance of the State will cease as soon as the concessionaires dispose of supplementary hydraulic power sufficient to make good the deficiencies of low water in installations that were carried out under clause 10a.

RÉSUMÉ.

Dans cette note, on a exposé les lignes générales de cet important projet que l'auteur a présenté au Gouvernement espagnol le 19 Mars, 1919.

La navigation par le fleuve, atteint seulement Séville, mais quand les travaux en projet auront été exécutés, on prolongera cet hinterland de 150 kilomètres, jusqu'à Cordoue, à travers une région d'une richesse agricole et minière extraordinaire.

Le projet a tenu compte des plans de l'Etat, pour tout ce qui se rapporte à l'irrigation, et les travaux de canalisation projetés les respectent tous. La base financière desdits travaux est l'utilisation de l'énergie hydro-électrique que l'on pourra obtenir au moyen de prises échelonnées, avec des vannes Stoney, par onze installations hydro-électriques sur les 98 mètres de dénivellation qu'il y a entre les deux extrémités du fleuve canalisé.

On indique également les conditions dans lesquelles cette concession a été sollicitée du Ministère des Travaux Publics.

La voie navigable sera au bénéfice de l'Etat, et l'exploitation hydro-électrique au bénéfice du concessionnaire.

Il faudra établir un consortium entre l'Etat et le concessionnaire pour l'exécution desdits travaux, puisqu'une partie en sera payée par l'Etat. Les bases principales pour ce consortium sont comprises dans les conditions de la concession, et un extrait sommaire en est donné dans la note.

THE REGIME OF FLOW OF SOME SPANISH RIVERS

CARLOS MENDOZA

Occasion has recently arisen for improving our knowledge about the regime of some of the Spanish rivers. Even though the results are not perfectly correct, they are sufficiently approximate to be interesting, since they give us an idea of the special hydrological features of a great number of the river basins in the centre and south of the Iberian Peninsula.

In all the centre and southern district of the peninsula we find no mountainous zones with perpetual snow; but we do find such areas in Sierra Nevada. At some heights, even above 1,500 metres, the snow disappears before the summer, combining with the heavy rains to produce torrential streams which differ in volume from season to season and even from year to year.

The greater part of the readings have been obtained at the dams of different Hydro Electrical Installations, many of them daily, for more than ten consecutive years, while some other results have been obtained from observations taken over more than twenty years.

From these observations, we may conclude that these areas of our country are not the most favourable for making normal use of hydraulic power, unless supplemented by auxiliary steam power stations, or unless great reservoirs are constructed to regulate the torrential discharges.

For this reason, the Hydro-electrical Companies of the centre and south of Spain are interesting themselves in the construction of large dams and of large steam power reserves; there are even some reservoirs already constructed, with steam power held in reserve. It will soon be necessary to go into the question of dams on a very large scale.

Nearly all the Hydro-electrical installations that have been constructed during this century have suffered from the consequences of commencing work on insufficient statistical data.

The differences are very considerable between low water limits, in some cases one to five, and the same applies to the maximum water discharges.

Let us examine some of the results obtained by observations on some of the more or less important rivers, in different basins.

THE RIVER MANZANARES. Measurements have been taken at the Santillana dam (Colmenar Viejo), 35 kilometres away from Madrid. At this place there are two Hydro-electrical installations having an aggregate power of 5,500 kilowatts, with a dam of 43,000,000 cubic metres capacity, which assures a regular supply of power.

The average rainfall for the year in Madrid is 450 mm. The minimum during the last 50 years was 269 mm. and the maximum 698 mm.

The year with the minimum rainfall was also the year of minimum flow of the river.

This was in the year 1903, and the total discharge of the river through the dam of Navallar (Colmenar Viejo) was 50,000,000 cubic metres.

The year before, when it rained just a little less than in the year of maximum rainfall, it reached a total of 580 mm., and the total flow was 203,000,000 cubic metres. Since, however, the only rain gauge station of the basin is at Madrid, it is impossible to know exactly the coefficient value of the flow.

Considering the information taken from the Madrid rain gauge, it will be seen that if the rainfall registered in this observatory in 1902 is applied to the basin of the river in Navallar, the volume of water which flowed during the year would have been 131,000,000 cubic metres.

As the volume of water in the river at this point actually reached 202,000,000 cubic metres, it showed clearly that the rains in the high part of the basin must have been greater than those registered in Madrid.

This shows that it is unwise to set too much store by the information of a rain gauge Station that is not in that part of the basin under consideration.

The relation between the value of the average minimum flow of water observed during ten consecutive years, and the extreme minimum flow of water, is a matter of considerable interest.

The value of this relation is approximately 2,000.

It is also interesting to note the specific values of the maximum and minimum flows of water. The maximum and minimum quantity of water observed is given in litres per second per square kilometre of the basin of the river.

The superficial extent of the basin of the river Manzanares in Navallar is about 230 square kilometres and the specific values of the maximum and minimum flow were 345 and 0·17 respectively.

RIO ALGAR. A gauge giving low water readings only may lead to big mistakes resulting afterwards in grave losses.

Near the Cape of San Antonio, in Alicante, flows the river Algar which was gauged at 500 litres per second for low water in 1901, although it had been stated in printed memoranda, published by men of technical standing, that it would be possible to count on a minimum flow of 1,000 litres per second.

With this figure in view, an endeavour was made to get the State to construct a channel 80 kilometres long in order to irrigate the Huerta of Alicante with these waters.

In the following year when the falls were constructed they only gave a flow of 400 litres per second. In the year after that it was immediately necessary to construct a steam raising plant to supplement the low water output; some years later this plant was the only one working for nine consecutive months, and during this time the amount of water flowing was less than 30 litres per second, which, of course, was not enough to irrigate the surrounding fields.

Although the river carried very little water, it had swollen very much. The annual rainfall was sometimes as small as 130 mm., and on some occasions it attained that value in 36 hours.

RIVER CHANES. The minimum flow at low water has varied from 25 litres per second to 200 litres.

The basin of the Chanes dam is of 70 square kilometres in the Alpujarra.

The minimum rainfall in 1913 was 202 mm. with a specific value of 0·31 during the last 15 years.

The maximum rainfall in 1916 was 623 mm. with a specific value of 280 at times.

The basis of calculating specific values is the same as was employed in the river Manzanares.

After deducting a certain amount of the coefficient of flow, the minimum value was 0·12 in 1913, during which year of minimum rainfall, as stated above, the flow of the river was reduced to 2,000,000 cubic metres for the whole year.

GUADALIMAR RIVER. The author has studied thoroughly the regime of this river, one of the principal branches of the

Guadalquivir, in the dams of Olvera, Escuderos and Vade of the Ollas.

Up to the dam of Olvera, the extent of the basin is 2,500 square kilometres.

During the year with the least amount of rainfall registered in Olvera (400 mm.) the total flow of the river was 164,000,000 cubic metres, and the coefficient of flow was 0·16.

During the year with the highest rainfall (657 mm.), the coefficient rose to 0·60, demonstrating once again the influence of the rainfall on this coefficient.

The minimum amount registered for low water was 500 litres per second, and the maximum amount during winter floods reached 547,000 litres per second.

From these facts it can be seen that the values of the minimum flow per second per square kilometre of the basin, and of the maximum, estimated in the same way, were respectively 0·20 and 200.

This provides no exception to the rule, for the relation between the values is 1 : 1,000.

RIVER GUADALQUIVIR. The River Guadalquivir has been studied at the dam of Mengibar, Voltodano and the Carpio.

The basin to Mengibar is 16,500 square kilometres in size.

The minimum quantity of water observed is 2·5 cubic metres per second, and the maximum 2,500 cubic metres per second.

The specific values of minimum flow is 0·15 and the maximum 153.

The relative value between them still obtains, 1 : 1,000.

Measurements taken in this river by the Hydrological Department in Sevilla have given for the minimum value at low water, 7 cubic metres per second, and during flood, the maximum of 8,000 cubic metres per second.

The superficial extent of the basin is as great as 47,000 square kilometres.

The specific values are 0·15 and 170 respectively. The relation is also approximately 1 : 1,000.

RIVER TAJO. From some measurements taken at the dam of Bolarque for the last few years by the Madrid Electrical Union, it was found that the specific values maximum and minimum, were 274 and 1·10 respectively.

We have no information previous to the year 1913, when there were years of drought, but for which we believe the value of 1·10 would also obtain for minimum flow.

RIVER DUERO. The Duero carries in Turones, according to information of the Hydrological Department, 1,600 litres per second at low water and 2,000 cubic metres per second when swollen. Its basin is of 8,000 square kilometres, and therefore the minimum specific value attains 0·20 and the maximum 250; the relation between them differing very much from that obtained from other rivers.

RÉSUMÉ.

D'observations qui ont été faites directement sur quelques fleuves espagnols des régions du Centre et du Midi de l'Espagne, l'auteur de cette note a déduit quelques chiffres très intéressants qui font connaître le degré d'irrégularité du régime desdits fleuves, dont quelques-uns, comme le Tage, le Duero et le Guadalquivir, ont de grands bassins d'alimentation.

L'auteur de la note déduit que l'on observe souvent que la valeur du rapport entre le débit minimum et maximum qui a été observé est fréquemment de de 1 : 1,000 ; et la valeur de ce rapport diminue encore dans les fleuves qui ont des bassins d'une superficie inférieure à 1,000 kilomètres carrés.

Le débit minimum *en litres, par seconde et par kilomètre carré de bassin d'alimentation*, que l'auteur appelle, *débit spécifique minimum*, est généralement de l'ordre des décimales, et le *débit spécifique maximum*, de l'ordre des centaines. Ces valeurs servent pour donner une première approximation qui est d'une grande utilité pour les cas où l'on manque d'observations directes lorsqu'il s'agit de cours d'eaux qui ont des conditions semblables.

CHARACTERISTICS AND BRIEF DESCRIPTION OF THE SCHEME FOR DEVELOPING HYDRAULIC POWER FROM TWO IMPORTANT GROUPS OF WATERFALLS IN THE BASIN OF THE RIVER DUERO

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(I.) DUERO FALLS.

(a) COMPANIES WHICH HAVE BEEN FORMED IN ORDER TO STUDY AND CARRY OUT THE WORK OF CONSTRUCTION.

These Falls have been the subject of special study by the Company " Consorcio de los Saltos del Duero," which has registered offices at Bilbao, and has been established by the " Banco de Bilbao," the " Sociedad General de Transportes Eléctricos," and Mr. Horacio Echevarrieta. This same financial group has also formed, for carrying out the construction work, the Company " Sociedad Hispano-Portuguesa de Transportes Eléctricos," with registered office at Bilbao, and a Share Capital of 150,000,000 Pesetas (£4,687,500 sterling).

The following data relative to the Duero Falls has been studied by the last mentioned Company, which has already spent more than £100,000 (3,200,000 pesetas) in acquiring rights, lands, concessions, in Spain and Portugal, for gauging, sounding, compiling projects, etc.

(b) DESCRIPTION OF THE PROPOSED FALLS, THEIR LOCATION AND CHARACTERISTICS.

The group of " Duero Falls " is supplied from the sources given below in the same order as they are situated along the lower course of the Rivers Duero and Tormes.

(1) *Spanish Fall on the River Esla* with Power Plant at the foot of Ricobayo dam, lie within the province of Zamora, a distance of 11.60 kilometres from the confluence of the Rivers Duero and Esla.

The proposed dam will develop a reservoir capacity of

563,020,000 m³; its height will be 70 metres, length of crest 176 metres, length of base 56.70 metres, with "Levy" section and volume of concrete 210,400 cubic metres.

(2) *Spanish Fall on the River Duero* with a power plant at the foot of Villardiegua dam (Province of Zamora), a distance of 1 kilometre from the Spanish-Portuguese frontier.

The proposed dam will develop a reservoir capacity of 161,780,000 m³; its height will be 80 metres, length of crest 227 metres, length of base 65·36 metres, with "Levy" section and volume of concrete 230,000 cubic metres.

(2) *International Fall* (Spanish-Portuguese) on the River Duero, projected in order to develop the available hydraulic slope of 190 metres, lying between the point at which the Villardiegua power plant releases the water and the confluence of the Rivers Duero and Esla (Province of Salamanca).

It is proposed to construct a 41.420 kilometre aqueduct with a constant capacity of 119·63 cubic metres per second which will be obtainable from the River Duero by regulating its relation with the reservoirs at Ricobayo and Villardiegua.

It is possible that a further study of the transverse and longitudinal profile of the international portion of the River Duero may lead to a partial substitution for this aqueduct of a number of stepped dams.

(3) *Spanish Fall of the River Tormes* with a power plant at the foot of Carbellino dam (Province of Salamanca), a distance 35.80 kilometres from the confluence of the Rivers Tormes and Duero.

The proposed dam will develop a reservoir capacity of 144,670,000 m³; its height will be 70 metres, length of crest 416 metres, length of base 57.19 metres, with "Levy" section and volume of concrete 221,000 m³.

It is proposed to construct a 2.655 kilometre aqueduct beginning at the point at which the Corbellino power plant releases the water, with an available head of 24 metres, having a constant capacity of 29.70 m³, per second, which will be obtainable by regulating the relation of the River Tormes with Corbellino reservoir.

(4) *Spanish Fall of the River Tormes* with a power plant at the foot of Argusino dam (Province of Salamanca), a distance of 19 kilometres from the confluence of the Rivers Tormes and Duero.

The proposed dam will develop a reservoir capacity of 27,040,000 m^3; its height will be 70 metres, length of crest 487 metres, length of base 57.19 metres, with a "Levy" section and volume of concrete 328,300 m^3.

It is proposed to construct a 13.330 kilometre aqueduct beginning at the point at which the Argusino power plant releases the water, with an available head of 240 metres, having a constant capacity of 32·90 m^3 per second which will be obtainable by regulating the relation of the River Tormes with the reservoirs of Corbellino (3) and Argusino (4).

(5) *International Fall* (Spanish-Portuguese) of the River Duero with a power plant at the foot of Aldeadávila dam, situated on the international portion of the River, a distance of 21 kilometres down stream from the confluence of the Rivers Duero-Tormes.

The proposed dam will develop a reservoir capacity of 38,750,000 m^3; its height will be 80 metres; length of crest 280 metres, length of base 65·36 metres, with "Levy" section and volume of concrete, 250,900 m^3.

It is proposed to construct a 31.853 kilometre aqueduct beginning at the point at which the Aldeadávila Power Plant releases the water, with an available head of 120 metres, having a constant capacity of 155.74 m^3 per second which will be obtainable by regulating the relation of River Duero with the reservoirs or Ricobayo (1), Villardiegua (2), Corbellino (3), Argusino (4), and Aldeadávila (5).

It is possible that a further study of this international portion may suggest a partial substitution for the aqueduct of a number of stepped dams.

(b) TOPOGRAPHICAL AND GEOLOGICAL CONDITIONS OF THE SITES.

The topography of the site is unusually favourable for developing hydraulic slopes and for establishing high dams, hence obtaining reservoirs of large capacity by flooding land of very little value.

The River Duero has a 79,000 kilometres water-shed and runs through the plateau of Castilla up to its last Spanish portion, where it drops steeply between high banks giving a head of over 500 metres over a distance of 183 kilometres.

The geological conditions are likewise ideal for the construction of large reservoirs, with absolute security for the foundations of dams and also in respect to the impermeability of the basins.

The River Esla Fall (1) has its lock on a gorge of granite which, though it has a different surface, is quite sound a few metres below that level. The excavation is on paleozoic ground with silurian lower strata running across the line of the river. On the left band the reservoir touches a slight extension of miocene.

The dam site of the River Duero Fall is of fine grain of gneiss nodular in layers all along the river, with sound and compact rock up to the surface.

The reservoir site is of granite and crystalline strata (Archaic) of isoclinal strata, N.W.-W.E. direction.

On the ***international portion*** (Spanish-Portuguese) of Falls (2) and (5) the ground is of metamorphic paleozoic rock (cambrian and silurian) running transversely to the river. At the beginning of the reservoir the ground is of crystalline slates and up stream, to the end, of granite.

On the River Tormes, Falls (3) and (4) nearly the whole ground is of granite with several layers of Archaic.

These results have been arrived at by geologists and are being verified by diamond soundings on the dam sites.

(c) REGIME OF THE RIVERS, THEIR REGULATION AND CAPACITY OF THE SUPPLIES.

For measuring the flows of River Duero and its tributaries Elsa-Aliste and Tormes, there are, besides official gauging stations, five private gauging stations belonging to the Company H.P. de T.E.

This kind of report does not allow of further discussion of the subject. We shall limit ourselves, therefore, to drawing attention to the following tables, in which the data give an idea of the river regime before and after the realisation of the works which we are considering.

	River Duero. Cubic metres.	River Esla. Cubic metres.	River Tormes. Cubic metres.
Total volume in the year	11,006,830,000·00	4,520,660,000·00	1,346,030,000·00
Max. flow per sec. ...	1,462·00	1,037·00	115·00
Min. flow per sec. ...	15·23	0·546	0·260
Mean flow in the year	348·07	143·349	42·565

These volumes, regulated by the proposed reservoirs, make the continual flow available (dry season) and periodical flow (winter season) stated below, which, when in use together with the corresponding falls, develop the power stated below.

FALLS.			Continual dry season. m^3 per sec.	Periodical winter season. m^3 per sec.	Continuous Power H.P.	Total Power, winter season. H.P.
Esla-Aliste	(1)	Spanish ...	59·65	109·65	37,393	74,726
Duero	(2)	,, ...	119·63	239·63	89,106	191,506
Duero	(2[1])	Spanish-Portuguese .	119·63	,,	242,450	242,450
Tormes	(3)	Spanish ...	29·70	,,	17,560	17,560
itm.	(3[1])	,, ...	29·70	,,	7,603	7,603
Tormes	(4)	,, ...	32·90	,,	21,245	21,245
itm.	(4[1])	,, ...	39·20	,,	84,224	84,224
Duero	(5)	Spanish-Portuguese .	155·74	275·74	127,615	230,015
itm.	(5[1])	,, ...	155·74	,,	199,347	199,347
				Total ...	826,543	1,068,676

(d) REGION OF CONSUMPTION AND POWER TRANSMISSION LINES.

The 3-phase current transmission lines, designed for 120,000 volts, have the following total proposed length :—

TRANSMISSION LINES IN SPAIN.

ESLA	(1)	Tordesillas—Valladolid—Vitoria—Bilbao	385 km	
ESLA	(1)	León—Oviedo	210 km.	
ESLA	(1)	Segovia—Madrid ...	248 km.	
ESLA	(1)	Ponferrada	120 km.	
			———	963 km.

TRANSMISSION LINES TO PORTUGAL.

ESLA	(1)	Saucelle	99 km.	
		Saucelle—Oporto ...	142 km.	
SAUCELLE		Lisbon	314 km.	
			———	555 km.

SPARE TRANSMISSION LINES (in Spain).

SAUCELLE	Avila—Madrid	282 km.	
	León—Bilbao	226 km.	
		———	508 km.
	Total		2,026 km.

(e). TOTAL ESTIMATED COST PER H.P.

(a) *Total Estimates.* These are as follows :—It is probable that they will be subject to revision owing to reduction in the price of materials.

Hydraulic works, buildings, machines, land, limestone quarries,

deposits, clay, auxiliary apparatus, research, concessions, constitution, interest on capital during period of construction, etc., etc.

(32 pesetas to £1)	£12,864,446
Power transmission lines in Spain	1,327,500
do. do. in Portugal	570,000
Spare transmission lines.(in Spain)	635,000
Total	£15,396,946

(b) *Price per H.P.* (power transmission lines inclusive).

It is obvious that the cost per H.P. cannot be the same for each of the above Falls; it is greater for the first one to be constructed, as the cost of this covers the construction of reservoirs, auxiliary apparatus, cement factory, etc., which can be used later for the construction of the succeeding works in the same group; hence the average price per H.P. varies as the constructional work is being carried out, as shown by the scale below.

(f). ACTUAL STATE OF THE CONCESSIONS.

(a) The Falls (1), (2), (3) and (4) receive water and are located absolutely within Spanish territory, thus their concession can only be granted by the Spanish Government. These applications for concessions are in their final stage of negotiation, and a definite and prompt decision is expected.

(b) The Falls (2[1]) and (5) are located on the frontier, and their concession is reserved to both Governments, as stated in the Spanish-Portuguese Agreement signed in September, 1912. The application for concession has been filed in accordance with the terms of that Agreement. These international concessions are covered by Clause III. of the Agreement, and being of great interest to both countries it is expected that the open diplomatic negotiations on the subject will result in an early settlement.

The delay in these negotiations will only effect, in any case, the construction of the international falls which constitute only a fraction of the group called "Duero Falls."

(II.) CARRION FALLS.

The regime of the River Carrion, a tributary of the River Pisuerga, which in its turn is a tributary of River Duero, will be regulated over practically the whole of its course by the Principe Alfonso Reservoir. The latter is located within Camporredondo (Province of Palencia), and is actually under construction by the Spanish Government.

1.° Cost per H.P. of maximum winter power of each Fall (inclusive of lines and spare machinery).

Falls	(1)	(2)	(2^1)	(3.3^1)	(4.4^1)	(5.5^1)
Price per H.P.	£37 11 5	£11 8 2	£13 18 2	£40 1 5	£20 0 1	£9 2 6

2.° Mean cost of H.P. per maximum winter power. This average is arrived at as the construction of the Falls, which constitute a group, is carried out.

Falls	(1)	(1+2)	(1+2+2^1)	(1+2·2^1+3·3^1)	(1+2·2^1+3·3^1+4·4^1·	(1+2·2^1+3·3^1+4·4^1+5·5^1
Price per H.P.	£37 11 5	£18 14 5	£16 8 9	£17 10 8	£17 18 10	£14 8 2

3.° Cost per H.P. of average continuous power (dry season).

Falls	(1)	(2)	(2^1)	(3.3^1)	(4.4^1)	(5.5^1)
Price per H.P.	£75 1 0	£24 1 1	£13 18 2	£40 1 5·	£20 0 1	£11 19 5

4.° Cost per H.P. of average continuous power (dry season). This average is arrived at as the construction of the Falls, which constitute a group, is carried out.

Falls	(1)	(1+2)	(1+2+2^1)	(1+2·2^1+3·3^1)	(1+2·2^1+3·3^1+4·4^1)	(1+2·2^1+3·3^1+4·4^1+5·5^1
Price per H.P.	£75 1 0	£39 8 11	£22 13 2	£23 15 8	£22 19 5	£18 11 11

The principal object in constructing this reservoir is to improve the irrigation conditions from the channel of Castilla; but, after it has passed this reservoir, and before reaching the irrigated region, the river runs over 41,000 kilometres with an available head of 313 metres, which is utilized for developing energy on the group called "Carrion Falls." A fall situated above the reservoir also forms part of this group; consequently it cannot enjoy the advantage from regulation of the regime of the river effected by the said reservoir.

We give below characteristics and further particulars regarding these falls, to be indicated hereinafter, (1), (2), (3), (4-5) and (6-7), which are the numbers of their concessions, although in describing them we shall follow their geographical order.

(a). DESCRIPTION OF THE FALLS, THEIR LOCATION AND CHARACTERISTICS.

The group called "Carrion Falls" has been formed, by the combination of several concessions, of the following four which are described in the same order as they are situated along the course of the River Carrion.

Fall No. 3—situated 21 kilometres upstream from the Reservoir Principe Alfonso, 1,403 metres above sea-level; dam situated at the confluence of Rivers Carrion and Aruz; diversion channel of 9,652 metres long; capacity of flow 4.000 m^3 per second; available head 116·00 metres. Hydro-electric Power Plant at Vidrieros (1,287 metres above sea-level).

Fall No. 1—with opening dam at Camporredondo, close to Reservoir Principe Alfonso; height above sea-level, 1,199 metres; diversion channel, 17,526 metres in length; capacity of flow, 8·600 m^3 per second; available head, 128·20 metres. Hydro-electric Power Plant at Guardo, height above sea-level of 1,071 metres.

Fall No. 2—Auxiliary to the construction of the other falls. Dam at Velilla; height above sea-level, 1,097 metres; diversion channel, 3,278 metres in length; capacity of flow, 6.000 m^3 per second; available head 26·00 m.; same Hydro-electric Power Plant as the one for Fall No. 1 at Guardo, height of 1,071 metres above sea-level.

Falls No. 4-5—are formed by the combination of two partial concessions, with dam at Guardo; height above sea-level, 1,067 metres; diversion channel, 16,316 metres in length; capacity of

flow, 17·000 m³ per second; available head 77·00 metres; Hydro-electric Power Plant at Pino, height of 990 metres above sea-level.

Falls No. 6-7—are formed by the combination of two concessions and have their opening at the point where Falls 4-5 release the water; length of channel, 16,000 metres; capacity of flow, 17.000 m³ per second; available head, 104 metres; Power Plant at Saldana (height above sea-level, about 886 metres).

The Falls 1-2 and 4-5 are actually under construction. The dams are of the weir type and of small height.

The diversion channels have trapesoidal section lined with concrete.

The geographical situation of these Falls is very favourable owing to their proximity to important mining and railway centres. Cities such as Gijón, Oviedo, La Robla, León, Palencia, Valladolid, Venta de Baños, Burgos, Bilbao and Santander, lie within a radius of 180 kilometres.

(b). REGIME OF THE RIVER CARRION AND ITS REGULATION.

The regime of the River Carrion, as with all Spanish Rivers, is very irregular.

The following data give an idea of the regime:—

	Year 1918. Cubic metres.	Year 1919. Cubic metres.	Year 1920. Cubic metres.
Total volume for the year	285,238,022·000	346,731,408·000	271,166,000·000
Max. flow per second ...	97·256	151·107	68·000
Min. flow per second ...	0·913	0·888	1·127
Mean flow	9·045	10·678	8·017

The dam of Principe Alfonso has a total height of 65 metres and an available height of 63-50 metres.

The total volume of stored water is 66,221,375 m³, and the available volume is 61,290,061 m³.

These volumes, taking into account the average of the three mentioned, permit of the following regulation of River Carrion.

8·370 cubic metres per second during 4 months of dry season.
10·120 cubic metres per second during 8 subsequent months.

These figures are the bases of the data given in the following table. The constant minimum flow that can be relied upon as regulation compatible with irrigation purposes, can be valued at 7.500 m³ per second.

(c). CAPACITY OF "CARRION FALLS."

As it is rather important, the capacity of the falls situated below the Principe Alfonso Reservoir is given on the following table, by regulating the regime of the river affected by this reservoir.

	Constant flow 12 months. H.P.	Average flow 6 months. H.P.	Winter flow, 3 months. H.P.
Fall No. 1	8,740	8,740	10,297
„ No. 2 (auxiliary) ...	230	920	1,380
„ No. 4-5	6,417	8,556	12,121
„ No. 6-7	8,688	11,584	16,410
Total	24,075	29,800	40,208

Respective cost per H.P. at turbine shaft (32 pts. to the £) :

Fall No. 1	£42 13 4	£42 13 4	£36 4 6
„ No. 2	£256 0 0	£68 19 8	£42 13 4
„ No. 4-5	£65 19 0	£49 8 11	£34 18 3
„ No. 6-7	£51 5 10	£38 9 6	£27 3 3
Average cost per H.P.	£54 0 10	£43 12 8	£32 7 0

RÉSUMÉ

Le " Comité Nacional de la Energia Hydraulica de Espana " à soumis à la conférence d'Energie Mondiale de Londres, un rapport relatif aux ressources existant en Espagne.

Parmi celles-ci, deux groupes de chutes d'eau sont cités, situés sur le versant du fleuve Duero, mivant qui l'opinion de l'ingénieur Civil, signataire de ce rapport, et en tenant compte de leur capacité, et d'autres circonstances économiques et techniques, sont dignes d'une mention spéciale.

Ces chutes d'eau sont :—

1. Le groupe appelé " Chutes du Duero " (qui bénéficie de l'eau et des versants de la rivière Duero et de ses tributaires (Rivière Elsa-Aliste et rivière Tormes) a une capacité constante (saison sèche) de 800.000 H.P. et en hiver une capacité de 1.000.000 H.P.

2. Le groupe dénommé " Chutes Carrion " (qui bénéficie de l'eau et des versants de la rivière Carrion-tributaire de la rivière Pisuerga qui à son tour est tributaire du fleuve Duero), a une capacité de 24.075 H.P. et une capacité en hiver de 40.200 H.P.

Dans les deux chapitres suivants du rapport une brève description est faite des projets concernant les travaux de construction, ainsi que des autres questions techniques et économiques relatives à la fourniture de l'énergie électrique des deux groupes mentionnés ci-dessus.

RECENT PRACTICE IN LAKE STORAGE —WHAT THE STORAGE MEANS TO WATER POWER UTILISATION IN SWEDEN

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The country of Sweden is formed of primary rock with a hilly surface and moderate altitudes. Where this rock is not entirely bare it is generally covered with earthy strata of slight thickness only.

This geological formation explains Sweden's great richness in lakes and rather extended river profiles, in which high concentrated waterfalls are rare, but of which rather low falls and more or less extended rapids and streams are characteristic.

Thus the topographical conditions generally preclude the possibility of the development of mighty water power plants with high head of fall, and the power stations are usually erected for a rather moderate head, obtained by developing the existing low falls in conjunction with the damming up of the intermediate rapids. As the water power is developed, the gently inclined river profile is thus transferred into series of still water basins—on different elevations and of various lengths—between which the water is drawn through the turbines and the gate openings of the power plants.

Owing to these circumstances, the utilisation of the Swedish water power, which generally may be developed at a reasonable cost, thanks to the good fundamental conditions, is further promoted by the possibilities of *pondage and storage* offered by the topographical conditions.

The possibility of utilising the available flow in accordance with the variable load of the power plants during the different hours of the week and of the day—a possibility of such vital importance for the economical development of the water power—may be attained by aid of the still water basins between the power plants. Owing to the favourable topographical conditions, the weekly and the daily regulation of the flow will thus be gained as a by-product at the development of the waterfalls and to a great extent without any extra cost.

The numerous lakes, often of a considerable size, make it possible to impound, to a great extent, the surplus flow during high water periods, *i.e.*, to arrange storage basins, for use during periods when the flow is small. Considering the additional energy, which is thereby gained, the cost of such a storage is generally very low. The storage will thus be very valuable, as, in the first place, the deficiency of power during low water periods may be to a considerable extent supplemented with cheap power. Furthermore, the natural second rate power, *i.e.*, the power which in the free stream is available during part of the year only, may be converted into power of higher value, or first rate power, without falling back upon expensive auxiliary steam plants, and may thus be used by those industries for which cheap power is a vital condition and which cannot bear the expenses of such auxiliary plants.

On that account lake storage has become an important factor in the development of the Swedish water power and has, to a considerable extent, contributed to make this power worth utilising.

The great interest in the storage problem, that has therefore been aroused, has brought about a scientific treatment of the theoretical part of the problem, as well as the necessary legislation for settling its legal points and practical forms for the carrying out and the utilisation even of very comprehensive storage works.

Since, in years past, different methods for calculating the influence of storage on the flow from a lake have been analysed by *G. Saetersmoen*,[1] *Nils Westerberg*,[2] *Hugo Flodin*[3] and others, the theoretical treatment of the storage problem has now been directed to new objects. At the utilisation of storage basins it has been necessary to weigh against one another the two desiderata for the power plants lower down ; on the one hand to increase as much as possible the total available amount of energy and on the other hand to raise the minimum capacity. The greater the amount of energy which is being gained by utilising the reservoirs, in such a way that these are more or less completely emptied even during short low water periods, the greater is the risk of a critical decrease of the capacity at the end of the longest dry periods. And the higher the demand is, on a guaranteed minimum capacity—even during long dry periods—secured by a cautious use of the water, the less will be the average increase of energy. Thus it has been necessary to

[1] " Teknisk Ukeblad," 1903, number 38.

[2] " Teknisk Tidskrift," " Väg och Vatten," 1908, number 1 and 1910, numbers 7, 8 and 9.

[3] " Teknisk Tidskrift," 1916, " Väg och Vatten," number 12.

draw up—on the basis of many years' observations—empirical "regulating schemes," by the aid of which it may be found how far each of the above desiderata should be met. From these schemes it is possible to find, from day to day, how the discharge from the lake should be fixed with regard to the water level of the lake on the day in question, even without an exact knowledge of the future variations of the flow. Such regulating schemes, meeting the requirements of the times, have recently been elaborated by the *Vattenbyggnadsbyran* (Consulting Hydraulic Engineers of Stockholm). It has, furthermore, been necessary to study how the effect of the regulation is influenced by the passing of the water, drawn from a lake in the uppermost part of the river, through a number of natural lakes further down. On this subject *A. Frey Samsioe* has recently published a theoretical treatise.[1] A subject closely related to the preceding, is the problem of calculating those variations of the flow which are due to the local pondage at such power plants where the load during the day is variable, and which affect the nearest water power plants lower down in the stream. This subject has been treated by *K.-G. Ljungdahl* in a paper on "the hydraulic co-operation between power plants in the same river, analysed as an electric current problem."[2] It has also been very important for the treatment of storage problems, to establish, through careful investigations, certain rules for calculating damage to fields, caused by raising the natural levels of the lakes. For this purpose *The Royal Board of Waterfalls* has appointed a committee of experts, who have recently reported on the influence of different drainage depths—in various kinds of earth—upon the harvest from cultivated land and meadow-grounds. Furthermore, *H. Hesselman* has made a close study of the influence of the drainage depth upon the growth of the forests.[3]

Regarding the recent legislation for the furtherance of storage works, the author begs to refer to *C. Kleman's* paper, published under "Section M." The new Swedish Water Law bears partly upon the settling of controversies with regard to such interests, representing buildings, agriculture, fishing, logging and navigation—sometimes also sanitary and æsthetic interests—as may be affected by the storage.

The regulation of the flow from a lake in order to increase the water

[1] "Teknisk Tidskrift," 1923, "Väg och Vatten," numbers 5, 11 and 12.
[2] "Teknisk Tidskrift," 1923, "Elektroteknik," number 10.
[3] "Svenska Vattenkraftföreningens publikationer" (The publications of The Swedish Water Power Association), 1922, number 140.

power, is evidently of mutual interest to all the power plants along the river below the lake. In recent years this has induced the owners of water power in various rivers to unite in special associations or " Regulation Companies," the functions of which are prescribed by law. Such Regulation Companies have become the practical form for the co-operation necessary for carrying out storage works and for the most suitable utilisation of the storage basins as well as for the just allotment of the costs involved. Thanks to these companies, the regulation of the flow from a lake should not necessarily be considered as a separate undertaking, but the utilisation of the different lakes for storage purposes—especially in rivers with many lakes—might be combined in order to obtain the greatest possible total benefit. Also with a view to deriving advantages as extensive as possible from such combinations, an endeavour has of late been made, to arrive at a general interconnecting of the power plants.

As soon as it has come about that the different power plants within each river district have been electrically interconnected for reciprocal power transmission, the storage works within each river district, taken as a separate unit, may be utilised up to the highest degree. As a general rule, the water should then be drawn from the reservoirs in such a way that the increase of the total capcaity be as great as possible, and that the total amount of energy produced in all the power plants at different times should as closely as possible correspond to the total demand. An account of the characteristic features of such a co-operation has been given by *M. Serrander* in his treatise on " hydro-electric river regulation."[1]

At first the purpose of a storage was to obtain, during low water periods, a flow from the lake as uniform as possible, but the demand for a scientific " hydro-electrical river regulation " has already brought about, and will, in the future, even further evoke, very far advanced requirements on the construction of " regulating schemes " and on the arrangement and utilisation of the storage. Concerning, in the first place, the draught in a certain storage basin, it must be emphasised that non-regulated tributaries generally enter the river further down, that the low water periods are usually of different lengths in the upper and in the lower courses of the river, that the surplus power may have a different value at different places along the river, etc. Owing to these circumstances the regulating schemes must be adjusted so that the draught in the basin is fixed

[1] " Hyllningsskrift, tillägnad F. Vilh. Hansen " (The Hansen Testimonial), 1922.

with a view to obtaining a certain result at a point further down the river, called the " regulation focus." Thereby the interest of the power plants immediately below the outlet of the lake may be, to some extent, disregarded and a deficiency of water may appear at certain times at these plants, but this has to be compensated by the transmission of power from the plants further down. Moreover, many of the lakes in the tributaries have such small drainage areas, compared with the surface of the lakes, that the storage basins that can be arranged in these lakes will be larger than required for the complete regulation of the flow from the lakes. When a hydro-electric regulation is fully accomplished, these lakes may be " over-regulated," *i.e.*, the flow to the lakes may be more or less fully retained during wet seasons and the draft on them concentrated on times when the main river is short of water. In this way the maximum increase of the valuable low water capacity is obtained in all the power plants below these lakes. The deficiency that will appear in the plants on the tributaries below the lakes at times when the flow in the main river is abundant, is compensated by surplus power from the plants in the main river. Finally, attention has been paid to the possibility in certain cases, not only of entirely stopping, at times, the flow from certain storage basins, but also of refilling the basins by letting the power plants below the lakes work as pumping stations by means of surplus power from other plants.

The utilisation of the storage basins may even be carried a step further, according as connection is already, or will be arranged, not only between the power plants along the same river, but also between plants of different rivers. The storage possibilities in different rivers being essentially different, the water in the lakes of an over-regulated river may be utilised for generating power for transmission, during low water periods, to the power plants in a river where the storage possibilities are not so good.

This is what I think should be said, in a few words, about the present standard of storage engineering in Sweden. In the following, some data may be given regarding accomplished or projected storage works, and the great influence of lake storage upon the future development of Swedish water power.

As the regulation of the greatest lakes of the country involves very comprehensive works which require the support of great power developments, and a systematic co-operation between the interested plants, and which could not be carried through by the aid of the

existing Water Law, the attention was at first focussed on lakes of small or medium sizes, and a great number of such lakes have now been regulated.

Although these undertakings have not been very far-reaching, they have, at any rate, played an important rôle in the development of the water power resources of this country. As an illustration of the result even of rather small storage works, it may be mentioned that the city of Boras, a centre of the Swedish textile industry, is specially supplied with very cheap power from two plants arranged for eight hours load and designed on the basis of storage in two lakes, for a maximum water supply of 20 cubic metres per sec. (about 700 cu. ft./sec.), which, as a matter of fact, is practically always available for the industrial load during the working hours of the day. The minimum flow of the same river before the regulation, was as small as 0·6 m^3/sec. (20 cu. ft./sec.). The greatest storage undertaking, so far carried out, was recently accomplished in the northernmost part of the country, where a storage basin has been created in Lake Suorvajaure up in the mountain regions, with a view to increasing the capacity of the State plant at Porjus. It is estimated that by the aid of this storage, the minimum flow of the river will be increased to 40 m^3/sec. (about 1,400 cu. ft./sec.) This figure will be further increased to about 100 m^3/sec. (3,500 cu. ft./sec.) after a more complete regulation of the lake at a future date.

For a great number of rivers, regulation companies have been formed by co-operation between the interested private parties, sometimes also in collaboration with state and municipal organisations; the majority of these companies have been organised in accordance with schemes elaborated by the above-mentioned *Vattenbyggnadsbyran* upon the initiative of its former director, *Sven Lübeck*, at present Minister of Communications. Through such companies, a number of storage works have already been completed and preparatory new works of great importance have been started. The most comprehensive work in this respect has been done by " Dalälven's Regleringsförening " (The Regulation Company of Dal River), which has already carried out many important storage undertakings. Among the works of this company, now proceeding, the legal preparations for the regulation of Lake Siljan, one of the greatest lakes of the country, is the most important. The regulation of this lake is likely to be carried through in the immediate future. Among the storage works already completed by the same company it may be mentioned, as an example of

" over-regulation," that in three lakes of a tributary river, storage basins with a total capacity of 310 million cubic metres (11 milliard cu. ft.) have been created, by the aid of which the flow to the lakes—after the power plants further down have been interconnected—may be almost entirely impounded during the wet summer seasons and drawn off during the low water periods of the winter. The flow during these latter periods, which has sometimes been as low as 2·5 m^3/sec. (about 90 cu. ft./sec.) and as an average 6·0 m^3/sec. (about 200 cu. ft./sec.), may be increased to an average of 20 m^3/sec. (about 700 cu. ft./sec.) This increase of the flow may be utilised in a total head of fall of nearly 200 metres (about 650 ft.)

Concerning other great storage works, which are now in preparation, it may be mentioned that in the river Lagan, which is very important for the power supply in Southern Sweden, the local regulation company has started preliminary works for the regulation of three lakes by which it is estimated that the normal low water flow may be increased from 18 to 45 m^3/sec. (about 600 to 1,600 cu. ft./sec.). In recent years the State has carried out very comprehensive preliminary works for the regulation of the biggest lake of the country, Lake Vänern, with an area of 5,570 square kilometres (2,150 square miles). The regulation of this lake will play a prominent part in the future power supply of Southern Sweden, as the enormous reservoir being created in this lake—in combination with the State's vast possibilities of power transmission between the power plants in different parts of the country—may act as a clearing for economising the water in a number of other river systems, and may thus become the best model of a storage basin, which, by means of a hydro-electrical regulation between different rivers, may be utilised in the most economical way for the country.

Regarding the importance and the extent of the interconnected water power plants of Sweden already established and proposed, I beg to refer to an account of this given by *W. Borgquist.*[1] The fundamental principles on this problem have been dealt with also by *Sven Lübeck* in his article on " Future Prospects of Sweden's Water Power."[2]

The great importance that the lake storage is expected to have for the future utilisation of the Swedish water power resources may, to some extent, be illustrated by the figures obtained from the

[1] See " Economic and Technical Organisation of Large Scale Power Distribution in Sweden," by W. Borgquist, Transactions of W.P.C., Vol. III.

[2] " Hyllningsskrift tillägnad F. Vilh. Hansen " (The Hansen Testimonial) 1922.

investigation of the possibilities for regulation of the two greatest rivers of Sweden, Indalsälven and Lule Älv, flowing through the northern part of the country. Concerning the former, it is estimated that, by regulating its greatest lakes, the present low water flow, in a section of the main river with a total effective head of fall of at least 225 metres (740 ft.), may be increased from an average of 70 to an average of 225 m^3/sec. (about 2,500 to 8,000 cu. ft./sec.). As to Lule Älv, the low water flow in a section of the river with a total effective head of fall of over 300 metres (about 1,000 ft.) is expected to be increased in the same way from 50 to an average of 250 m^3/sec. (about 1,800 to 9,000 cu. ft./sec.).

Although the estimates that have been made of the additional power, obtainable in the future by means of a general regulation of the lakes of this country, cannot give any exact values, it may be mentioned, at all events, that the results so far seem to indicate that the natural low water flow in the Swedish rivers represents a total power, worth developing, of 2 to 2·5 million kW., and that this capacity, by means of utilising the storage possibilities of the lakes, might be increased to 4 to 5 million kW. The corresponding increase of the energy during the low water periods has been estimated at 4 to 5 milliard kW.-hours per year, *i.e.*, an amount of energy fully corresponding to Sweden's total normal import of coal, which now amounts to about 4 million tons per year.

Naturally the costs involved in the regulation of the lakes vary considerably, and at the present prices they may fluctuate from a few thousandths of a penny for each developed kW.-hour, for the great lakes in the mountainous regions in the North, if the power is fully utilised, up to one to two-tenths of a penny for some lakes in the southern part of the country, where it is necessary to calculate with more or less considerable compensation to the riparian owners, even when the storage height, *i.e.*, the maximum difference in the water levels of the regulated lake, is very moderate.

In the introduction it was pointed out that the benefit of an increased low water capacity is not only the value of the additional kW.-hours during the low water periods, but also that the second rate power of the non-regulated river is converted into power of higher rate. Keeping in view the figures which have been presented above, regarding the amount and the price of the total increase of power obtainable by regulating the lakes, and considering the possibilities offered by such regulation to counterbalance local and temporary irregularities in supply and consumption, the splendid contribution of a scientific utilisation of the storage

possibilities of Sweden's numerous lakes to the development of its water power, is obvious.

RÉSUMÉ.

L'utilisation des forces hydrauliques en Suède est très favorisée par sa configuration topographique qui permet, ou une régularisation du débit, ou l'utilisation de réservoirs compensateurs (journaliers ou hebdomadaires).

Ses nombreux lacs, souvent d'une grande superficie, admettent la retenue de l'eau en temps d'abondance pour la fournier en nouveau en temps de pénurie. L'utilisation de ces réservoirs naturels s'obtient généralement à l'aide d'une dépense faible en comparaison avec le gain d'énergie. Aussi la régularisation des lacs, formant une partie importante dans l'exploitation des forces hydrauliques en Suède, a beaucoup contribué à les faire valoir.

L'intérêt, qui en est résulté a amené un assez grand développement dans le traitement théorique de ces problèmes, dont un résumé est donné. Grâce à une législation moderne on a trouvé un bon moyen de coopération à l'aide des " Associations pour la régularisation des cours d'eau," qui s'occupent non seulement de l'éxécution des travaux, mais aussi du service de la régularisation et de la répartition des dépenses.

En reliant entre elles les usines hydro-électriques, permettant des échanges d'énergie, on utilise les réservoirs de manière que le gain commun d'énergie soit le plus grand possible. Pour pouvoir bien a ménager une telle " régularisation hydro-électrique " il est nécessaire d'avoir étudié scientifiquement le régime hydraulique et les variations de la demande d'énergie pour en concevoir les règles générales pour l'utilisation des réservoirs.

Le prix de revient de l'énergie gagnée par ces régularisations varie, au prix d'aujourd'hui, de quelques centièmes d'un " öre " par kWh. dans les cas les plus favorables dans les montagnes du nord de la Suède jusqu'à 1 " öre " dans les endroits les plus cultivés du sud.

L'importance de ces régularisations est illustrée par quelques exemples choisis parmi les régularisations accomplies ainsi que parmi celles à l'étude. On comprend l'importance au point de vue du développement futur, si l'on considére que pour toute la Suède le nombre de kW. à l'étiage, facilement utilisables, est estimé à 2 ou 2,5 millions, mais que cette puissance peut être augmentée jusqu'à 4 ou 5 millions de kW. par la régularisation des lacs. L'énergie gagnée s'élève à 4 ou 5 milliards de kWh. par an, c'est à dire à une quantité plus grande que celle qui peut être produite par toute la quantité de houille que la Suède importe, et qui se monte actuellement à environ 4 millions de tonnes par an. On conçoit la grande valeur nationale que présente l'utilisation des nombreux lacs de la Suède.

GENERAL CONDITIONS GOVERNING WATER POWER PRODUCTION IN SWEDEN

A. EKWALL

INTRODUCTION.

The energy produced by the development of a waterfall is, in respect of the conditions for its economic utilization, on an equal footing with any other production of commodities, i.e., it is subject to the economic laws of supply and demand. Supply in this case consists of the presence of water with a suitable fall, and the demand depends on whether other sources of energy are available which may compete with the hydraulic power. The nature and extent of this demand will be detailed later on. Competing with water power is energy produced by coal or oil in motors or steam power plants and, in certain parts of the country by wind motors. With regard to the production of goods for export, Swedish water power has also to compete with that of other water power countries: Norway, the Alpine countries, North America, etc.

SWEDISH RESOURCES OF WATER POWER.

It is calculated that the amount of Swedish water power worth developing and available for nine months in the year amounts to about 6 million H.P. Of this quantity, about 1·4 million H.P. or somewhat more than 20% has hitherto been developed. The resources are very unevenly distributed over various parts of the country as will be seen from Mr. F. V. Hansen's paper on " The Power Resources of Sweden " to be presented at this Conference.* It will be observed that the most important resources of water power are situated in Upper and Middle Norrland, where the proportion developed is relatively low. In Southern and Central Sweden the most valuable waterfalls have already been made use of. This is due to the fact that in these latter parts the density of population is greater and industry more developed, and that previously to the introduction of electric power distribution the iron industry, in

* See Transactions of W.P.C., Vol. I.

particular, made use of a large amount of water power either for direct drive or through mechanical transmission from water wheels and turbines.

HEIGHT OF FALL.

At existing Swedish hydraulic power stations the head varies between a very low and a relatively high figure very seldom above 100 m. There are in Sweden no actual high pressure plants with drops of several hundred metres of the type built in the Alpine regions and in Norway. The largest proportion of water power stations in Sweden is found under relatively low falls, viz., largely between 4 and 8 m.; but also between 8 and 15 m.; more rarely between 15 and 50 m. Only a few plants have been built with heigths of 50—100 m. or more.

THE RELATIVE VALUE OF LOW AND HIGH FALLS.

Naturally, the low falls are more expensive per effective unit of power developed as, of course, both the buildings and the machines installed have dimensions depending in a great degree on the volume of water consumed, while the power produced is directly proportional to the height of the fall. One may, however, say that a considerable improvement has been brought about in recent years in the costs of developing lower falls, partly by the employment of single runner turbines giving much larger units, i.e., a smaller number of turbines and therefore cheaper constructions than before. In addition, the possibility of increasing the specific speed of these turbines has brought down the cost of electric generators for direct coupling between turbine and generator shafts. For falls of medium head, i.e., between 15 and 50 m., the first cost has usually exceeded that of greater heads and even that of actual high pressure plants with only a small amount per H.P. The additional difficulties in developing extremely high heads, often due to the inaccessible situation of the fall, necessitate the construction of expensive transport lines and the use of special devices for tubes and their protection against "water hammer," etc., arrangements seldom needed for power stations of medium head.

EXAMPLES OF PRESENT PLANTS.

As an example of a modern power station with low head, one now under construction at Lilla Edet on the Göta älv may be mentioned, which, as shown

on the cross section (Fig. 1), has a head of about 6·5 m., and will be equipped with units of 10,000 H.P. The discharge through each turbine is about 150 cu. m. per sec.

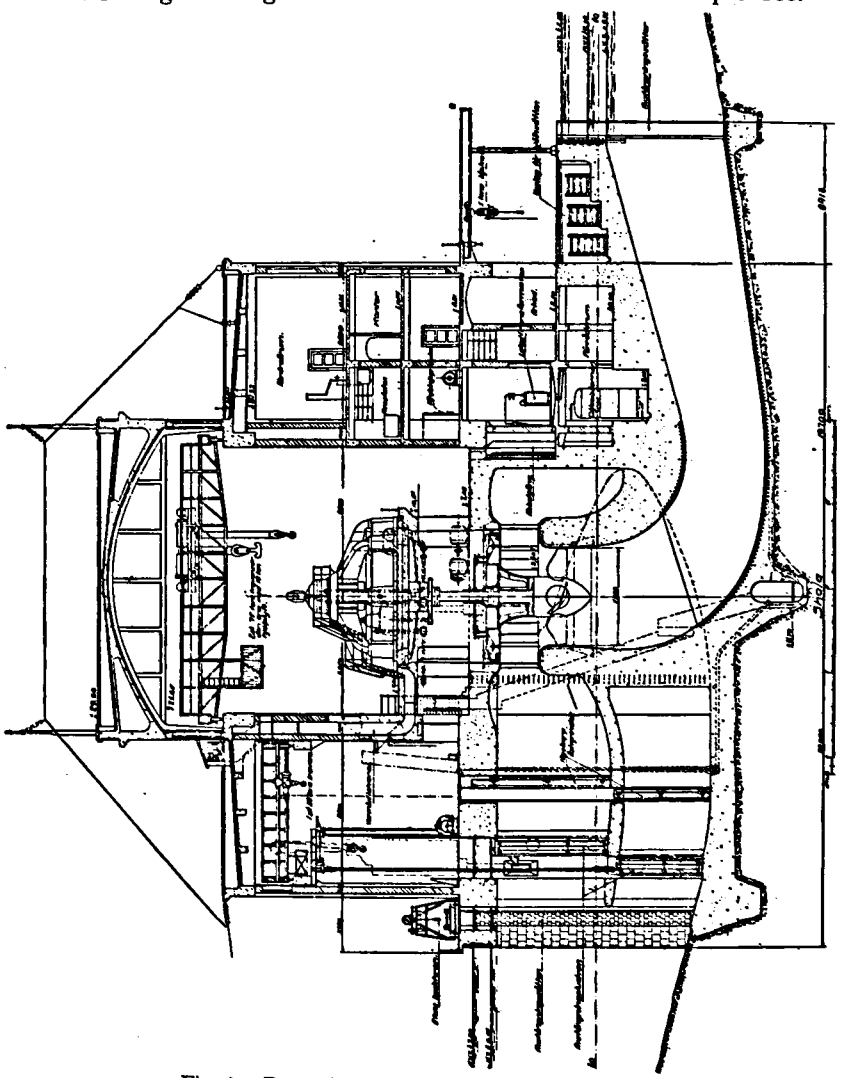


Fig. 1. Power Station at Lilla Edet. Cross Section.

Accordingly these turbines will probably be the largest turbines in the world with regard to the amount of water discharged. The power station at Trollhättan with a head of about 30 m.

(Fig. 2) is an example of a power station with medium head. The turbines installed are double runner Francis turbines of 10—13,000 H.P. with horizontal shafts enclosed in pressure casings. A high pressure plant with somewhat more than 100 m. fall has been commenced at Harsprånget (Fig. 3), but its completion has been deferred on account of trade depression. It will probably be equipped with vertical single runner turbines of 25—40,000 H.P. each, and with the power station blasted into the mountain itself, in which case the water from the turbines will be returned to the river at the foot of the fall through a tunnel, 5·5 km. long.

PROBABLE FUTURE DEVELOPMENT.

A. Height of Fall.

The future development of water power with regard to the head employed, depends in the first place upon the height of the natural waterfalls. As in a very large number of Swedish rivers the gradient is slight, efficient utilization of the water profile, where the width of the river and the condition of the ground allow it, the development certainly will take place with comparatively high heads, brought about by means of high dams. Long rapids and cataracts will be dammed up, and a storage reservoir, very desirable for the operation, will be thus obtained above the power station. In many rivers it is, however, not permissible to build high dams on account of the existing settlements in the valley, which, of course, must not be damaged to any great extent for the sake of the water power development. This, together with the high cost of dams, will generally limit the height of the steps to about 8—15 m. In many cases the concentration of the fall is attained by the construction of long supply channels, open tailraces or tunnels along the river. The cost of the dams is thus considerably reduced.

RIVER TRANSPORT.

River and canal traffic has, in a few rivers, a certain influence on the development of water power in Sweden. This influence, however, is of less importance than in a number of European lowland rivers, where boat traffic takes place in the natural channel. The development of the water power certainly reduces the velocity of the current, but, on the other hand, the

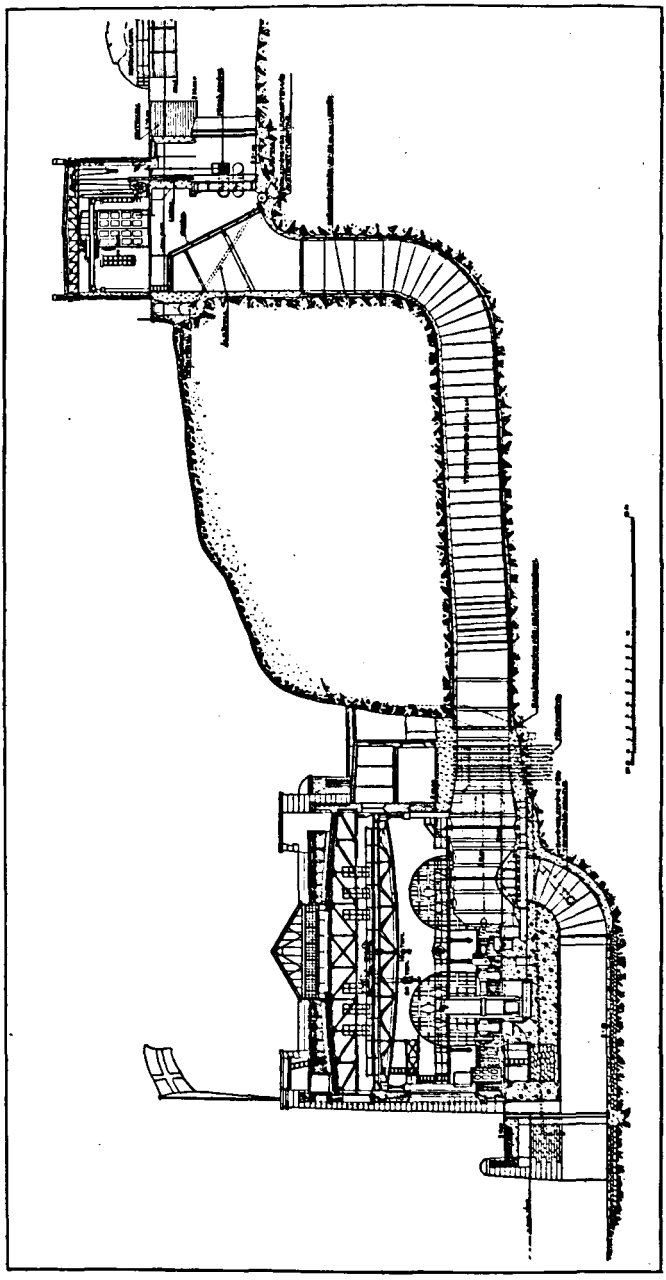


Fig. 2. Power Station at Trollhättan. Cross Section.

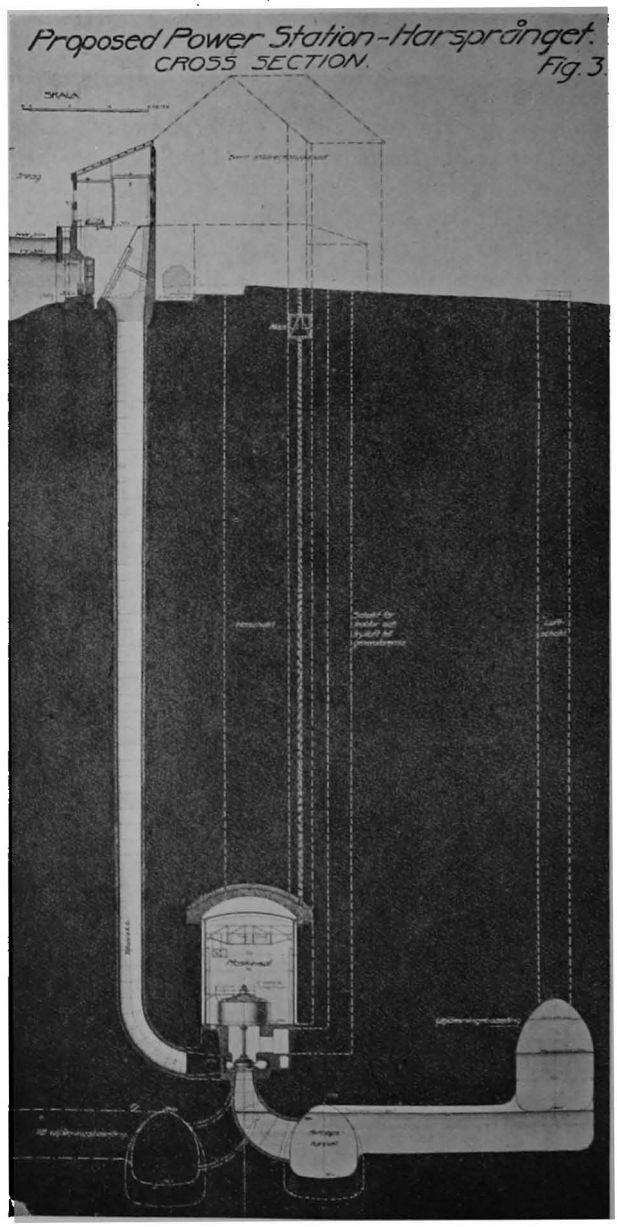
necessary introduction of locks at the power station will be of some hindrance to navigation. Such traffic occurs only rarely in Sweden on account of the geological fact that the ground of the country generally consists of primary rock or else of moraines or glacial clay. The rivers therefore form concentrated falls in passing rock cliffs and form rapids where they pass through moraine formations, but flow very slowly through country with deposits of clay. It is only in these latter sections that the speed of the current is sufficiently low to allow river traffic, but there, on the other hand, the difference in water level is usually too small for any power development of importance.

CANALIZATION.

In connection with the development of water power it is, however, possible to canalize the river in a more suitable manner than otherwise. This has, for instance, been the case in Göta älv at Lilla Edet, where the river has been stepped up 2 m. to advantage both for the reconstructed Trollhättan canal and for the power station under construction at Lilla Edet, the head of which was increased from 4·5 m. to 6·5 m. The advantage to the canal, which is now able to take vessels of 4 m. draught with a cargo of about 1,300 tons, was represented by the fact that a lock which otherwise would be necessary in the river, could be dispensed with. In this way suitable co-operation may take place between the water power interests and the canal interests, since it is to the advantage of both to concentrate a larger number of small falls and rapids in a few larger falls and between these to have distances of slow current.

B. Quantity of Water.

The water power available depends, both on the *head*, and also upon the *quantity* of water in the river, which again is dependent on rainfall, evaporation, percolation and the natural storage capacity of existing lakes. The rainfall varies between the relatively low figure of 4—600 mm. per annum in the Eastern districts of the country, to 6—800 mm. in the West, near Gothenburg, but in certain mountain regions, especially on the Norwegian border, it reaches 1,500 mm. or more. Evaporation and percolation depend on the geological conditions and the occurrence of forests, and therefore vary considerably. After deduction of these factors the average volume of water per annum amounts to about 50% of the rain-


Proposed Power Station - Harsprånget.
CROSS SECTION.
Fig. 3.
SKALA

fall. In certain districts it goes down to about 35%, in others it may reach 60—70%. The higher figures are generally for the northern mountain rivers, where the ground as a rule is hard, resulting in a small percolation. Above the forest boundary the absence of woods in combination with the cold climate causes the annual evaporation to be relatively low, providing further reasons for the high percentage of flow. The natural lakes which are peculiar to the Swedish landscape, and which are found in very large numbers along most of the rivers, have been formed by flooding the lowlands, where the rivers pass over rocks and moraines.

With the exception of a number of relatively small lakes throughout the country, the Swedish lakes may be classified into the following two groups. The first group consists of four great lakes (Vänern, Vättern, Mälaren and Hjälmaren), all located in central Sweden. Of these Vänern is the third largest lake in Europe. The second group of lakes consists of a number of lake systems along the rivers in the northern part of the country between the Norwegian border and the "Inland" railway, which runs through the country parallel to the coast. These lakes form a valuable property in their natural storage capacity by equalizing the flow of water and facilitating further regulation in order to adapt the quantity of water during various times of the year to the power consumption.

THE DEMAND FOR WATER POWER.

As mentioned in the introduction, water power has to compete mainly with coal and oil. Although there is in Sweden only a little coal, and consequently nearly all the coal has to be imported, mostly from England, the price of coal in many places of consumption compares favourably with water power, due to relatively low freight rates. This is above all the case for industrial and domestic heating purposes, for which latter purpose, however, wood may often be used with greater advantage. For the distribution of electric power, coal fired steam power plants may be employed, especially when the power is used for only short periods during the year. It seems, however, that during the last few years small steam central stations are unable to compete with water power on account of the relatively high running costs, while, on the other hand, modern large steam central stations with mechanical devices for transport and stoking and very large steam turbine

generators, are serious competitors. Large hydraulic power plants nowadays often install large steam stations as supplements, in order to meet peak loads of short duration.

Internal combustion engines are, of course, principally used for motor vehicles and for the propulsion of vessels. Electric automobiles will probably find increasing use for land transport with the improvement of electric accumulators. With regard to stationary engines, it is only for small local requirements, or as reserve, that motor power can compete with water power.

Finally, considering the wind power, windmills were formerly used to a great extent in Sweden, especially for grain grinding, but, since the distribution of electricity has become more common throughout the country, most of these windmills have been replaced by electric mills.

POSSIBILITIES OF DISPOSING OF POWER.

The factors governing the development of water power on a large scale are, as indicated in the introduction, dependent on the possibilities of disposing of power for such purposes as can pay prices satisfactory to the owners of the power plant. In Sweden, two main types of power consumption may be separately considered, on the one hand, light and motor power in towns and in the country, and on the other hand, industrial requirements other than the driving of motors, i.e., for electro-chemical and electro-thermal purposes. The former requirement, which generally speaking, is proportional to the density of the population, is greatest in the southern and central parts of Sweden, where about 4/5 of the population is to be found. Of the latter, the consumption of power has been due, mainly, to the electro-chemical factories for the production of fertilizers, carbide, etc., and the electro-thermal requirements in the production of iron, ferro-alloys, zinc and similar products. As far as the production of iron is concerned, these industries are principally located in central Sweden, where the large deposits of iron ore have for a long time promoted the growth of an extensive iron industry. As, however, large iron ore deposits in upper Norrland are now being exploited, principally for export purposes, it is probable that the electric production of pig-iron will be taken up on a fairly large scale in the vicinity of these deposits. Other electro-chemical and electro-thermal industries are not to any great extent dependent on the proximity of raw material, but they must be situated at points

where cheap electric power is available in abundance. As this is no longer the case in southern and central Sweden, the future development of these industries must lead to its gradual shifting further north ("Norrland") where large unexploited power resources can be employed.

Long extra high tension power transmission will increase the possibility of utilizing the water power of Norrland, for which reason it is anticipated that the hydraulic power available, at any rate in central Norrland, will quite soon be carried south to supplement that of southern and central Sweden, where the available power will soon be insufficient.

After this short account, showing the dependence of hydraulic power development upon supply and demand, the description of the hydrography of the Swedish river basins and the various possibilities of development arising therefrom, we will briefly deal with the method of design and construction which appears to be best suited to the conditions as to the cost of plant and to running expenses, and at the same time to retain adequate security. Later we shall discuss the question as to how the economic exploitation of water-power is facilitated by the regulation of the flow, combining this question with that of co-operation between a number of power stations.

LAYOUT.

TYPE OF MACHINERY.

Having decided upon the most suitable head with regard to the various interests concerned, there remains to be found a suitable type of machinery, size of unit and corresponding buildings, cranes, etc. The development of modern concrete construction facilitates hydraulic construction of requisite durability to the extent that almost any requirements may be filled as to the size of the intake and pertaining arrangements.

SIZE OF MACHINERY.

As to turbines and generators, these, too, have recently been greatly increased in size. This is especially due to the perfection of the vertical type of machine, which was in turn made possible by the design and manufacture of thrust bearings to support safely the very heavy load of the generator and turbine in addition to the hydraulic thrust on the turbine vanes. The maximum thrust on one of the bearings at Lilla Edet is 440 tons. As the size of the generators even formerly, on

account of railway transport, necessitated their assembly on site, there does not appear to be any great difficulty for the manufacturers in dividing up their generators still further with a further increase in size. With regard to turbines it has hitherto been considered that the size of the machine would be limited by a runner which would permit of railway transport. This requirement is not as a rule difficult to fulfil, when it is a question of turbine constructions for falls of average height, i.e., above 15 m. or more. For very low waterfall conditions modern rapid running turbines have the appearance of propellers. In comparison to Francis turbines, the number of vanes has been greatly reduced, and consequently the space between them increased, thus facilitating the use of vanes separately made and rigidly bolted to the hub. Large turbine runners of this type may be assembled in their final position in the power house. The largest turbines constructed in this manner are no doubt those now being built for the power station in the Göta älv at Lilla Edet for a fall of 6·5 m., and with a diameter of about 6 m. (20 ft.). The volume of water for one of the turbines reaches about 170 cu. m. (6,000 cu. ft.) per second. In the development of low falls in large rivers it is possible that even larger turbines might be employed, but in most cases the size of the machinery is limited by other factors. Thus in the case of power stations intended to supply a certain district or a certain industry, one must arrange for the necessary reserve of power in order to allow for the repair of machinery and to use the available water at a varying load with good efficiency. It is therefore not advisable in smaller rivers to utilize the entire energy in a single turbine, unless the necessary reserve can be obtained by co-operation with other power stations, and unless smaller requirements of power can be supplied by smaller turbines at one of the co-operating plants. Even for installations where a storage basin permits of complete control of the quantity of water required for different loads, the number and size of units should be determined so that too low efficiencies may be avoided, no matter whether a reduction in efficiency is the result of too low or too high loads on the various machines.

RESERVES.

Concerning the necessary reserve, it was formerly held that each water power station should have so many machines that

one of them could be entirely shut down for thorough inspection, and that in the case of a slight repair of another machine, the remaining machines should be able to take care of a certain overload, thus supplying the power for which the plant was designed. As, however, modern turbines and generators have generally proved free from breakdowns, it has been found possible to reduce the requirement of machine reserve, particularly when hydraulic power stations are interconnected with each other or with steam power plants. It would therefore seem sufficient for larger plants to have one unit as a reserve. For plants of less importance the reserve may generally be dispensed with.

RUNNING EXPENSES.

In a modern water power station the running expenses are generally low compared with interest and amortization of the capital and with depreciation. Running expenses are generally lower for larger machine units. As an example, a power station with 10 machine units may not be left to one mechanic, who on the other hand probably would easily supervise 3 large machines of the same total output. Similarly the consumption of lubricating oil, etc., will be lower for a small number of large machines than for a larger number of small ones. The maintainance, too, is generally cheaper per horse-power in large machine units.

STOPPAGES.

These may arise, apart from faults in the hydraulic construction work or machinery, by substances in the water, such as sand, leaves, timber, but particularly by ice. Accumulations of sand and gravel, which in many rivers are a great nuisance to hydraulic power plants, are of comparatively rare occurrence in Sweden on account of the large number of lakes and smooth sections of rivers in which sand and gravel, carried by the more rapidly flowing tributaries, are deposited. The occurrence of leaves and other impurities in the water may at times be quite inconvenient, but by suitable arrangement of the screens in front of the turbine inlets the leaves may be removed by scraping.

LOGGING.

Logging is practised to a considerable extent in most Swedish rivers, the logging of raw timber being the cheapest method of transportation from the inland forests to the coast, where

the saw mills and pulp mills are located. Logging is, however, only possible during the summer, at which period the amount of timber transported may be very large. In certain rivers it amounts to 8 or 10 million logs each summer. When this quantity of timber is to pass waterfalls or rapids, difficulties often arise in the form of timber jams, whereby the logs in shallow water heap up in enormous quantities and prevent further logging. The construction of water power stations will reduce these inconveniences if thereby the river is stepped as referred to above, concentrating series of low falls and rapids in one plant by damming up the river. On the other hand the transportation of the floated timber past the regulation dam is often a difficult problem to solve. With high water in the river the timber is allowed to pass through the dam and into the natural river bed, but when the water is low the floating timber is guided in special logways through the dam to the still water below the power plant. The planning of these logways and the devices necessary to lead the timber to the inlet of the logway are questions which during the last few years have been the subject of close study at a number of plants. Generally speaking, the difficulties and the increased expenses imposed upon logging operations, owing to the exploitation of water power, are fully compensated by the reduced trouble from jams in the river in its natural state.

ICE.

The greatest disturbances to the plant are those caused by ice which, on account of the northern situation of Sweden and the consequent low temperature in winter, may be very thick. For the reasons above indicated, the rivers are, however, either naturally stepped down between lakes and smooth river stretches or artificially stepped in connection with the development of water power. It may therefore be said that there are no great difficulties with drift ice in the rivers in Sweden. When the warmer weather sets in the ice melts on the lakes without being carried down to the power stations in great quantities. Difficulties may, however, arise in the early winter during snowfalls and simultaneous cooling of the water before a cover of ice has formed on the river just above the power station, owing to the water becoming mixed with snow and ice needles. On account of the whirls in the water at intakes, supply channels, &c., leading to the power stations, finely divided ice

from the surface becomes spread throughout the entire mass of water and fastens to the screens, gate supports, etc., at the intake chambers in the power stations. If no special measures are taken, the entire flow of water to the plant might thus be stopped, as such ice crystals very soon completely close the openings between the screen bars. In falls of average height or in higher falls, such as at Älvkarleby and Trollhättan, with about 15 to 30 m. drop, this inconvenience has been overcome by warming the screen bars by means of low tension electric current. The waste of energy for this purpose is under heavy ice conditions about 15 kW. for each cu. m. of water per sec. passing through the screens, corresponding to that produced by a fall of about 2 m. In the case of low falls this method is therefore not economical as, besides the initial cost of plant, it results in the waste of a considerable proportion of the energy. For plants with large turbines, which consequently have deep screens, etc., involving considerable difficulties for the mechanical removal of ice, the problem has generally been solved by temporary removal of the screens when necessary in order to allow free entry of the water into the turbine.

In the case of installations in the northern part of the country, such as Porjus, 50 kilometres north of the Arctic Circle, ice difficulties have proved to be considerably smaller in spite of a more rigorous climate than further south. This is due to the fact that the plant at Porjus, by means of a closed feed water tunnel, takes its water direct from a large, artificially dammed lake, in which the velocity of the water is low and where therefore the ice cover is formed very rapidly. Once the surface ice has settled there is no risk of the formation of ice needles. The future exploitation of the water power in Lule älv below Porjus will probably be carried out in such a manner that the falls will be developed one by one, starting with the upper one. In this way the turbine water will never come in contact with the cold air but will be taken in to the first power station from the lake above it and pass through this plant in tunnels and closed conduits, being carried under the ice to the intake lake of the next plant.

On account of the natural conditions at the site some plants must have open supply channels in loose earth. In such plants, difficulties arise during the winter by the thick covering of ice which reduces the efficient section of the channel and consequently the power output of the station. It is therefore

advisable, particularly in the northern parts of the country, to avoid the construction of earth supply channels with slow current.

WATER REGULATION.

In planning water power stations for supplying power for single purposes with continuous running, such as for pig-iron production, the manufacture of electro-nitrate, etc., it is a simple matter to arrive at the correct capacity for the power station. This must simply correspond to the total power requirements of the industrial plant. By regulating the lakes of the river basin, it is endeavoured to obtain as far as possible a constant flow of water. Naturally, this may be done only to some extent, due to the amount of excessive water, which will have to pass the power station after periods of continuous rain or during the rapid melting of the snow.

In most cases, however, the large hydraulic power stations supply energy for a great variety of purposes. The existence of a requirement such as that just mentioned of a continuous nature throughout the year, day and night, Sunday and weekdays, represents a fixed constant increase to the required quantity of water and to the size or number of units.

DAILY VARIATION.

As an example to show how the load varies, the total consumption in that portion of central Sweden which is supplied by the State power stations in that district, has been chosen. The power stations consist of those at Trollhättan, Älfkarleby and Motala, with a total machinery installation of about 175,000 kW., co-operating with a steam central station at Vesterås of 40,000 kW. The total length of transmission lines of 10,000 volts or more is about 4,500 km. After deduction of the power used for electro-thermic processes and of that which may be used at periods of high water for steam generation by electricity, mechanical pulp mills, etc., the remaining part will be the amount of the variable load in that portion of the country. This, accordingly, includes power requirements for lighting and for the running of motors in towns and rural districts, for industry, agriculture, communications, etc.

Fig. 4 is a diagram showing the normal variation of the power consumption during week days. The upper curve represents the load variations for the winter, the lower one for the

summer. During week days two load peaks are apparent at 9 a.m. and 4 p.m. respectively, being heaviest in the winter. The altitude of these tops as well as their time of occurrence are greatly influenced by the energy required for light. In the summer when this demand is slight the peak loads occur at 10.30 a.m. and 4 p.m. respectively, with a smaller peak on account of light at 10 p.m. The great decrease in load at

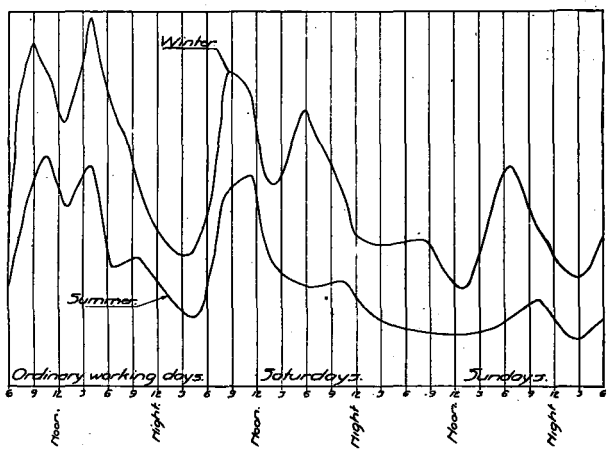


Fig. 4.
Diagram showing typical load variations for Government Power Stations in Central Sweden.
(Power required for electro-chemical and electro-thermal purposes and for steam generation is deducted.)

noon is due to the stop for lunch at factories and farms and to the trifling demand for light at this time. The continuous difference between the loads of winter and summer is due to the greater demand for electricity in the winter for the purposes of light and heat. The maximum load for an ordinary working day exceeds the average by about 50% both in winter and summer.

WEEKLY VARIATION.

For the variation of the load during one week a typical load curve is shown in Fig. 5, which is a diagram over the total consumption for the above mentioned purposes during one calendar week. The first five days of the week show an equally high consumption of power; Saturday is distinguished

by a marked drop due to the fact that many industries close at noon. During Sunday the power consumption is still smaller, most industries being entirely idle and the only requirements being for communications and light.

In Fig. 5 is shown the typical variation of load for Saturday and Sunday. The relative amount of energy required for light is apparent by these curves, particularly for Sunday afternoon during the winter. The consumption of power during each of the first five days of the week exceeds the average consumption of the week by about 10%.

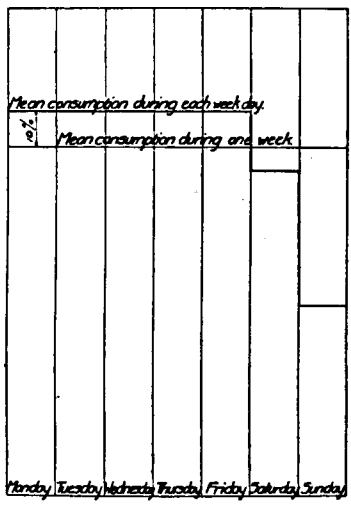


Fig. 5.

Diagram showing power consumption for one week.

YEARLY VARIATION.

Finally, in Fig. 6, the variations in the average consumption per week for a total year is shown. The relatively smaller consumption during the spring and summer months, compared to the autumn months and winter, are apparent. In addition, it will be seen from the diagram that there is a very marked decrease in the use of energy during the more important holidays, especially Christmas and New Year, Easter and Midsummer, when practically all factories are idle for some time.

The figures given in respect of the consumption thus indicate very large variations, not only during the day but for the week and the year as well, in spite of the fact that a number of restrictions have been introduced in the majority of agreements with the object of reducing the consumption when there is a shortage of power. Thus, in most contracts a certain increase in the charge for power is stipulated at periods with a smaller flow of water in the river.

In other contracts, especially for agricultural consumption, a

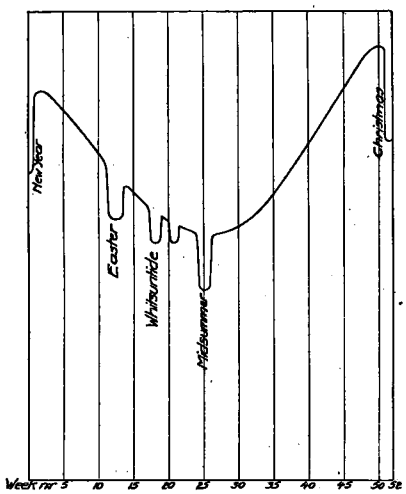


Fig. 6.
Diagram showing power consumption for one year.

higher charge is made during times of great demands for light, but a lower one at other times of the day.

In addition a fixed charge for maximum kW. plus a relatively low charge per kWh. is usually stipulated in the contracts in order to encourage the consumer to take the greater part of his required energy at times of low load.

SIZE OF PLANT DEPENDENT ON POSSIBILITIES OF REGULATION.

If the hydraulic power station were to be designed so that the entire consumption could be met by water power, the size of the power station would stand in the following relation to the volume of water flowing in the river. By reason of the

variation of the power consumption during the day, the size of the power station would have to be increased by 50% and, as a result of the weekly variation, this figure would again be increased by 10%. Owing to the possibility of saving water by the reduced consumption during the long holidays, a further increase of about 5% would be necessary. Finally, by the carrying out of a regulation covering the year, the degree of development otherwise corresponding to the economic figure would have to be increased by a further 50% in order to correspond to the ratio between the maximum consumption per week and the annual average. Thus, the machinery installed would represent: 1 × 1·5 × 1·10 × 1·05 × 1·50 = 2·60, corresponding to the required degree of development if all the above indicated regulating measures were to be taken into account.

If one compares, for instance, the flow of the river Dalälfen throughout the year with the variations in consumption at different periods of the year, it is evident how little the supply corresponds to the demand for water power. When the demand has its maximum, i.e., at the end of the year, the supply is generally insufficient, and this shortage becomes still more apparent during the winter. During the spring and summer months, when the demand has its minimum, the supply is greatest on account of the melting of the snow. The annual regulation which may be made in the Dalälfen is moderate, and will probably increase the natural low water quantity by only about 45%. This circumstance is, of course, dependent on the special nature of the shores of the lake systems. With regard to daily and weekly regulation of the Dalälven conditions are somewhat more favourable. By the employment either of the dam reservoir above each power station or by the use of regulation facilities in the narrow lakes suitable for this purpose, good daily and weekly regulation may be obtained for most of the power stations.

In projecting hydraulic power stations, endeavour should be made to transform secondary power into primary power. This should be done by annual regulation as well as by daily and weekly regulations in order to transform night and Sunday power into working-time power.

It should therefore be observed that the waterways and power stations should be so located as to facilitate extension in case of the future employment of a considerably greater quantity of

water. During the relatively short periods of maximum loads a lower hydraulic and mechanical efficiency may be permitted for power stations where most of the water is utilized.

CO-OPERATION.

A number of Swedish river basins are lacking in natural regulation facilities. It has accordingly been found favourable for better agreement between consumption and production to co-operate various power stations, thus transferring the surplus of energy from one power station to a consuming district where there is a shortage. Such co-operation has already been introduced to a great extent by a number of power stations in Sweden. The advantage obtained by such collaboration depends to some extent on the variation in the natural flow of water occurring in the various rivers, but to a greater extent upon the varying possibilities of regulating the river basins and finally upon the fluctuations in consumption in the separate distribution areas.

By such co-operation and by simultaneous regulation of available lakes the resources of water power in the country are more completely utilized. Especially would the use of the great storage basin arranged by hydraulic regulation of the Lake Vänern be of service to large areas of southern and central Sweden. After carrying out such a regulation and establishing suitable co-operation, this lake would be a main accumulator for the water power in this part of the country, the flow in the Göta älv thus being made to correspond to the power requirements at any given occasion, provided that the co-operating power stations on rivers with smaller regulating facilities have made the best possible use of their water resources. Ordinarily, the accumulated water in Lake Vänern should be used during the winter, when most rivers are short of water.

FORECASTS.

The question as to how accurately this problem of utilization may be solved depends to a great extent upon the forecasts which can be made with regard to hydrographic conditions prevailing in the immediate future. In estimating the flow of water in rivers for the following summer, available statistical figures concerning the thickness of the snow-cover in the watershed areas provide a good guide. During the period of regulation, i.e., during the winter, one should accordingly be

able to judge the amount of stored water which could safely be utilized without risk of insufficient supply in the reservoir. More exact forecasts will probably in the future be based upon variations of temperature in the Atlantic and in the Arctic Ocean, and upon changes in weather conditions and consequent rainfall in Scandinavia. As these points become better known we shall gain in the direction of most efficient utilization of Swedish water power resources from the national economic point of view.

A gradually increased co-operation between different power stations is also probable in Sweden for the reason that the power requirements of central and southern Sweden must be filled by the transmission of power from central Norrland, above all from the Indalsälven and the Angermanälven, with a transmission distance of about 400 km. If in the future the transmission of power over still longer distances should prove successful, and particularly that between upper Norrland and southern portions of the country, a distance of over 1,000 km., this would open up prospects of important gains due to the comparatively easy possibilities for the regulation of the northern rivers. The entire rainfall could thus be collected in storage reservoirs and be used during seasons when power is most needed, i.e., when there is a lower water level in rivers with smaller regulation facilities. Such " super-regulation " of a river basin may prove to be suitable in the case of a combination of regulation and co-operation between the different power stations.

In the above account I have endeavoured to explain the conditions under which the production of hydraulic power is operating in Sweden and the directions which future developments are likely to follow. It would appear that Swedish water power production will have to meet severe competition, both from other water power countries and from other sources of energy, but that the comparatively favourable circumstances governing development, especially in connection with the regulation of rivers and co-operation between large power stations in various parts of the country will make possible the efficient utilization of the available water power. As Swedish industry has good technical resources, able labourers, and particularly important resources of timber and iron, which form a natural basis for the further development of industry, one

may expect a considerable expansion in the future of the Swedish water power production.

RÉSUMÉ.

Après un court compte rendu des chutes d'eau facilement utilisables et de leurs répartition entre les différentes parties de la Suède, l'auteur donne quelques exemples d'entreprises modernes hydroélectriques Suèdoises.

Il indique ensuite les possibilités techniques de développement dans l'avenir et qui dépendent essentiellement de l'amélioration du profil des rivières, qui peut être obtenu, en construisant des barrages sur les longs rapides et les petites cataractes. L'influence de ces changements dans le profil des rivières sur la navigation intérieure est examinée.

Après une étude de l'énergie disponible, concurrente à l'énergie hydraulique et des possibilités de pouvoir disposer d'une plus grande quantité d'énergie hydraulique, une discussion intervient sur les améliorations techniques probables des stations centrales hydrauliques. Dans cette partie, la construction de la centrale même est examinée, le progrès dans la construction des machines en ce qui concerne la dimension d'une unité ainsi que les machines de réserve nécessaires dans les stations hydrauliques. On signale que les trains de bois et la glace n'ont que peu d'influence sur l'utilisation de l'énergie hydraulique.

En projetant des stations d'énergie hydraulique on ne doit pas perdre de vue l'importance de songer aux agrandissements futurs qui peuvent être réalisés après la régularisation du cours d'eau. Cette régularisation peut être effectuée de trois manières différentes par rapport au temps: Régularisation de 24 heures, régularisation hebdomadaire et régularisation annuelle. En utilisant convenablement les possibilités sous ce rapport on trouve qu'une station centrale construite en vue d'une distribution ordinaire d'énergie doit avoir des machines ayant une capacité d'environ deux fois et demi la capacité d'une centrale construite sans considérer aucune régularisation du cours d'eau.

Suit une description indiquant comment l'énergie hydraulique peut être mieux utilisée en reliant entre elles les stations centrales de différentes parties du pays. Grâce à une telle coopération on utilise également beaucoup mieux les diverses possibilités de régularisation des différents cours d'eau.

Finalement l'auteur fait remarquer qu'en raison des circonstances favorables et en raison des possibilités de régularisation de l'alimentation dans les cours d'eau, on peut prévoir une augmentation continue du développement de l'énergie hydraulique en Suède, tant pour les besoins ordinaires de distribution que pour l'industrie. Les grandes ressources naturelles en minerais de fer et en bois font prévoir une augmentation de la demande d'énergie hydraulique, particulièrement de la part des industries fabriquant du fer et de l'acier, les bois et la pulpe de bois pour les besoins de l'exportation, ainsi que pour les usines utilisant ces matières premières pour leurs produits.

PLANNING OF HYDRO-ELECTRIC PLANTS WITH REGARD TO RELIABLE OPERATION

K. E. NYLANDER

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The first large Swedish power plant, the State hydro-electric power station at Trollhättan (first development begun in 1906), has a fairly complicated diagram of connections on the low tension side. The reason for this is that a considerable amount of power is directly distributed at generator voltage and that the station contains a great number of generating units. More recent generating stations have a much simpler layout. Right from the beginning, the unit

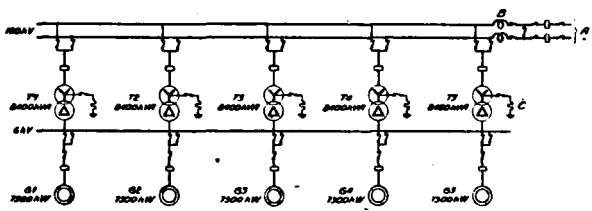

Fig. 1.
Diagram of Connection for the Untra Power Station.
A Transmission Line.
B Surge Coil.
C Earth Resistance.

principle has been followed as far as possible, the power stations accordingly being divided into a number of relatively independent generator-transformer units. This tendency has, during later years, become still more marked. An example of this is the Stockholm Municipal Power Station at Untra (first development begun 1912), see Fig. 1. Also from other State plants than Trollhättan, a good deal of power is generally directly distributed to large consumers in the neighbourhood and this has led to the adoption of a general scheme like that in Fig. 2, which refers to the Motala plant—the latest State development—as it will look when completed.

The unit principle, however, is usually not followed so far as to

make the operation quite dependent on every single part of the unit. Of the main unit (turbine and generator) practically absolute reliability is required. This unit must be able to run continuously without interruptions other than a short overhaul annually, for which the most convenient time may be chosen. The elimination of all risk of failure is naturally impossible in practice and a shut-down of a main unit on account of turbine or generator fault must be counted with, but it is usually required that the operation of main units should be independent of the reliability of auxiliary equipment, such as exciters, oil pumps and so on. For the auxiliaries and other vital parts, sufficient reserve is usually provided. Particular emphasis, however, is always laid on high reliability and practical arrangement of the different parts of the plant in order to make the risk of failure as small as economical construction will allow.

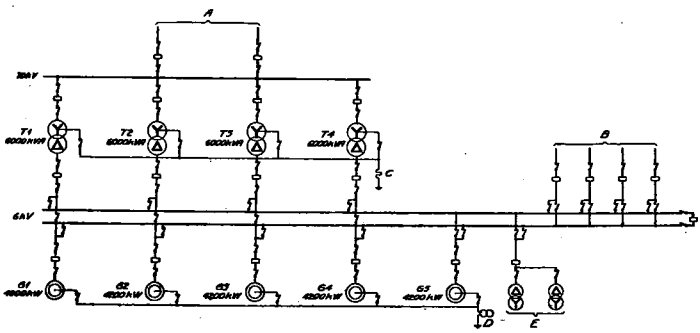

Fig. 2.
Diagram of Connection for the Motala Power Station.
A Transmission Lines
B Distribution Cables.
C Earth Resistance.
D Potential Transformer for Grounding.
E Station Transformers.

GENERATORS AND TRANSFORMERS.

For generators quite strict specifications have always been stipulated, the requirements going somewhat farther than the rules in other countries at the same time. The temperature rise at full load was thus at first limited to 45 deg. C. above the incoming cooling air (measured by resistance method). Since then a higher temperature rise has been allowed in accordance with the tendency in other countries. For large generators, however, a temperature rise, lower than the standard rules admit, is still usually required. In recent specifications hot-spot temperature clauses have also been

included. An insulation test with twice the generator voltage for a period of 15 min. is usually specified.

In order to secure high reliability also, the transformer specifications from the very beginning were made rather exacting as compared with common practice at that time. The result, however, was not always as good as with the generators, and it has been necessary to raise the requirements from time to time, especially with regard to the insulation. Moreover, early transformers were not always short-circuit proof. This induced the customers to give the constructional details more attention when buying transformers. In order to increase the damping action on short circuits, later transformers have been given considerably greater reactance than was allowed earlier (the short circuit voltage has been increased from 3 to about 6 per cent. and sometimes up to 12 per cent.)

CIRCUIT BREAKERS AND CURRENT TRANSFORMERS.

When the first large-capacity circuit breakers were designed, unfavourable interrupting conditions were feared and a very heavy construction was therefore introduced. Experience has shown, however, that the conditions are usually less severe than anticipated, because in water wheel driven generators the short-circuit currents in most cases are relatively moderate and because, as said above, modern transformers are usually given rather high reactance. Special choke coils for limiting the short circuit currents are at present used only in exceptional cases, but may have to be installed in certain stations at some future date. On account of the damping effect of the transmission lines, the parallel-operation of different power plants has not resulted in any considerable increase in magnitude of the short circuit currents. Thanks to these favourable circumstances, it has not been necessary to introduce certain special arrangements—such as explosion-proof tanks, etc—which in some other countries are coming into use in order to secure greater interrupting capacity in large breakers. The only special arrangement of this kind used in Swedish practice—and that only in a few cases—is the quenching chamber.[1] On the other hand, experience has shown that for smaller circuit breakers the strain at first was underestimated, and consequently it has been necessary to resort to more liberal designs. It has also been found necessary to pay more attention to the short circuit stresses in current transformers and this has contributed to the adoption of the short-circuit proof bushing transformers now quite generally used.

[1] See "Modern A.C. Switchgear in Sweden," by Mr. K. E. Eriksson. (Transactions of W. P. C., Vol. III.)

INSULATION AND OVER-VOLTAGE PROTECTION.

The electric plant can either be insulated just strongly enough to stand any normally occurring stresses, but must then be equipped with special devices to protect it from excess voltages or, on the other hand, it may be so strongly insulated that special excess-voltage protection becomes unnecessary. The latter method has, during the last ten years, been used in the State power plants and accordingly no spark-gaps or surge-coils are used. In early stations, space was usually reserved for lightning arresters, but experience has shown that very likely there will never be any reason to install such apparatus. Most of the modern power plants in Sweden have followed this example and, at least, amplitude protection has usually been omitted. The only excess-voltage devices in common use in later developments are shunt resistances on current transformers, fore-contact resistances in circuit breakers and earth resistances in the neutral. Since, however, it is impossible to design a power system so that the insulation at all points will stand with certainty every excess voltage, a system of graded insulation has been introduced, according to which the insulation at different points of the system is chosen with different safety margins in proportion to the damage caused by a breakdown. Unavoidable breakdowns are then likely to occur at points where the resulting damage is as small as possible. Thus, for instance, the busbar insulators for the switching equipment are chosen to constitute the weakest point of the system.

RELAY SYSTEM AND NEUTRAL EARTHING.

In the foregoing, the most important methods for *prevention* of disturbances have been mentioned. Other methods for safeguarding the continuity of operation aim at the *limitation* of the disturbances.

The most effective means for limiting the disturbances is a rapid disconnection of the faulty section. For this purpose, a reliable relay system is required. In Sweden, as in other countries, a great number of different relay systems have been used. Attention will here be given only to one system, the so-called dis-symmetry connection (see Fig. 3) which is extensively used in Sweden. This relay connection first came into use at the Trollhättan power station (about 1911), and was intended to disconnect automatically defective sections not only at short circuits and other dangerous overloads, but also in case of earth faults. The last function is secured by an earth current relay arrangement consisting of an overload relay so connected to the current transformers that, when an earth fault

occurs, a secondary current, corresponding to the unbalanced current, flows through the relay. It should be mentioned, however, that due to the magnetising current of the transformers the relay current will not be quite equivalent to the earth current. It is of interest in this connection to note that direct earthing is not used in Sweden, except for stations of moderate tension, a few thousand volts or less. The neutral, instead, is connected to earth through an ohmic resistance or in some cases through a potential transformer. The resistance is given such a value that enough unbalance current will flow to operate the relay, while on the other hand dangerous currents are prevented. As earth faults are the most common disturbances, the quick disconnection of a defective section, secured by this relay arrangement, is very valuable. An inherent disadvantage, however, is that occasional earths of short duration are often liable to cause disconnection. As an experiment, Petersen coils have therefore been installed in certain stations in parallel with the earth resistances,

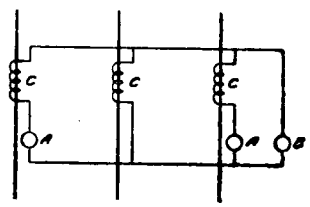

Fig. 3.
Diagram of Dis-symmetry Relay System.
A Overload Relay.
B Dis-symmetry Relay.
C Current Transformer.

which then normally are disconnected. Earth faults are indicated by sound signals and in case of a permanent fault the earth resistance is thrown in by hand, permitting the dis-symmetry relay to disconnect. If this system is found satisfactory in practical operation, Petersen coils or other earth current compensators probably will be more generally adopted in Sweden.

COMPARTMENT SYSTEM.

If, as said before, great care has been taken to avoid earth faults, still more attention naturally has been given to the question of phase-to-phase short circuits. To prevent such short circuits and restrict flash-overs in switching stations to comparatively harmless earth faults, the compartment system is used rather generally, the

different phases being separated by fireproof partitions. At first, this system was used both on the low and on the high tension side of the power stations and sometimes even in the substations. According to present practice, the compartment system is used on the primary side of the power station, while in the substations, partitions are used only between different three-phase circuits. At voltages above 55 kV. partitions are never used.

FIRE PREVENTION.

As soon as the Trollhättan power station was built, the prevention of explosions and fires was given considerable attention. For this reason the electrical equipment was distributed in a number of rooms separated from each other by fireproof walls. The transformers were placed in special booths outside the walls of the station building proper, in order to prevent a transformer explosion from endangering nearby transformers and apparatus, even if the roof of the booths were blown off or the doors thrown open. Since no serious transformer explosions have ever occurred in Sweden, the system with isolated transformer booths has been abandoned, the transformer compartments usually being incorporated with the building in the same way as other rooms.

Even though fires in power stations, fortunately, are very rare, the damage usually is so great if one should occur, that it pays to invest a good deal in fire prevention apparatus. The first measure would then be to equip the power stations with chemical fire-extinguishers, but it must be remembered that such extinguishers are practically useless for fighting large fires, as they are intended for extinguishing the fire as soon as it breaks out. Since it is often necessary to play the stream from the extinguishers on live parts, water or other conducting material cannot be used as an active medium, and powder (usually bicarbonate) or carbon tetrachloride is, therefore, often employed. Compared with powder extinguishers, tetrachloride extinguishers have the disadvantage of producing poisonous gases. After testing a number of different extinguishers the Board of Waterfalls, in spite of the risk mentioned, during later years has equipped the State power stations with a large number of tetrachloride extinguishers. By carefully instructing the station hands in their use, the personal risk has been eliminated as far as possible.

In fighting generator fires the previously mentioned extinguishers are not practical, especially if the generators are enclosed, as in these cases it is impossible to reach the seat of the fire by such apparatus.

For this purpose a fire-fighting system, known as the Lux system, based on the use of carbon dioxide, has been developed during later years, which seems to meet the requirements well. For other systems with carbon dioxide, where this leaves the containers as a gas, large pipes are required, and the containers must be heated in order to prevent the liquid carbon dioxide from freezing. For the Lux system ½-inch piping is sufficient and the heating of the containers is unnecessary. This has been achieved by connecting an upright pipe arrangement to the containers, which makes the carbon dioxide flow through the pipes as a liquid, gasifying only when leaving the pipes close to the fire. As this occurs at a temperature of −79 deg. C. the carbon dioxide has not only a choking, but also a cooling effect on the fire. The Board of Waterfalls has lately begun to install stationary fire-fighting apparatus of the Lux system for all large generators. Fig. 4 shows an installation of this kind made at

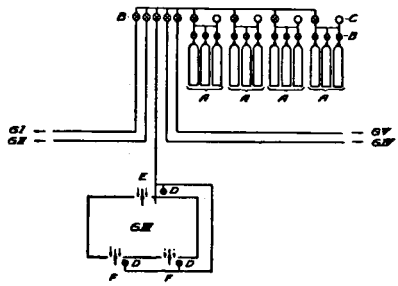

Fig. 4.
Diagram of Fire-Fighting Installation at Älvkarleby.
A CO_2 Battery.
B Cocks.
C Pressure Gauge.
D Automatic Device for Shutters.
E Air Inlet.
F Air Discharge.

the Älvkarleby power station in the beginning of this year. Some additional information regarding this installation might be of interest.

The carbon dioxide containers, each holding 20 kilogram CO_2, are placed at a central point in batteries of three. These batteries are connected by cocks to gas injectors in the generator air inlets. In the air ducts automatic shutters are installed both on the inlet and on the discharge side. These shutters are kept open by an automatic device connected to the gas injectors by a small pipe. When a generator fire occurs, the cock nearest to the injector is first opened,

then the main cock of one of the batteries and, lastly, the cocks on the containers. The carbon dioxide then rushes through the piping to the generator, at the same time actuating the automatic shutters which close by counterweights. A pressure gauge serves to denote that the battery is filled. According to tests a single battery will suffice to give a carbon dioxide concentration of between 30 and 40 per cent. in the generator, while 15 per cent. is quite enough for extinguishing the fire.

RÉSUMÉ.

Dans les grandes centrales hydro-électriques en Suède, le schéma de couplage a montré une tendance vers la simplification. Autant que possible le générateur et son transformateur sont traités comme une unité électrique. On exige que la sécurité de fonctionnement soit aussi grande que possible, surtout pour la machine principale (turbine et générateur).

On a réussi en général à conserver les anciennes stipulations de garantie pour les générateurs. En ce qui concerne le maximum de température permise on a même pu être moins strict. Quant aux transformateurs on a rendu les anciennes stipulations, plus rigoureuses en particulier celles concernant l'isolation. Il a été nécessaire d'apporter beaucoup de soin afin de permettre aux transformateurs de résister aux courts-circuits.

Le construction d'interrupteurs de forte capacité que l'on a employé dès le commencement s'est montré suffisant.

Dans les installations modernes on s'efforce de limiter au minimum les appareils de protection contre les surtensions et on élimine en tout cas ceux d'amplitude, au lieu de ceux ci l'isolation est suffisamment renforcée. En cas de rupture on tâche par la graduation de l'isolation de faire claquer celle-ci aux points où elle cause le moins d'interruption.

Pour la disjonction automatique des mises à la terre, on se sert ordinairement de relais de courant terrestre en couplage assymétrique, le neutre du système étant mis à la terre par une résistance ohmique. Les bobines Petersen sont installées à l'essai sur certains réseaux.

Pour éviter les court-circuits entre les phases, on s'est beaucoup servi du système de cellules tant dans les centrales que dans les sous-stations. Aujourd'hui on limite l'emploi du système de cellules au côté primaire des centrales à générateurs.

Quant aux dangers d'incendie, un grand nombre d'extincteurs à tétrachlorure ont été fournis aux stations électriques de l'État. On combat le feu dans les grands générateurs fermés par des extincteurs stationnaires à acide carbonique, où l'acide carbonique est gardé sous forme liquide dans les tubes d'acier habituels.

RECENT PRACTICE IN SWEDISH WATER POWER ENGINEERING

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INTRODUCTION.

In presenting to foreign readers a review of the development and experiences gained during latter years with regard to the utilisation of the sources of power contained in Swedish rivers, it would perhaps be well shortly to summarise the general conditions governing water power installations in this country. Sweden has, as a result of the action of the great glacial period, a very large number of lakes and rivers. These amount to more than 8 per cent. of the 448,000 sq. km. or thereabouts, comprising the superficial area of Sweden. Concerning the size of the various river basins it may be noted that there are no less than 118 such basins, with a drainage area exceeding 200 sq. km., and of these forty-five are more than 1,000 sq. km., fourteen above 10,000 and six exceeding 25,000 sq. km. The largest river basin, that of the Göta Älv, comprises approximately 50,000 sq. km. Most of the rivers flow through a number of lakes, which by their storage capacity act as regulators to the supply of water. As a result, the difference between the high water quantity and the low water quantity in the same river is not so great as it is in the majority of other countries. Thus the high water quantity rarely amounts to 100 times the low water quantity and for the more important Swedish rivers is only 25 to 50 times the minimum flow. In basins containing a particularly large number of lakes, the quantity of water varies within still narrower limits, for instance in the Göta Älv, where the ratio between low water and high water flow is even less than 1·3. The natural storage in the lakes can, of course, be improved and increased artificially by means of storage dams, tapping channels, etc. In order to make use of the water power it is often necessary by altering the inclination profile of the waterway, *i.e.*, by a so-called *profile regulation*, to concentrate at a certain point waterfalls or cataracts, which may be distributed over a varying distance of a river, so that

a rational " stepping " of the river can be obtained either by building dams or by clearing the river bottom or else by conveying the water alongside the river in open or closed channels.

It is characteristic of Swedish conditions that the falls, formed by nature or which by the above mentioned process can be concentrated, are relatively low and only in a few exceptional cases reach 100 metres in height. High pressure plants with a head of several hundred metres are unknown in this country.

The larger power installations, therefore, work with relatively great quantities of water, and consequently need capacious waterways, comprehensive construction work and correspondingly large size of machinery.

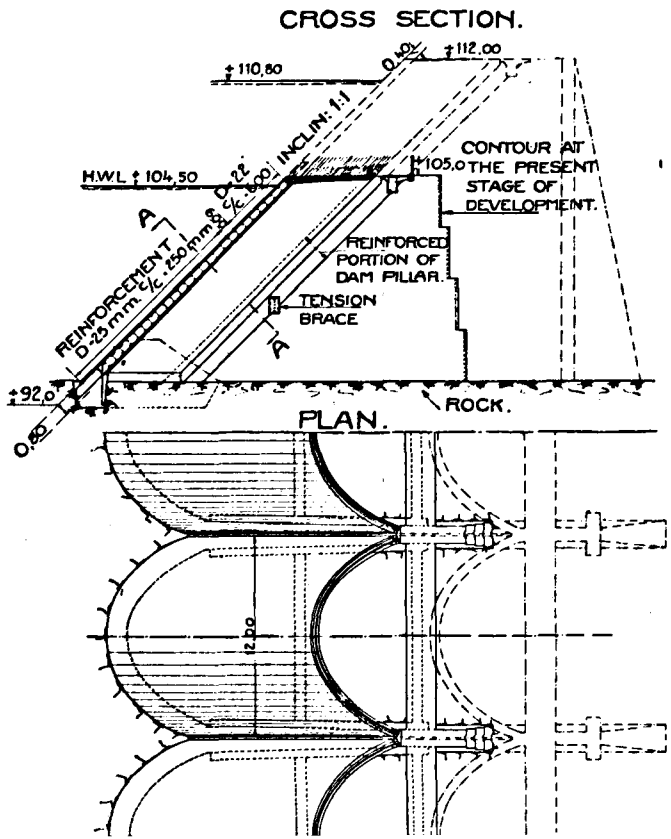
The building arrangements vary considerably more in low pressure plants than in those for high pressure, according to the local conditions afforded by nature, which will always vary considerably in each individual case. The utilisation of low waterfalls, therefore, offers a considerably larger variety and a greater field for experience and for the use of different constructions and designs. Furthermore, attention should be drawn to the great differences in climatic conditions, which are the result of the great extension of the country in the latitudinal direction. Sweden extends from Lat. 55° 20, north, corresponding, for instance, to the north coast of Ireland, up to Lat. 69° 4, *i.e.*, considerably beyond the arctic circle.

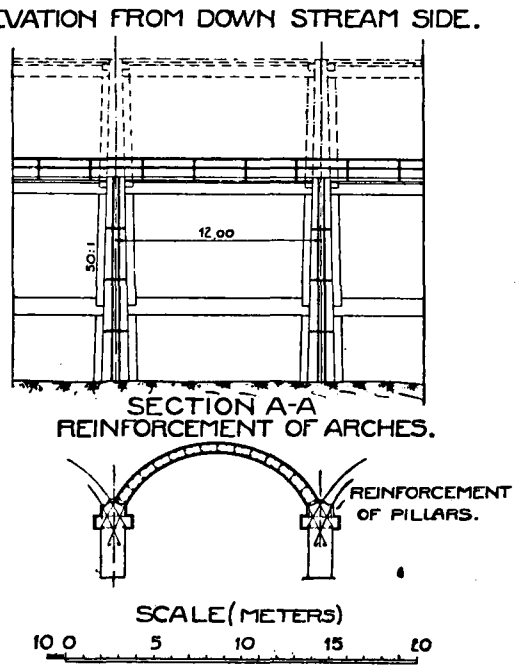
The building ground is generally good, and to a great extent consists of solid rock such as granite, gneiss, etc. Within limited areas there is silurian rock and in many cases the buildings must be erected on layers of shingle, sand or clay, which, however, as a rule forms a sufficiently solid foundation.

DAM CONSTRUCTIONS.

Dam buildings, both large and small, were formerly generally constructed as gravity dams with a solid section of natural stone masonry or mass concrete, the latter with or without a stone facing. In suitable cases also filled dams and arch dams were used, the latter often built of mass concrete. As in the course of time the actual distribution of stresses in gravity dams has been more closely investigated and as it has been found that the degree of safety in this type of dam is considerably less than was previously assumed, the confidence in this type has been reduced, at any rate for greater depths of water. At the same time more reliance has been placed in the durability of reinforced concrete structures, and it is now generally considered that there is no risk of corrosion of the iron

MULTIPLE ARCH DAM OF SUORVA.





reinforcement, provided that the concrete work has been erected with the necessary care and skill.

As, in addition, gravity dams, particularly of large dimensions, are not economical by reason of the fact that the material is much too inefficiently utilised, endeavours have been made, especially in the case of high dams, to replace the gravity type by other designs allowing a more even distribution of stresses and a safer calculation of the same. For this purpose, reinforced concrete constructions have been adopted, particularly reinforced arched dams with one or more arches. Examples of this type are the two large storage dams, of which the first building stage of each was completed in 1923, at the lakes near *Suorva*, forming the source of the Stora Lule älv, which, in spite of their situation in inaccessible mountain regions 100 km. north of the arctic circle, were built as multiple arch dams of the type shown in Fig. 1. These dams are intended to be increased in height in future by 7 metres, to withstand a total hydraulic pressure of up to about 17 metres. The construction of a dam 40 metres in height planned at *Harsprånget* in the Stora Lule älv will probably be designed as a reinforced concrete arch with a single span of about 300 metres. A similar single arch dam with a length of 65 metres and a height of about 15 metres was in 1918 completed at the *Gideåbacka* power station on the Gide älv (the quantity of water utilised $Q=20$ cu. m. per second, the head $H=29$ to 32 m.).

As an example of an unusual type of filled dam, Fig. 2 shows the section designed for certain portions of the large dam completed in 1914 (with a total length of 981 m.) at the *Porjus* power station on the Stora Lule älv ($Q=60$ cu. m. per sec., $H=49$ to 55 m.), which is built to resist a water pressure of from 5 to 10 metres. As considerable quantities of blasted stone were available from the large tunnel blastings for the power plant, the section on the lower side of the concrete core was built with this blasted rock and, in order to increase the counter-pressure against the total pressure of the water and earth on the front side, the stone filling was arranged as a sliding plane leaning towards the core, whereby active pressure could be relied on from the top portion of the rock filling. In designing the dam it was decided to construct as large a portion as possible as a filled dam, because such a dam can with greater safety than other types be calculated to withstand the pressure of the ice covering the large area of water above the dam, which would arise when this ice cover expanded through a rise of temperature. Such ice pressure can, in the case of an earth dam, at

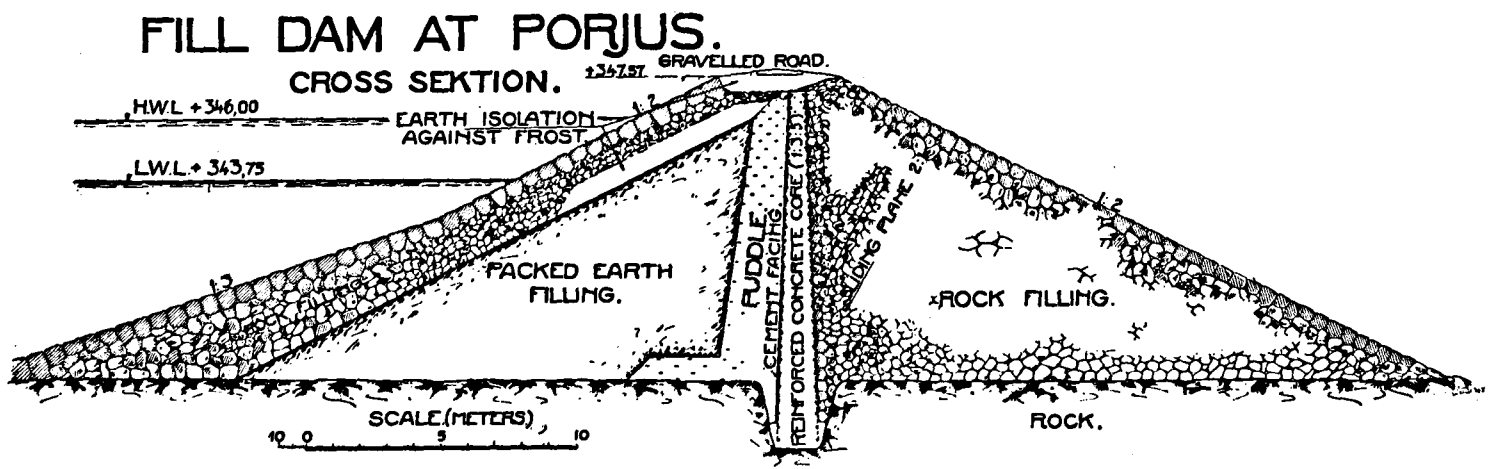

FILL DAM AT PORJUS.
CROSS SEKTION.
+347,57
GRAVELLED ROAD.
H.W.L +346,00
EARTH ISOLATION AGAINST FROST.
L.W.L.+ 343,75
PACKED EARTH FILLING.
PUDDLE
CEMENT FACING
REINFORCED CONCRETE CORE (1:3:5)
CONCRETE PLANE 2.5
ROCK FILLING.
ROCK.
SCALE (METERS)
10 0 5 10

Fig. 2.

most cause a local displacement of the layer of earth and stone covering on the upstream side, which does not endanger the dam itself, and may easily be repaired. Hitherto no damage caused by ice pressure has been observed, although the thickness of the ice has amounted to about 0·75 m.

With regard to the amount of the pressure against the dam, caused in the manner indicated above by ice, new Swedish investigations have shown that by reason of the viscosity of the ice at the temperatures usual in this country, the ice pressure can, even under the most unfavourable circumstances, not exceed 30 tons per metre of length at a thickness of 1 m. of ice and about 20 tons per metre of length at 0·75 m. thickness.

The majority of dams must be designed with openings to carry off the excess water. To close these openings, gates or needles of wood were in most cases formerly employed, generally operated by hand. As the area of the free outlet is, by these arrangements, limited to a size much too small, particularly having regard to the passage of ice, floating timber, etc., it has become more general to employ electrically operated iron gates such as roller dams and large gates of various types.

With regard to dam buildings it should further be mentioned that special arrangements are often necessary within them or alongside of them for navigation, also for logging and for the passage of fish. Logging generally in low falls takes place through certain of the openings in the dam, below which, in this case, specially reinforced protection aprons are placed. In other cases the floating timber is led into special water-chutes, generally built of wood, past the falls. In order to avoid the loss of water for power purposes, which the floating thus causes, several proposals have been made, intended to make it possible to transport the timber past the fall by mechanical means with a smaller use of power than that represented by the loss of water, and it is quite possible that such arrangements will gradually be adopted. With regard to the passage of fish, especially salmon and eels, the authorities concerned have provided regulations concerning the design of salmon ladders and eel ways for the passage down the river of grown eels and upwards of young ones.

LEVEL CHANNELS FOR HEAD AND TAIL RACE.

Head race and tail race channels for concentrating the head at a suitable point for the utilisation of its power may, depending on local conditions, be constructed either as open channels or as

tunnels. In the case of open channels consideration must be taken, in the northern part of the country, to the reduction of the useful sectional area and the action upon the canal walls caused by ice. Where the canals are carried through rock it is sometimes found economically advantageous to reduce the loss of head by smoothing off the roughest parts of the walls with a covering of concrete or stone masonry. Open channels in earth rarely require special measures for waterproofing the walls, as the usual kinds of earth generally contain clay. Channels through sand or shingle are generally covered with a layer of clay, sometimes with concrete, unless in such cases a level tube is preferred. The largest tube of this type is that built in 1912 as a supply tube at the *Ljungaverk* on the river Ljungan, the horizontal part being about 2,000 m. long (Q=50 cu. m. per sec., H=about 40 m.). It has a circular section with a diameter of 5 m. and is built of steel sheets with circular angle-iron reinforcements and has expansion joints. At the Borås Municipal Power Station, *Haby*, on the Slottsån (Q=20 cu. m. per sec., H=27·8 m.) there is such a level tube built of sheet steel with a diameter of 4 m. and a length of 630 m., completed in 1914. The same year a level tube of wood with a diameter of 3 m. and a length of 460 m. was completed at *Gideå Bruk* on the Gide älv (Q=20 cu. m. per sec., H=13·5 m.).

On account of the usual good qualities of the existing rock, tunnels can generally be made of very large dimensions without lining. Feed and tailrace tunnels of the Porjus power station, with a length of 525 and 1,274 m. respectively, have thus a sectional area of 50 sq. m., although certain portions, where the rock was of inferior quality, had to be lined with concrete.

Thanks to the circumstance that all the water conduits of the Porjus plant are laid underground (the forebay alone being open but protected by a superstructure) and thanks to the fact that the water is taken from a large and deep dammed up lake, the water supply is completely undisturbed by the extreme cold of the winter up beyond the arctic circle.

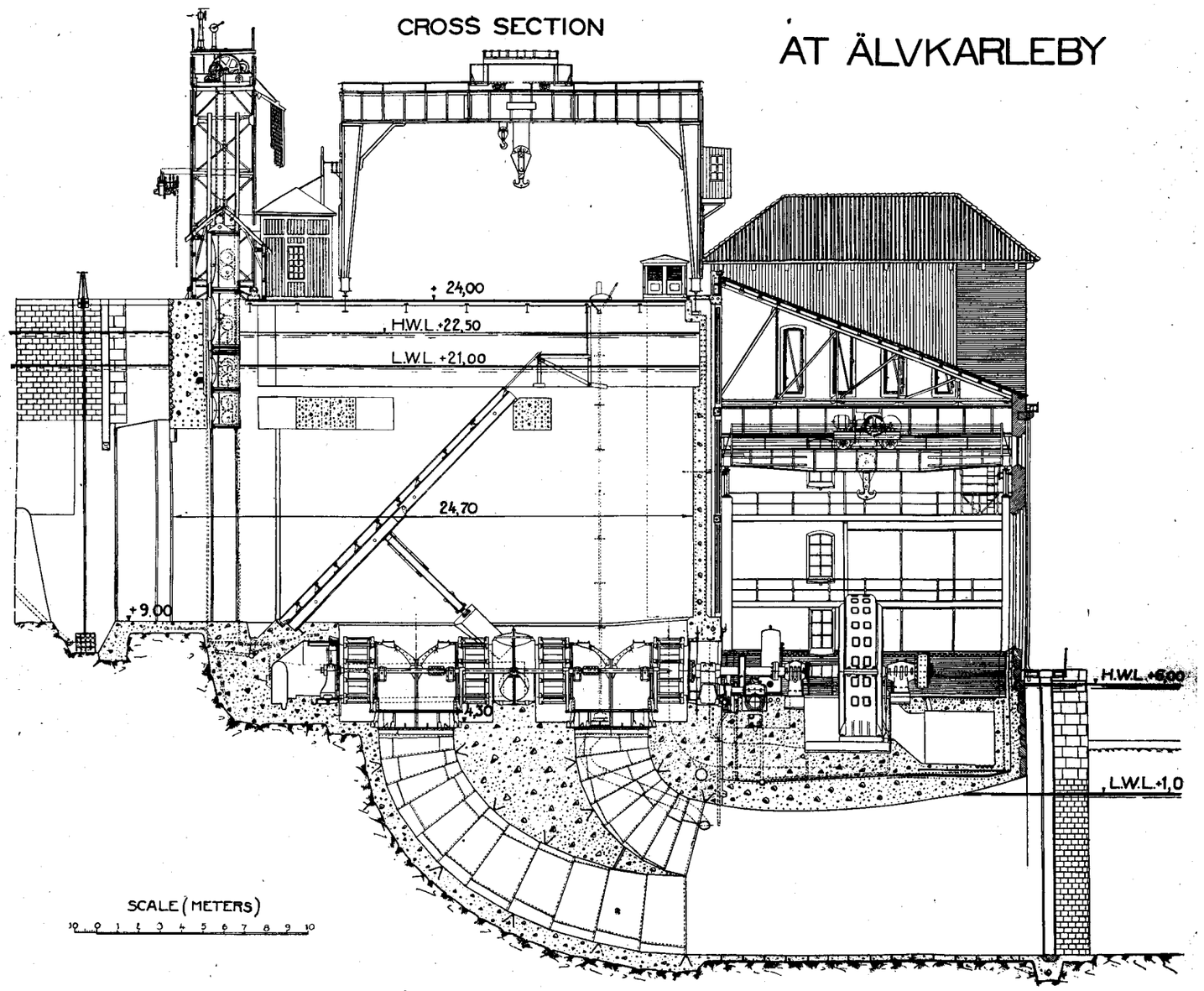
The largest power tunnel in Sweden is that which was built for the *Trollhättan* power station (Q=460 cu. m. per sec., H=about 30 m.) in 1918 in connection with its latest extension. The water approach is here, for a distance of about 160 m., brought through an unlined rock tunnel with a sectional area of 85 sq. m.

POWER STATIONS WITH OPEN MOUNTING OF TURBINES.

In order to take full advantage of the power available with as

SWEDISH GOVERNMENT POWER STATION

CROSS SECTION AT ÄLVKARLEBY



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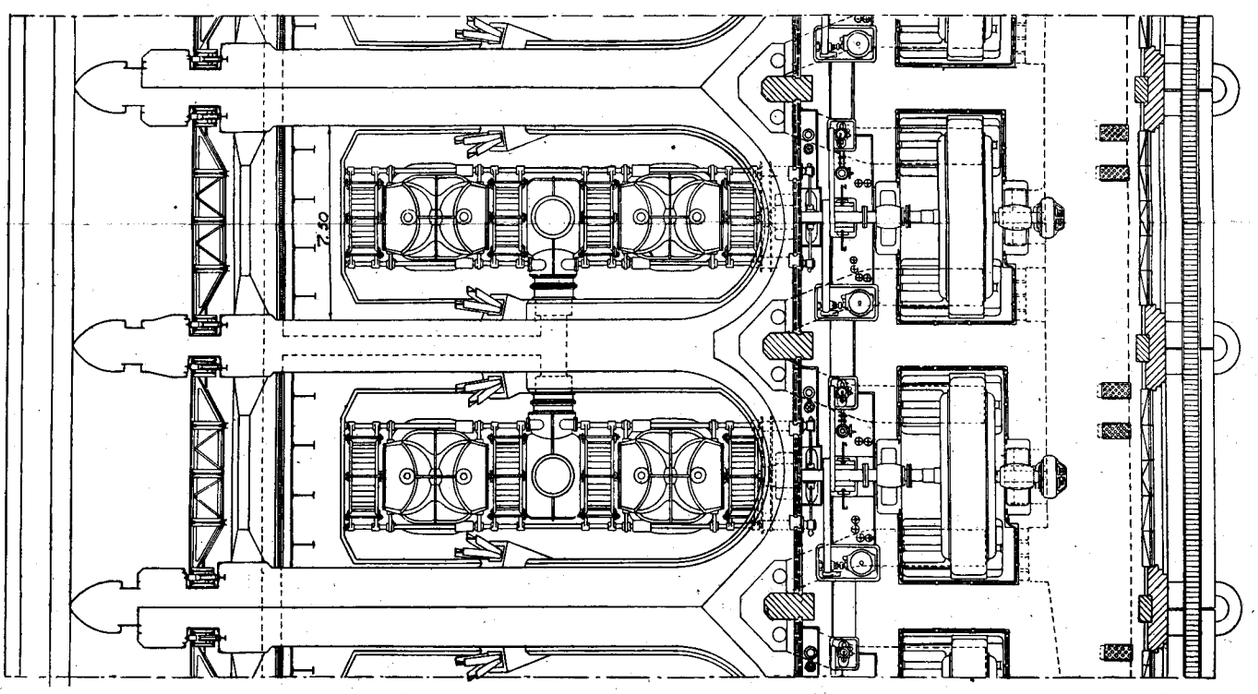

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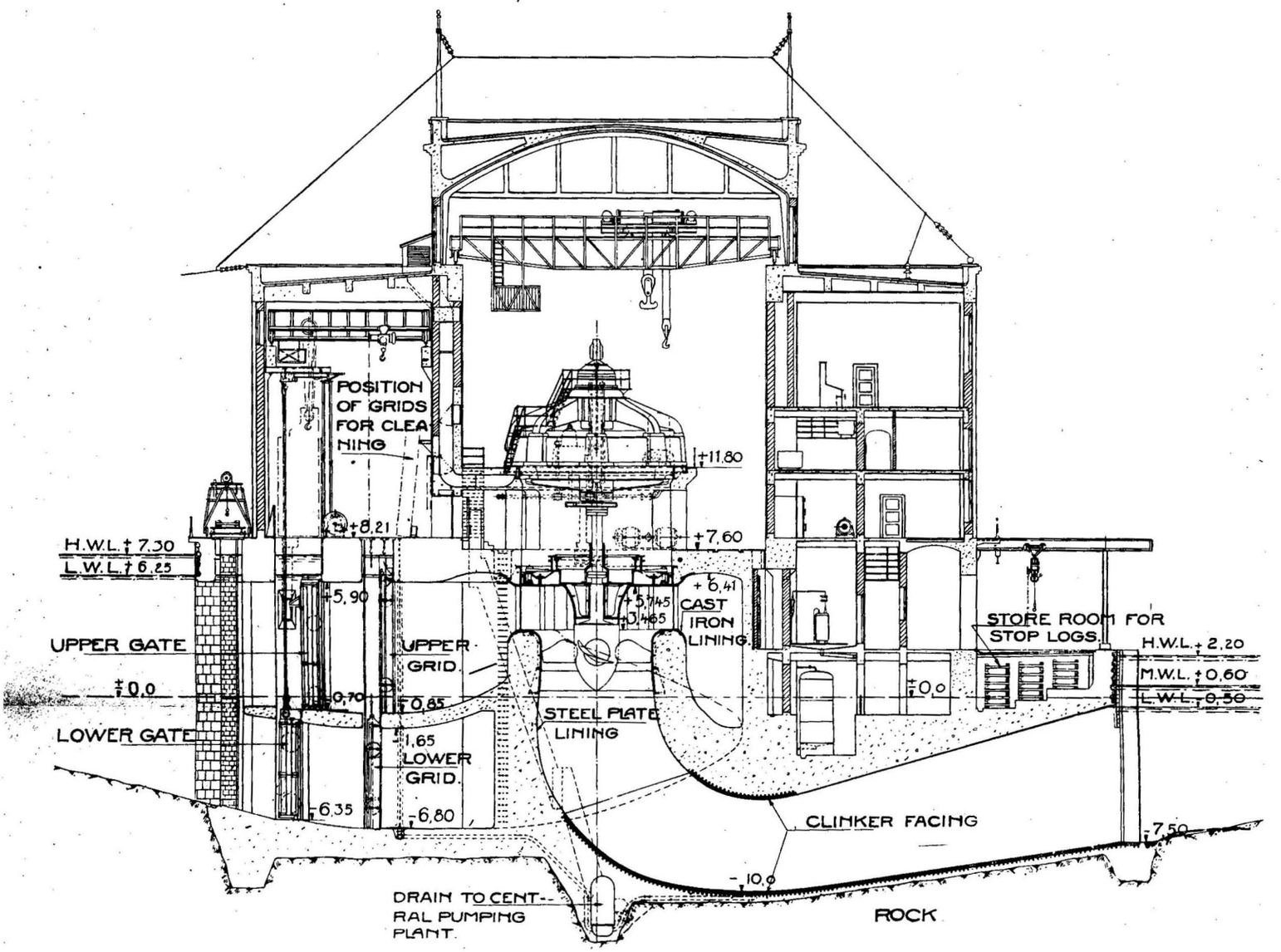
Fig. 3.

SWEDISH GOVERNMENT POWER STATION AT LILLA EDET.

CROSS SECTION.



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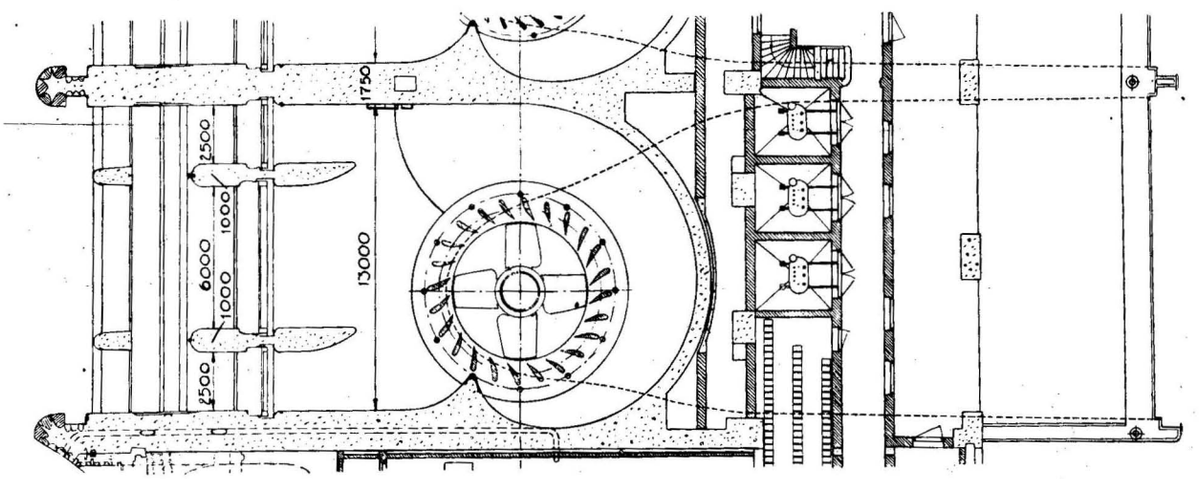


Fig. 4.

small a loss of head as possible, it is desirable to erect the turbines in open chambers directly connected with the dam or forebay. In many cases such an open position cannot be obtained, especially if the head is too great or if local conditions prevent the concentration of the head otherwise than by a pressure conduit. Formerly the open mounting of turbines was seldom used for heads exceeding 10 m. in height but, thanks especially to the development of concrete engineering, heads up to about 20 m. are now designed with turbines mounted in open chambers. As an example may be mentioned the five turbine chambers of reinforced concrete with internal dimensions of: length 24·7 m., width 7·5 m. and depth 19·7 m. (Fig. 3) built during the years 1913-15 at the *Älvkarleby* power station on the Dalälven (Q=250 cu. m. per sec., H=16·5 to 20 m.) and two similar turbine chambers built in 1920-21, with the dimensions 12·7 m. long, 6·5 m. wide and 13·9 m. deep, at the *Motala* power station on the Motala Ström (Q=70 cu. m. per sec., H=about 15 m.). At both these plants the average proportion of reinforcing iron in the turbine chambers is 1 per cent., the quantity of reinforced concrete in the chambers corresponds to about 1·0 and 0·8 cu. m. respectively for each 1,000 kg. of the total water pressure on the turbine chamber, figured in the direction of the inlet and above the floor level. At Älvkarleby the walls received a well finished coating of cement mortar of 30-40 mm. thickness and were painted with inertol. Where the water pressure exceeds 4 m., the mortar has been reinforced by the insertion of iron netting of wires 1·5 mm. thick with 20-24 mm. meshes. Within the walls, vertical drains of 50 mm. tubes at a distance of 0·5 m. apart have been laid. The turbine chambers at Motala have been built in a similar manner with the exception that the internal cement coating, not more than 25 cm. thick has, as an experiment, been omitted from the upper portion of one of the chambers down to a depth of 8 m., and has been replaced by thin coating finish of neat cement, upon which the inertol paint has been applied. During the period which the plant has been running, or since the beginning of the year 1922, no difference in the water-tightness has been noticed between the two chambers. It must, however, be pointed out that in carrying out the reinforced concrete work of the walls and the turbine chambers, special care was taken to obtain a very tight concrete mass.

At the power station at *Lilla Edet* in the Göta älv, now under construction (Fig. 4, Q=460 cu. m. per sec., H=only 6·5 m.) the walls of the intake chambers and the intake spirals will as a rule

be retained in the condition in which they are found to be on removing the forms, without any finishing. By the choice of suitable concrete material and mixtures (1 : 4·5, where resistance against water pressure is necessary, otherwise 1·6) and by careful execution of the concrete work a very tight and hard surface is obtained, which only in certain spots, where local faults have arisen, needs improvement by cutting away and repairing the surface with, for instance, a cement gun. A lining of clinkers is, however, applied over those portions of the walls and the spiral, especially the inner side wall, where the velocity of the water will exceed about 2·5 m. per second. The sharply curved wall surfaces nearest to the guide vanes, where the speed is greatest, are lined with a cast-iron covering.

POWER STATIONS WITH ENCLOSED MOUNTING OF TURBINES.

Where the open mounting cannot be obtained the water is conveyed from the dam or the forebay at the lower end of the head race to the turbines through enclosed pressure conduits. Such conduits used to be generally constructed in the form of cylindrical pipes of wood staves held together by iron bands and placed either on the open ground or covered to protect them against frost. Now, especially in the case of larger quantities of water, tubes of iron, or less frequently of reinforced concrete, are employed, often without any covering. At *Gideåbacka* a tube conduit of 376 m. in length of reinforced concrete, with a diameter of 4 m. and a wall thickness of 0·35 m., was constructed in 1918 to withstand a water pressure of up to 26 m. To protect it from changes of temperature the tube is covered with sand to a depth of 1·5 m. Expansion joints, tightened with asphalt, have been arranged at intervals of 8 m.

In several cases pressure conduits have been placed in the rock in blasted shafts or tunnels, in which cylindrical steel plate tubes have been fitted with a filling of concrete between the rock and the tube. Thus, for instance, at the *Trollhättan* power station where the thirteen tubes, each having a diameter of 4·25 m., first go vertically down from the intake for about 13 m. and then continue in an almost horizontal direction, with a length varying from about 50 to 100 m. till they reach the power station at the foot of a rock. The latest extension was completed in 1918). At the *Porjus* power station the tubes in their entire length, about 36 m., are enclosed in vertical shafts through the rock and have a diameter of 3·5 m. With the latest tubes (constructed in 1920)

the thickness of the plate for the tubes has, for economical reasons, been reduced so as to correspond to a tensile stress of 2,000 kg. per sq. cm. against 1,250 kg. per sq. cm. in the older tubes. In the lower section a tensile stress of 1,250 kg. per sq. cm. was retained.

In cases of enclosed setting of turbines the junction between the dam or forebay and the pressure conduit consists of a tube inlet which, in more modern plants, is generally constructed of concrete and is, just as the water intakes for the open turbine setting, fitted with fish grids, gates and guides for stop logs; further, in case of need, with a superstructure over these, containing arrangements for manœuvring the gates and often with travelling cranes for facilitating erection.

DEVICES TO PREVENT DAMAGE FROM WATER HAMMERS.

Where the water is supplied through a long channel or tube, or where the tail race is a long one, special measures have to be taken to limit the effect of water hammering in the event of sudden changes in the load on the power station. If this cannot suitably be secured by allowing larger areas in the supply tube or tail race, whereby the speed of the water can be kept within safe limits, then this is generally accomplished by surge tanks or other types of regulating devices.

The previously mentioned power stations *Ljunga-plant, Haby, Gideåbruk* and *Gideåbacka,* are fitted with surge tanks consisting of vertical steel cylinders which, at Haby, has a diameter of 15 m. and at both the last named a diameter of 12 m. At the *Porjus* power station the area of the open forebay is governed by the amount of the hammering energy exerted by the water on the feeder tunnel and it has, in order to obtain further security against the sudden cutting off of a large proportion of the load, been constructed with an overflow of ample dimensions from which the water through a vertical shaft is conducted to the tail race tunnel. On the tail race side corresponding measures have been taken by blasting out surge basin in the rock communicating with the part of the tail race tunnel nearest to the suction pipes, which allow a sufficient storage capacity for the water coming from the turbines, until the speed of the water in the tail race tunnel has been accelerated up to the velocity corresponding to the increased load.

SUCTION PIPES AND TAIL RACE CHAMBERS.

Suction pipes are often steel lined nearest to the turbines and are otherwise constructed of concrete. In the older parts of the

Trollhättan power station it has proved to be necessary to reinforce the bottoms of the tail race chambers with a lining of clinkers, and this practice has been followed in carrying out the latest extension. In the *Forshuvudforsen* power station on Dalälven, completed in 1922 (Q=210 cu. m., H=10·2 m.), the walls of the suction tubes have been entirely lined with clinkers. In the new power station at *Lilla Edet* (see page 8) where the velocity of the water in the tail race is exceptionally high, large proportions of the walls are to be lined with clinkers, especially where the speed, according to model tests, has been calculated to exceed 2·5 m. per second.

FISH SCREENS.

As fish do not migrate during the cold season of the year, fish grids need not be in position during the winter. They are, however, as a rule used even at this season as a protection against ice. In larger plants where the turbines, on account of their size, offer a wide passage for ice, stones, bark, etc., carried with the water, they are now often allowed to run during the winter without grids or with grids of wider openings.

The grids are generally constructed of steel bars spaced 20 mm. and are, in order to facilitate the cleaning off of leaves, branches, ice, etc., usually more or less inclined. The cleaning is generally done by hand with the aid of scrapers but is sometimes replaced by devices for flushing the grids in a direction opposite to that of the usual current. At the *Forshuvudforsen* plant the fish grids, which are vertical, have been divided into a number of sections with horizontal grid bars and are so arranged that all the sections may simultaneously be turned, each round its horizontal axis. At *Lilla Edet* (see Fig. 5), where the depth of water at the intake is 14 m., the grids are arranged in two tiers and are guided in separate grooves. Each grid consists of a main cast steel grid with openings of about 0·2 m., the opening being fitted with a separate finer grid, constructed of steel bars with a spacing of 20 mm., which may conveniently be hoisted up when they are to be cleaned or, during the winter, to be removed. Electric heating of fish grids is employed, for instance, at the *Trollhättan* power station and has proved to be of great advantage on those occasions when the grids in winter show a tendency to become choked up by sludge ice.

RESERVE GATES.

Reserve gates at intakes and outlets generally consist of stop logs, which, for smaller spans, are constructed entirely of timber;

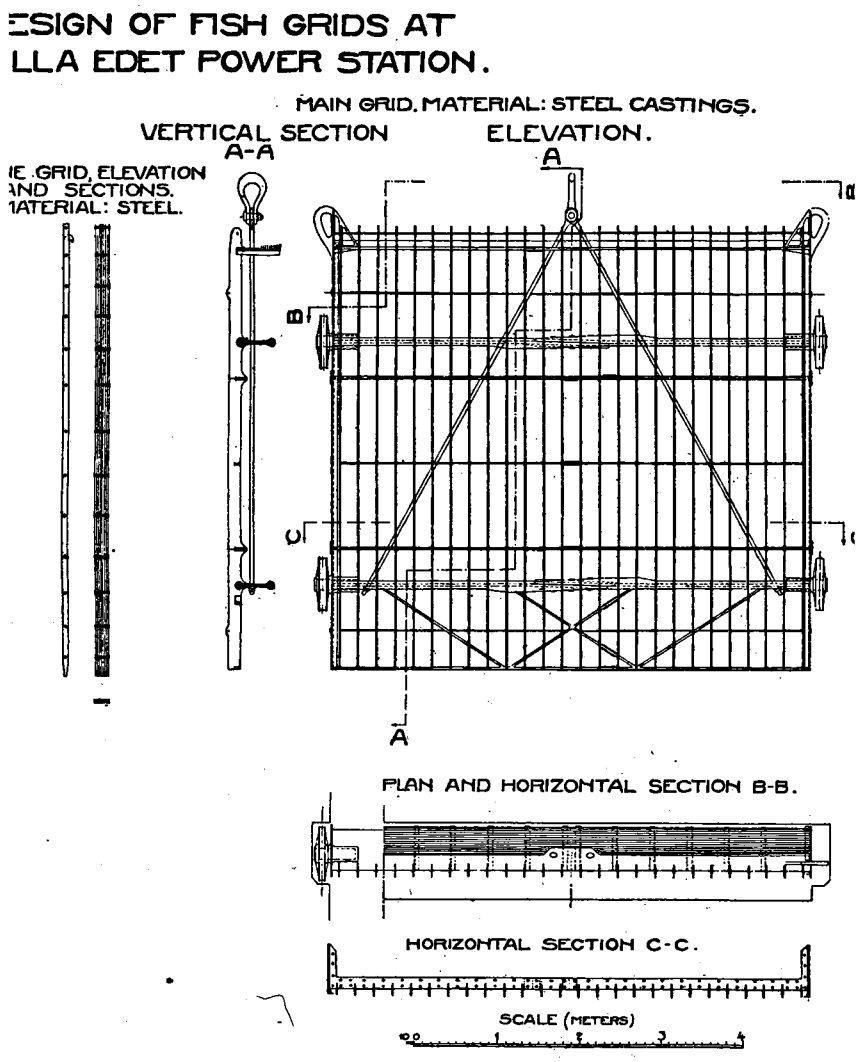


Fig. 5.

for larger spans, of steel beams with tight fitting liners of wood on either side ; or, in certain cases, they consist of special iron constructions with more or less simple arrangements for lowering and raising.

CLOSING DEVICES.

Concerning other important constructional parts, this account should perhaps in the main be limited to mention of present practice with regard to certain closing devices for larger openings in the dams and intakes to canals, tunnels, tubes and turbine chambers.

Roller dams have, in comparison with other movable dam units, proved to be relatively expensive to build, but they are easily operated, even in winter, and can be used for very large spans, which is of importance, especially in rivers with a large flow and much ice, for instance, Göta älv and the Dalälven or else for logging, etc. For easy operation during the winter it has been found that it is sufficient to heat those portions of the side walls of the dam which are in contact with the tightning liners, when the rollers are operated. Various arrangements for electric heating have been used with an average consumption of about 1·7 kW. per sq. m. of the heated surface. In Table I. certain illuminating com parative figures are given in regard to a few large roller dams.

At the *Forshuvudforsen* power station each of the four dam openings, having a free span of 17 m., are controlled by roller dams of which two have a height of no less than 8·59 m. and are the largest which have hitherto been built in Sweden. The others have heights of 5·99 m. and 3·49 m. respectively.

TABLE I.

COMPARATIVE DETAILS CONCERNING ROLLER DAMS.

Roller dam at	Porjus.	Trollhättan.	Älvkarleby.	Lilla Edet.
Free span	12·0 m.	20·0 m.	20·0 m.	22·0 m.
Height...	3·5 ,,	4·0 ,,	2·8 ,,	3·8 ,,
Greatest water pressure ...	3·5 ,,	4·4 ,,	3·3 ,,	3·8 ,,
Total pressure surface ...	42 sq. m.	80 sq. m.	56 sq. m.	83·6 sq.m
Total water pressure ...	73·5 tons	192 tons	106·4 tons	158·8 tons
Weight of roller	16·05 ,,	55·0 ,,	33·9 ,,	49·0 ,,
Ditto, per sq. m. surface ...	0·38 ,,	0·69 ,,	0·61 ,,	0·59 ,,
Ditto, per ton water pressure	0·22 ,,	0·29 ,,	0·32 ,,	0·31 ,,
Total weight incl. gear segments and racks, safety chain with screw, winch foundation and machinery..	25·6 ,,[1]	74·8 ,,	41·0 ,,	73·5 ,,[1]
Ditto, per sq. m. surface ...	0·61 ,,	0·94 ,,	0·73 ,,	0·88 ,,
Ditto, per ton water pressure	0·35 ,,	0·39 ,,	0·39 ,,	0·46 ,,
Weight of machinery only ...	2·15 ,,	9·0 ,,	5·4 ,,	9·0 ,,

[1] For Porjus and Lilla Edet the weight of the steel construction carrying the machinery is included in the total weight. In other roller dams the winches have a foundation of masonry columns.

TABLE II.

COMPARATIVE DETAILS FOR LARGE GATE DESIGNS (REFERRING TO ONE GATE OR A PAIR OF GATES)

Number.	Power plants and kinds of gates (Gates Nos. 2 and 3 have four supports, all others have only two supports).	Free opening.		Theoretical span.	Theoretical surface under pressure.			Depth of upper edge below h.w.l.	Total water pressure	Bearing wheels.		Weight, in tons, of ironwork of gate (incl. all parts affixed to the gate such as rails, support wheels, roller carriages, guide wheels, etc).			Weight of ironwork in grooves, support and guide rails where grooves are made		Weight in tons, of winches, chains and wire ropes.		Weight in tons of operating bridge or bent.		Total weight in tons.		Approximate distribution of total costs (in per cent.)			
		Height	Width		Height	Width	Average depth below h.w.l.m.			Number.	Diam.	Total.	Per sq. m. surface.	Per ton water pressure	Of iron.	Of concrete.	Total.	Per ton water pressure	Total.	Per ton water pressure	Total.	Per ton water pressure	Gate constr.	Grooves and rails.	Winches	Bridges or bents.
		m.	m.	m.	m.	m.		m.	tons.		m.															
	Trollhättan.																									
1	Canal intake gate	—	17·4	18·0	7·14	17·40	5·43	1·86	674·6	50	0·20	64·65	0·52	0·096	—	11·0	22·60	0·033	10·30	0·015	108·55	0·161	—	—	—	—
2	5 tube intake gates in 1st and 2nd stages	5·10	7·3	8·4/3	5·52	8·0	5·74	2·98	253·5	28	0·12	11·50	0·26	0·045	8·20	—	9·20	0·036	—	—	28·90	0·114	34	32	34	0
3	3 do. do. ...	5·10	7·3	8·4/3	5·52	8·0	5·74	2·98	253·5	28	0·425	15·50	0·35	0·061	8·20	—	9·20	0·036	—	—	32·90	0·130	42	26	32	0
4	5 tube intake gates in 3rd building stage	6·35	6·0	6·56	6·45	6·2	7·28	4·05	291·0	8	0·54	17·70	0·44	0·061	8·86	—	4·15	0·014	1·05	0·004	31·76	0·109	49	25	23	3
	Porjus.																									
5	Canal intake gate	6·67	7·5	8·25	6·67	7·75	8·62	5·28	445·6	8	0·75	27·81	0·54	0·062	12·55	—	5·54	0·012	3·69	0·008	49·59	0·111	50	19	24	7
6a	4 old tube intake gates ...	4·0	7·0	7·51	4·07	7·40	5·97	3·93	179·8	8	0·68	16·90	0·56	0·094	11·18	—	7·50	0·042	1·17	0·007	36·75	0·204	32	22	44	2
6b	1 new tube intake gate ...	4·0	7·0	7·51	4·07	7·70	5·97	3·93	179·8	8	0·68	18·14	0·60	0·101	11·18	—	5·50	0·031	1·30	0·007	36·12	0·201	45	25	30	0
	Älvkarleby.																									
7	4 dam sluices	—	10·0	10·60	3·60	10·24	3·30	1·50	121·7	6	0·475	12·60	0·34	0·104	—	4·85	2·97	0·024	4·00	0·033	24·42	0·201	47	18	20	15
8	1 dam sluice	—	10·0	10·60	2·50	10·24	2·75	1·50	70·4	4	0·475	8·60	0·34	0·122	—	3·45	3·26	0·046	3·75	0·053	19·06	0·271	40	16	27	17
9a	2 upper canal gates	—	12·8	15·0	5·15	13·38	2·58	0	177·8	24	0·15	29·83	0·43	0·168	—	20·19	13·13	0·019	16·62	0·023	116·56	0·164	53	16	18	13
9b	2 lower canal gates	—	12·8	13·70	5·15	13·38	7·73	5·15	532·7	48	0·20	36·79	0·53	0·069	—											
10a	5 upper turbine-chamber intake gates	5·31	7·3	8·10	5·41	7·60	7·10	5·90	291·9	8	0·625	24·25	0·59	0·083	12·80	—	15·16	0·025	14·60	0·024	87·60	0·142	50	11	28	11
10b	5 lower do. ...	3·69	7·3	8·10	3·69	7·60	11·66	11·32	327·0	8	0·625	20·79	0·74	0·064												
	Motala.																									
11	2 turbine chamber gates ...	5·0	6·5	6·90	5·04	6·55	4·98	2·46	164·4	4	0·90	15·33	0·46	0·093	4·33	—	5·55	0·034	—	—	25·21	0·153	54	10	36	0
12	1 dam sluice	3·70	6·5	6·90	3·74	6·55	4·33	2·46	106·1	4	0·70	9·90	0·40	0·093	3·04	—	5·00	0·047	—	—	17·94	0·169	51	9	40	0
	Suorva.																									
13	2 regulating sluice gates ...	6·0	5·0	5·8	6·1	5·2	23·75	20·75	753·4	10	0·95	39·33	1·24	0·052	24·0	—	9·65	0·013	2·95	0·004	75·93	0·101	47	25	25	3
	Lilla Edet.																									
14	3 upper turbine chamber gates	6·6	13·0	7·0	6·7	13·06	4·65	1·30	407·0	4	0·90	28·0	0·32	0·069	—	5·30	—	—	—	—	—	—	—	—	—	—
15	3 lower do. do.	5·0	13·0	7·0	5·125	13·06	11·087	8·525	742·3	4	1·05	30·0	0·45	0·040	—	6·50	—	—	—	—	—	—	—	—	—	—
	Untra.																									
16	5 turbine-chamber gates ...	7·4	9·5	10·10	8·025	9·70	7·0	2·7	544·9	22	0·25	43·0	0·55	0·079	—	10·0	9·6	0·018	17·0	0·031	79·6	0·146	—	—	—	—
17	4 dam sluices	-	12·5	13·25	4·2	12·77	2·4	0·3	128·7	12	0·20	18·5	0·35	0·144	—	4·5	7·1	0·055	13·75	0·107	43·85	0·341	—	—	—	—
18	2 do.	—	12·5	13·25	5·0	12·77	2·5	0	159·6	14	0·20	23·0	0·36	0·144	—	4·5	7·1	0·045	13·3	0·083	47·9	0·301	—	—	—	—
19	2 do.	-	5·0	5·25	5·0	5·08	2·5	0	63·5	8	0·41	5·85	0·23	0·092	—	1·4	5·0	0·079	4·6	0·073	16·85	0·265	—	—	—	—
	Forshuvudforsen.																									
20	6 upper turbine-chamber gates	5·0	3·1	3·25	4·59	3·17	2·30	0	33·5	8	0·24	6·0	0·20	0·042	—	—	3·2	0·022	—	—	—	—	—	—	—	—
21	6 lower do. do. ...	4·6	3·1	3·25	4·76	3·25	7·11	4·69	110·0	0	—															

B—To face page 350.

With regard to *larger vertical control gates* of steel, including sluice gates and head gates for canal intakes, tube intakes and turbine chambers, reference is made in Table II. (see inset), giving certain figures with regard to such gates, mutually comparable and comparable also with those given above for roller dams. The table relates to gates hitherto built by the Swedish Government for the water power plants at *Trollhättan, Porjus, Älvkarleby and Motala,* and gates for closing the two tapping tunnels for the storage reservoir of the *Stora Lule älv* at *Suorva,* and also those which have been designed for the power station at *Lilla Edet.* In the table certain corresponding information has also been included which is available in respect of the municipal and private power stations at *Untra* (Q=350 cu. m. per second, H=12·35 to 15·3 m.) and *Forshuvudforsen,* both on the Dalälven. The table is intended to give an idea of the dimensions and principal design of the various gates and also to facilitate an approximate economic comparison between them. For the latter purpose the relative weights have been separately calculated per sq. m. of the vertical projection of the surface exposed to the water pressure, and also per ton of the water pressure, in order to make allowance for the position of the pressure surface in relation to the surface of the water.

For a just comparison between the various constructions it is, of course, necessary to have a more complete description than that which space will here allow, and which would make it possible to judge the general suitability of each with regard both to maintenance and operation. In order, however, to indicate to some extent the direction which development has hitherto taken, the following information is given concerning various constructional details of the gates. With regard to the gates described in Table II., these will be indicated according to the numbers in the first column of the table.

The design of *grooves, supporting rails and guides,* has gradually been simplified. This refers principally to tube-intake and turbine chamber gates, in front of which there is a reserve gate, so that the grooves can be exposed for repair. The grooves of gates Nos. 2, 3, 4, 5, 6 and 10 are of concrete with a steel plate lining, while for Nos. 11 and 12 the concrete of the grooves are not lined. For the older gates the supporting rails were of cast iron and were fastened outside the steel lining; in the case of newer gates, such as Nos. 4, 5 and 10, the supporting rails are made of steel bars fixed to the steel lining and supported by iron beams which have been cast in with the concrete underneath the lining. The newer gates

are guided sideways by double flanges on the bearing wheels of only one side of the gate which catch the supporting rail, and in the direction of the flow of water by special guide wheels which run on an ordinary railway rail or something similar, mounted in the concrete. At the new plant in *Lilla Edet* each of the turbine chambers will be closed by an upper and a lower gate, Nos. 14 and 15. As will be seen from Fig. 6, the load is transferred from each of the gates by four fixed supporting wheels only to the two dividing walls of the water intake. Grooves can thus be entirely avoided in the side walls, which is a great economic advantage for the concrete construction. They are replaced by a simple steel plate lining, against which the sides of the gate are to be tightened.

DESIGN OF GATES.

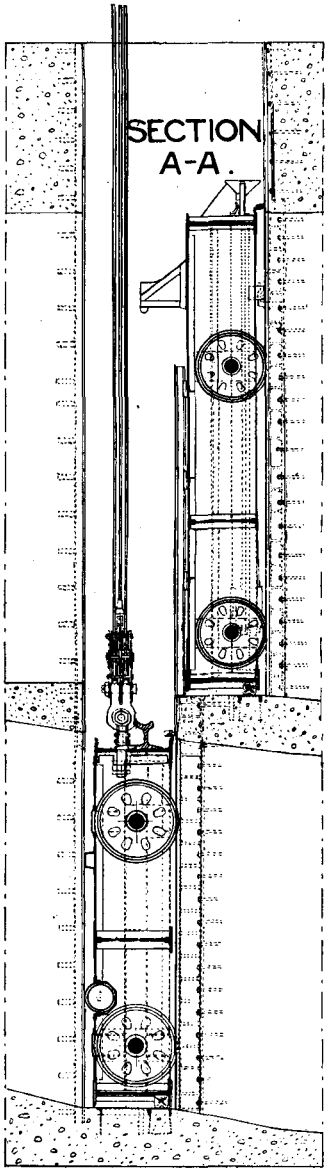
The gates in the older constructions of the Government power stations, such as Nos. 1, 2 and 3, are built up of a number of horizontal beams with a covering of plane sheets, while the number of horizontal beams in Nos. 4, 5, 6, 10a, 10b, 11, 14 and 15 was reduced to three, in the case of Nos. 9a and 9b to four, and for Nos. 7, 8, 12, 14 and 15 to two only. The covering consists either of buckled plates or, more recently, as in Nos. 7, 8, 11, 12, 14 and 15, of plates cylindrically bent, presenting a concave surface to the water and supported partly by the horizontal beams and partly by vertical side beams and a necessary number of intermediate beams.

All the gates at *Untra*, Nos. 16-19, have been designed with a large number of horizontal beams with straight edges on the down-stream side, and a convex bend against the water pressure on the up-stream side, to which the covering sheets, bent in the same manner, are riveted. The same construction has been used for the upper turbine chamber gates at *Forshuvudforsen*, No. 20, while the lower gates at the same station, No. 21, have a concave covering against the water pressure, this also being supported by a large number of horizontal beams, of which there are twelve.

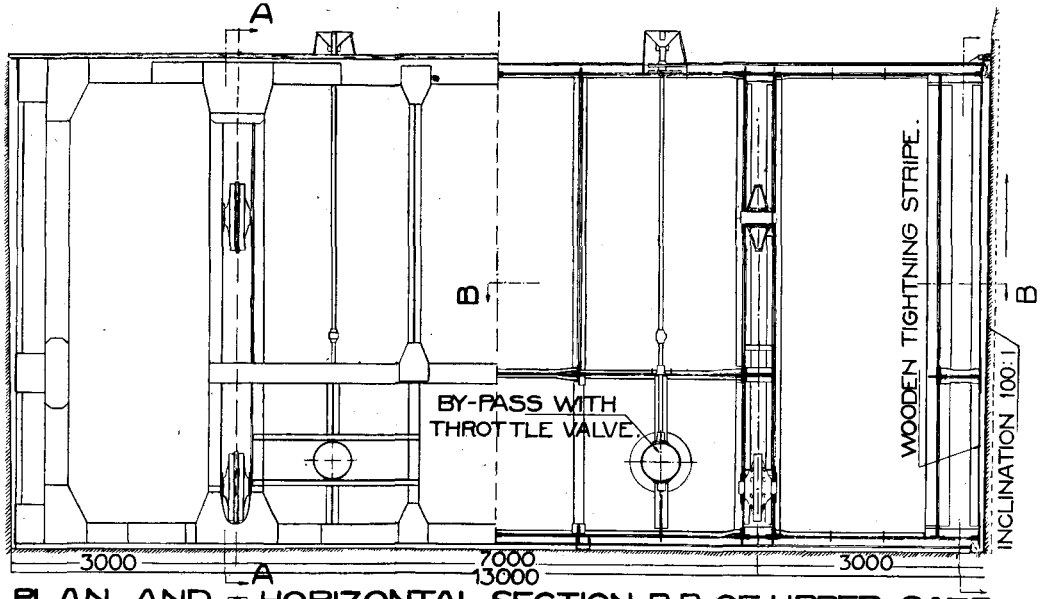
In the case of gates Nos. 1, 2 and 9, the water pressure is transferred to the supporting rails through *roller-carriages* with a large number of small rollers of the so-called *Stoney type*. The roller-carriages slide during the lifting of the gate for only half the distance of the gate itself and consequently, when the gate is lifted, they are subject to the action of the flowing water, ice, etc., which fact is apt to cause difficulties. If the roller-waggons are not manufactured with the greatest possible care, and if the rollers have

GATES FOR TURBINE CHAMBERS AT LILLA EDET

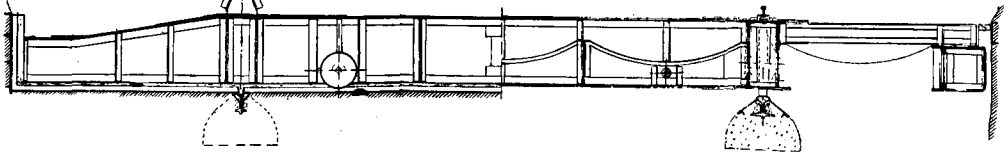
VERTICAL SECTION THROUGH ONE
UPPER AND ONE LOWER GATE.



ELEVATION AND VERTICAL SECTION OF UPPER GATE.



PLAN AND HORIZONTAL SECTION B-B OF UPPER GATE.



PLAN AND HORIZONTAL SECTION OF LOWER GATE.

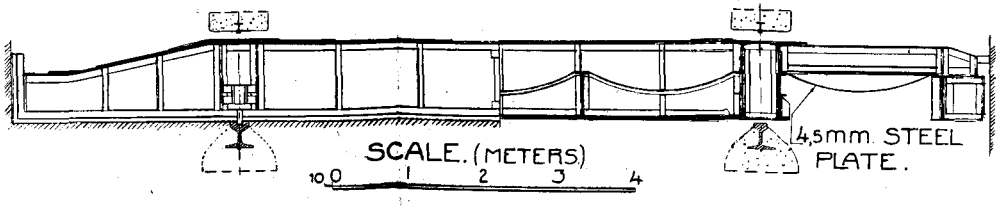


Fig. 6.

B—To face page 352.

not exactly identical diameters and absolutely horizontal and parallel bearings, then unequal movements are apt to occur, leading to an uneven wear and heavy stresses on those constructional parts, which, therefore, require careful inspection and numerous repairs. All other closing gates of larger dimensions supplied to Swedish Government power stations have, therefore, been fitted with as few as possible *fixed supporting wheels*, the number of which is shown in the table. Where the number for each gate exceeds four, the supporting wheels (except for gates Nos. 3 and 13) are coupled together in pairs to form bogeys in order to be able to determinate the load on each wheel. It will be seen from Table II. that the fixed bearing wheels had often to be given a very large diameter, at *Lilla Edet* even up to 1·05 m., in order to be able to support the heavy loads. The total weight has, however, not thereby been increased.

Gates Nos. 16, 17 and 18 at the *Untra* station have been fitted with Stoney roller carriages, which also at this place have proved to be more or less unsatisfactory in practice. Gates No. 19 have fixed supporting wheels grouped in pairs.

Of the turbine chamber gates at *Forshuvudforsen* only the upper ones, No. 20, have been fitted with supporting wheels (two fixed wheel couples on each side), while the pressure from the lower gates No. 21, which are only operated at the same water level on either side of the gate, is transferred by flat iron rails which, at the same time, form a tightening at the sides.

For tightening the aperture between the gate and the sill, the Government power stations as a rule employ a wooden beam screwed to the bottom edge of the gate. At the sides and, where necessary, at the upper edge, tightening is generally also effected by means of wooden laths. Instead of, as formerly, fastening these to the gate by means of metal springs, which permit of so much movement that the laths may be pressed against the contact surfaces of the gate opening by the water pressure, it is now preferred to screw the laths fast to the gate in a position which leaves a clearance of a few mm. between the packing laths and the contact surfaces which on both sides of the gate are given a slight inclination, for instance, 1:100 from the vertical. At the same time the small opening is closed by a strap doubled over and nailed to the wooden laths in a suitable manner, whereby the tightening is much improved.

At *Untra*, Nos. 16-19, the tightening is effected by means of a coarse

hemp rope sewn into a piece of jute cloth which is led into a wedge-shaped groove on the underside of the bottom beam and which in the closed position of the gate is pressed against the sill, which is made of smooth finished granite. For tightening the sides, round rods made of 3½-in. tubes are employed which, being mobile in a vertical direction for a few cm., are hung at the upper edge of the gates and which, when the gate is closed, are pressed by the water against contact irons on the gates and grooves, so placed that a wedge-shaped opening is formed between them and closed by these rods.

As previously mentioned, the lower turbine chamber gates at *Forshuvudforsen*, No. 21, are closed by flat iron rails, while the upper ones, No. 20, are closed by coarse hemp rope round which jute sacking has been spun and which is pressed into wedge-shaped grooves by the water pressure.

The *suspension* of the gates was at the earlier power stations by means of Gall's chains. At the later works, *i.e.*, for gates Nos. 4, 6, 11 and 12, wire ropes in 8-16 parts for each gate have been employed with advantage. At *Lilla Edet* each gate will be suspended on ten ropes. Gates Nos. 16, 17 and 18 at *Untra* are suspended on Gall's chains, while gates No. 19 are fitted with rack and pinion. At *Forshuvudforsen* racks are used for the lower gates and ordinary chains are used for the upper ones.

The *operating* is in the case of gates Nos. 1 and 5 carried out with machinery for manual power, at other gates mentioned it is effected by means of electric winches. The electric motor and a part of the machinery are, however, in the case of gates No. 7, common to four gates, at Nos. 9a and 9b, common to both pairs of gates and at Nos. 10a and 10b common to five pairs of gates, for which latter there is an additional electric motor in reserve. At *Forshuvudforsen* the electric motor is common to all three pairs of gates, to the winches of which the power is transmitted by a single axle and friction couplings. In the same way the five turbine chamber gates at *Untra* are operated (No. 16) by one single motor. Generally speaking, the lowering is done without using the motor and is regulated by centrifugal brakes, except in the case of the sluices Nos. 17-19 at *Untra* and No. 13 at *Suorva*, where also the closing takes place with the aid of electric power.

Of larger *closing mechanisms of other types* which, of latter years, have been employed, may here shortly be mentioned the eight large cylindrical *sector gates* with a bend having a radius of 6 m. and with underlying pivots, each having a free span of 11·9 m. and

a water pressure of 5 m., which are used to close the inlet channel at *Untra*; also two adjustable crests with a water pressure of 3·75 m. and a free span of 6 m. each, installed in connection with the third stage of building at the *Trollhättan* power station. These also have submerged hinges. The latter gates are intended to close two openings in the forebay for carrying off ice and surplus water.

Throttle valves of cast iron have recently been employed to close smaller dam openings, and one of these, circular with a diameter of 2·25 m., has been used to close an opening at the bottom of the dam at *Motala* against a water pressure of 13·5 m. Two rectangular ones with an area of 1·2×3·7 sq. m. have been inserted in the bottom of the dam at *Porjus* at a pressure of 14·2 m.

TURBINES AND GENERATORS.

Both turbines and generators are generally delivered from Swedish workshops, which manufacture this class of machinery up to the largest dimensions. Of such sets may be specially mentioned the turbines intended for the power station at *Lilla Edet* which will have runner diameters of 5·8 to 6 m., and the generators belonging to them, the weight of which will be about 300 tons and the diameter 9·4 m.

The turbines are most frequently of the Francis type. The fact that large double runner Francis turbines have for a few years back been constructed without central bearings in the suction casing is of special importance for hydraulic power development, as thereby considerable savings can be made in the cost of construction, for instance, in a case like that of the *Älvkarleby* power station. Lately, rapid running turbines of the propeller type, according to the two separate patents of Prof. *V. Kaplan* and Dr. Ing. *F. Lawaczeck* have begun to find use, for instance, just at *Lilla Edet*, whereby it has there been possible to employ at a fall of 6·5 m., up to 150 cu. m. of water per second in each aggregate, consisting of a single runner turbine with a vertical shaft, having a guaranteed efficiency of 86-87 per cent.

THE CONSTRUCTION WORK OF PLANTS.

Lastly, a few important points concerning the construction work of water power plants should be alluded to. The continually increasing price of human labour has resulted in efforts being made as far as possible to cheapen the work by the use of machinery where possible. For earth excavation work of larger proportions excavators are thus in general use, of which the more powerful

single shovel machines are most suitable for hard ground. Rock drills of good Swedish manufacture have a very wide field, as also have electrical hoisting machinery and mechanical transporting machinery of different kinds.

Modern concrete engineering occupies a prominent place in the building of hydraulic power stations, as concrete, which will have been seen from the above, is used for all types of such building works in the form of coarse concrete for foundations or simpler dam constructions, etc., as also reinforced concrete for more complicated dams, tube intakes, tunnels, turbine chambers, buildings, etc. There is no longer any difficulty in using concrete constructions, also, for works in the most rigorous winter climate, for instance for the dams at *Suorva*. In this case, however, certain precautionary measures must be carefully observed, *viz.*, when designing the construction to take into account the action of the temperature and the shrinkage of the concrete and, with the concrete work, to keep the materials heated to a sufficient degree and otherwise to carry out the preparation of the concrete in the best possible manner. In many cases it is necessary to build over the site with a provisional covering, inside which the air is kept heated a few degrees above freezing point. This is especially necessary in such cases where it is desired to keep the cast concrete damp with water for a month or so, in order to reduce the shrinkage of the concrete and the increased stresses caused thereby in the finished material.

For concrete constructions more heavily reinforced, where it is necessary to prevent the rusting of the iron by a covering of concrete as dense as possible, the proportion of water added in the mixing of the concrete is generally chosen so that it corresponds to 17 or 18 per cent. of the total dry weight of the cement and sand employed. The consistency then becomes plastic and there is more security for an effective union of the iron and stone material. It is, however, necessary even with this consistency, to work the concrete mass well into the form, in order to drive away air and the excess of water, which latter, together with " laitance " should be removed, as it collects over the concrete. In connection with the considerable concrete work latterly carried out for the turbine chambers at *Lilla Edet*, a hoisting tower with sheet iron transport chutes suspended from a derrick boom fastened to the tower and with control over the entire area of the site, have been advantageously employed for the transport of concrete of such consistency. A slope of about 25° has proved to be sufficient for these chutes.

RÉSUMÉ.

L'auteur a examiné dans son rapport les caractéristiques fondamentales des installations de force hydraulique en Suède, notamment, la régularisation assez fréquente des cours d'eau par des lacs naturels et les améliorations possibles dans ce sens ; les chutes par contre, sont le plus souvent de faible hauteur et le climat varie dans de grandes limites, allant de régions relativement chaudes dans le sud à des régions très froides dans le Nord. Le sol est généralement bon pour la construction des travaux d'art.

Dans l'examen des développements réalisés durant ces dernières années dans la construction des centrales hydrauliques, une mention spéciale est faite sur la construction des barrages, ceux du type " gravité " sont ou peu économiques ou pas très sûrs. D'autres systèmes ont donc été adoptés, l'auteur cite ceux avec voûtes en béton armé et en particulier le barrage de Suorva, terminé en 1923, situé dans une région montagneuse et aride à 100 km. au nord du cercle arctique. De nouvelles recherches sur la pression exercée par la glace sur les barrages, ont montré que la pression de la glace dans les conditions existant en Suède, même avec une épaisseur de glace dépassant un mètre, ne peut être supérieure à 30 tonnes par mètre de longueur.

Pour les conduites en palier destinées à l'alimentation ainsi qu' à l'écoulement des eaux, on a utilisé de grands tuyaux en tôle d'acier où le sol était trop poreux, dans d'autres cas des tunnels taillés dans le roc et ayant jusqu'à 85 m^2 de section.

L'auteur examine les *chambres d'eau* pour centrales de faibles chutes et cite les grandes installations de Älvkarleby et Motala.

Les conduites sous pression pour centrales avec turbines fermées sont construites en bois, en acier ou en béton armé, ce dernier type pour pression d'eau de 26 m à Gideåbacka. Afin de limiter l'effet du coup de bélier, lors d'une augmentation ou diminution brusque de la charge, on a installé en plusieurs endroits des réservoirs construits généralement en tôle d'acier et des galeries enfoncées dans le roc.

En ce qui concerne le dispositif des tuyaux de tirage, l'expérience de Trollhättan prouve que la partie inférieure de ces tuyaux ne résistera pas suffisamment à l'usure si elle est construite en béton ordinaire. A Trollhättan ainsi qu'à Forshuvudforsen et à Lilla Edet, le béton est protégé par une garniture de scories.

L'auteur a examiné ensuite rapidement les échelles à poissons utilisées dans les deux dernières centrales mentionnées plus haut, également un système de chauffage électrique de ces échelles ; une description plus détaillée est faite, sur les derniers perfectionnements adoptés pour les *dispositifs de fermeture* des ouvertures de grands barrages et de prises d'eau de canaux, tunnels, tuyaux et chambres d'eau.

Des tableaux de chiffres comparatifs ont été compilés, relatifs à des barrages à rideau et à de grandes vannes verticales en acier, d'après des installations récemment terminées.

Une étude complète est faite des différents systèmes de vannes donnant dans chaque cas les résultats obtenus.

Les turbines et générateurs électriques sont construits dans le pays jusqu'aux plus grandes dimensions ; ce sujet toutefois faisant l'objet d'un rapport séparé par Mr. le Prof. Hj. Dahl, l'auteur n'a abordé que quelques points particuliers concernant la question de construction hydraulique, notamment l'omission du palier intermédiaire dans les turbines Francis à double rotor, et l'introduction de turbines à grande vitesse de types entièrement nouveaux, semblables à des hélices, et qui faciliterons beaucoup l'exploitation économique des basses chutes, tel que celle de Lilla Edet.

Finalement les perfectionnements apportés aux méthodes de travail; l'utilisation de plus en plus grande de machines tels qu'excavateurs, perforatrices, treuils électriques, etc. ; sont examinés rapidement. Mention spéciale est faite sur l'emploi très répandu maintenant du béton armé et de la possibilité de l'utiliser même où les installations sont sujettes à de très fortes gelées. Des renseignements sont donnés sur les constructions en béton exécutées à Lilla Edet.

GENERAL REVIEW OF CURRENT PRACTICE IN WATER POWER PRODUCTION IN AMERICA.

JOHN R. FREEMAN,
Past President Am.Soc.C.E. and A.S.M.E.

In the United States, as in the world at large, we are now in the midst of the greatest activity ever known in water power development.

Following invention and successful practice in the transmission and distribution of power by electricity, the art has been developing with marvellous rapidity during the past twenty-five years; and practice in the development of water power has become so perfected and so standardised, and the units have attained such magnitude in discharge, head, power and efficiency, that now there seems small chance of further important change in the design of a water power plant to meet the conditions imposed by nature at a given waterfall, although there may possibly be many improvements in the electrical transmission and distribution of power generated from either water or fuel.

To-day, the foremost problems connected with water power which await improvement are those of the inter-connection of plants manufacturing power from water and steam (or from internal combustion) for the purposes of better service and greater conservation of capital, as well as for the conservation of natural resources, and perhaps the most important of the problems now before us are those of public relations and of future public welfare; of the distribution of industries away from crowded cities into the country where conditions are better for wholesome family life, rather than to let cheap and facile transmission of power cause greater congestion of industry and population.

In the old days the presence of a power site often created a new and wholesome industrial village or city. To-day the electrical transmission is taking away this opportunity, but it need not always be so. The wires can just as well carry power from the inter-connected system of steam power and water power units

to carefully selected districts where smaller communities may be gathered around an industry under the most favourable social conditions, and the new builder of an industry can conserve his limited capital all for direct use, instead of having to begin by a large investment in water rights, dam and turbine, and can buy his power cheaper than he could manufacture it.

In attempting to review current hydro-electric practice in the fewest words, and viewing the hydraulic rather than the electrical end, we may summarise the present status as follows:

TURBINES.

Hydro-turbines have all come to be very nearly alike in form and detail for all ordinary conditions where maximum economy in use of water is of high importance. In nearly all large power plants these now are set on a vertical axis, and the generator is carried at the top of the turbine shaft, and the combined generator shaft and turbine have their weight suspended from near the top.

All are of the so-called Francis type, which might properly be called the Francis-Swain-McCormick-Leffell type, because each of those named has added important features to the Francis idea of "Centre-vent" or inward flow.

In order to obtain speed of revolution convenient and economical in electric generator design for different heads, the radial and axial angles of guide vane and bucket are slightly varied in turbines of the same general design in order to give each the required "characteristic" curve, and variation is made in the ratio of inlet height to diameter, in order to give over-load capacity and facilitate speed regulation, while retaining an efficiency curve which is tolerably flat near its summit. Also there may be slight differences in clearance at inlet to the turbine runner and in flare at outlet of runner, or in some detail of gate mechanism and speed ring; but if it were practicable to set up a dozen turbines for about the same fall and discharge, all of most recent design, each by a different maker, all in a row (not including the recent "High Speed Runner" or "Screw Turbine"), the casual observer would have difficulty in finding important difference between them, and the most careful observer would become satisfied that very little further economy of material or labour was possible in the design of hydro-turbines for meeting a wide range of conditions.

TURBINE EFFICIENCY.

The efficiency, or percentage of useful effect to the theoretic power expended in the fall of water, is now well above 90 per cent. in large size units by several makers, and when one considers the unavoidable friction losses in water at high velocity twisting its way in tortuous passage through angles of more than 180°, with some unavoidable shock of impact upon runner vane, and considering also the necessary friction of the rapidly revolving mass, weighing many tons, upon its supporting bearings, combined with the air resistance to the swift revolution of the generator, it well may be accepted that designers have now practically reached the end of the road in improvement of efficiency.

THE MODERN HIGH SPEED TURBINE.

Notwithstanding that the conditions for obtaining highest average efficiency over a broad range are now well understood, situations are often found where it may be true economy to sacrifice a little in percentage of useful effect in the turbine runner, in order to conserve capital investment. To meet such conditions there has been very recently developed a so-called "high-speed runner," somewhat resembling a windmill, or in form somewhat similar to a screw propeller reversed in function.*

The fundamental idea in the "Screw Turbine" is old, but its development to a remarkably high stage of efficiency is recent, and it cannot safely be said that the limit to improvement in this line has quite been reached. It promises usefulness in situations where water is abundant and capital scarce, or where the turbine will be in use but a small part of the time, as for example, an emergency turbine for use in time of flood. Also it promises to be of use in developing small heads because of its lessened cost per horse power of installation in at least three directions: in turbine, turbine-setting and in electric generator. Also its wide, direct passages give promise of freedom from obstruction by rubbish or fragments of ice.

It would seem feasible to design this simple, high-speed, large capacity type in strong and tolerably efficient form for any head, or for any diameter within the range of the slower speed turbine of the ordinary type, and with a few more experiments in the testing flume or laboratory, the screw type of

* A recent European invention of great promise in this line looks much like a "Screw pile."

hydro-turbine doubtless will soon be standardised for use over a wide range of heads and capacities, perhaps in two forms: one similar to the propeller of a steamship, the other looking more like a screw pile.

SCROLL CHAMBER.

In standard practice for large units and for high heads, the water chamber surrounding the turbine is now nearly always formed somewhat in the form of a snail shell, or "Scroll," in order to give a spiral approach of the water, thus leading it into the guide vanes without shock.

This spiral chamber may be shaped from riveted steel plates or from castings, or may be shaped within the mass concrete of the power house foundation in continuation of the penstock, being given conical form, with a carefully designed lessening of diameter such as to give nearly uniform velocity of approach of water all the way around the guide inlets, and by this means high velocities may be used and structural costs lessened, both in chamber and in its feeder pipe, all without serious loss of head by friction in the current.

DRAFT TUBE.

It is now standard practice to so design this that it serves to lift the turbine mechanism to a height of about 15 to 20 feet above the tail-race water level, and also serves the important purpose of adding to the power of the turbine by converting into head much of the energy in the high velocity with which the water leaves the turbine. The divergence of the draft tube cone is carefully proportioned. Bringing the turbine mechanism well above the tail-race level obviates all the old-time trouble of pumping out a wheel pit.

Very recently great attention has been given to obtaining the maximum efficiency in draft tubes; recourse has again been had to the testing flume while evolving the "hydraucone" and other shapes for lessening the eddy loss while changing the direction of current from vertical to horizontal. The 1 per cent., or perhaps 5 per cent., saved by careful attention to these details of form cost almost nothing in construction in proportion to the whole, and the saving goes on forever. Moreover, the improved shape of the draft tube base evolved in these recent experiments lessens the depth of excavation required, and may also lessen the volume of masonry, and, if desired, permits a central core

to be extended up so as to give support or steadiness to the base of the turbine shaft.

The whirling component of the velocity given to the water at its exit from the turbine appears greatly to aid in diffusion through a much wider conical angle within the draft tube than would be practicable in an ordinary venturi tube without this rotary motion. In other words, complete diffusion and a reduction of exit velocity to three or four feet per second with maximum conservation of energy may be obtained within a draft tube only twenty feet tall.

In certain recent large installations with high vacuum, the admission of a small quantity of air through a few 2 in. pipes set close below the turbine, has been found to cushion the shocks from separation and coming together of the water column.

The recent best practice is to make the draft tube vertical and avoid inclination down stream, lest air bubbles collect and lessen its efficiency. Doubtless some small additional draft tube gain of a fractional percentage may be had by further experiment in the hydraulic laboratory, and the shape of draft tube thus readily be standardised once for all, but already the end of possible improvement of the draft tube is near at hand.

BEARINGS.

The design of a proper footstep bearing to carrying the weight of revolving mass of runner and shaft and gear of turbines far smaller than those of to-day, was for seventy-five years one of the difficult problems of turbine design, particularly for sites where water was gritty. With the addition of many tons weight in the electric rotor, and with larger turbines and higher heads, the problem became still more difficult, until suddenly about fifteen years ago it was completely solved by the disc suspension bearing, located out of the water above the turbine, and more recently placed near the top of the shaft. It is worthy of note here that this idea of top suspension was used by the great designer, Boyden, in some of the earliest American turbines seventy-five years ago.

In the earlier disc bearings a film of liquid was maintained between the discs by pumping it in at high pressure, but more recently there has been generally adopted the "Kingsbury" type of bearing, in which the revolution of a segmental disc, containing openings very slightly wedged-shaped at their forward

edges, drags the lubricant between these discs by means of its own viscosity. By these means this problem of support of the vertical turbine has been completely solved notwithstanding the weight to be supported while revolving at high velocity on a single bearing in the case of the recent Niagara-Queenston turbines is 480 tons. The Keokuk turbines now have been running ten years continuously night and day with bearings of this type each carrying a load of about 240 tons. Thus the problem of support may be considered as completely solved.

SPEED GATE.

The great problem of the "speed gate," or series of valves by which water is admitted to the turbine, and its power and speed controlled, is one upon which a score of inventors have tried their skill during the past seventy-five years. About fifteen or twenty years ago practice settled down to a single type for large turbines and high heads. The difficulties of the early inventors were those of obtaining a high efficiency when the gate is partly closed, and the obtaining of an easy working gate that could be shut tight enough to stop the wheel. There have been plain cylinder gates, flanged cylinder gates, winged cylinder gates, two-story and three-story runner-inlets, winged runner-inlets, Swain gates, register gates and wicket gates in many varieties.

The survivor, the wicket gate, now in almost universal use on the largest modern turbines, is new only in its superior strength and superior workmanship. The same type with less rigid control mechanism and less accurate workmanship was in common use more than fifty years ago in the Leffell turbines popular at country mills. This old and modernised gate consists of a series of adjustable guide vanes, each turning through varying angles, upon a strong shaft parallel to the turbine axis, so placed that the water pressure is largely balanced by the areas of guide-vane on the two sides of this pivot shaft. All are simultaneously swung to open or to close at their inner edges by each being keyed to its pivot shaft which carries a strong lever arm actuated by linkage to a heavy ring, central with the main turbine shaft, which ring being revolved through a small angle by strong connecting rods, by means of convenient gears connected to the water wheel governor, moves all these guide vanes simultaneously. Precision of workmanship in machinery, and rigidity in design give watertightness and rigid control.

By thus varying the angle of the guide vanes as the gate is partly closed eddy losses are avoided.

Clearance between the discharge edge of the gate-vanes and the inlet edges of the runner-buckets is now much broader than in early designs. This broad clearance seems to permit mutual adjustment between the jets, favourable to high efficiency.

It may fairly be said that now that details and workmanship have been perfected there is no further demand for a better turbine speed-gate.

WATER-WHEEL GOVERNORS.

About thirty years ago it began to be recognised that under the suddenly varying loads due to electric street railway service and the like, and with the occasional instantaneous cutting off of all outside load by the breakage of an electrical transmission wire, something must be devised far better than the old-time slow-moving water-wheel governor; and it became obvious that the speed governor proper could not well be given power enough for opening or quickly closing the speed gates of the ponderous turbine, and must only be required to close or to open quickly, with delicate adjustment, the valve to a powerful hydraulic piston, or equivalent gate-moving device having power sufficient for any desired rapidity of action, and capable of such control that disastrous water-ram or dangerous surges would not be created within the pipe supplying the turbine, by the water column acting like a hydraulic pendulum, building up surges to successively higher stages, while a slow-moving governor was feeling for control.

Powerful governor-gear for meeting somewhat similar conditions on great steamship engines and mill engines requiring instantaneous control had previously been devised, as the writer found to his sorrow some thirty years ago, by a whole sheaf of references to steam engine control when he applied for a patent on a water-wheel governor.

This principle was soon adapted to water-wheel practice in the Lombard water-wheel governor, and after a time others were devised by various makers of large turbines, so that now all requirements seem to be met satisfactorily, or as well as conditions creating penstock surges will ever permit.

SURGE TANKS.

About twenty years ago, with the introduction of higher heads and longer supply pipes, the vast momentum changes of these

long water columns under rapid changes of velocity caused by the quick working governor in response to sudden variations of demand for electric power often gave rise to conditions liable to rupture the scroll chamber or the penstock, and thus flood the power house, or cause general wreckage.

Sometimes break-plates were placed near the end of the penstock so that they would be the first to yield, and would discharge outside the power house; and sometimes great safety valves were provided near the end of the water supply line. Break-plates and pressure relief valves might forestall wreckage, but obviously such devices could not prevent surges from racing back and forth in the supply conduit, and quickly building up higher pulsations under the mutual reaction of governor and surge, until conditions were reached that were at least disastrous to steady voltage, and might cause rupture of penstocks, if unchecked. Moreover, in avoiding water-ram and surges due governor control, by means of deflecting nozzles on high-head impulse wheels, much valuable water was wasted.

The writer, after briefly studying the ameliorating effect of simple surge tanks, found that in certain cases these were likely to prove unsatisfactory in damping the surges and called to his assistance the exceptional mathematical skill of Mr. R. D. Johnson, who seems to have solved the problem satisfactorily for many conditions by his differential surge tank, which promptly damps the surge, instead of permitting it to build up.

Extremely difficult conditions are still sometimes found at the end of long penstocks under high head, but the surge-tank, carefully designed under expert mathematical study of the special conditions, now is standard.

Recent advances in the studies of mathematical relation between quantities and velocities in full size structure and small size model promise much aid in these problems.

EMERGENCY PENSTOCK VALVES.

Higher heads in larger diameters made the head gate problem one of increasing difficulty, and after sketching the outlines of a balanced valve worked by internal water pressure, and in shape a cylinder with conical ends, placed within a swelling in the penstock line, the present writer also turned this problem over to Mr. R. D. Johnson, who worked out details for the well-known valve that bears his name, which appear satisfactorily to meet extremely difficult conditions, save that so large and heavy a

structure for withstanding heavy pressures is necessarily costly, and the requirements of economy frequently compel one to be satisfied with a simpler arrangement of ordinary sluice gates, or sometimes, balanced butterfly valves, placed at the head of the separate penstock line for each unit, and all arranged for quick electrical or other control in case of emergency.

PRESSURE TUNNEL VERSUS STEEL PENSTOCKS.

The common method of delivering the water to the turbine under a high head is by a steel penstock leading down a steep slope from a forebay located at the end of a main conduit and on the hydraulic grade line. The economy of making these pipes smooth on the inside by avoiding all projections such as rivet heads is now well recognised, and for extremely high heads welded pipes are the rule. The writer doubts if the matter of permanent maintenance of smoothness by avoidance of rust has yet received the attention that it deserves. These large steel pipes are very expensive where the power house is distant from the forebay or dam.

For those cases where the lie of the land compels a long canal or tunnel in order economically to concentrate the fall, the present writer has long believed that important economy may be found in carrying the water with velocity low enough to avoid momentum troubles, in a pressure tunnel under such deep coverage in the rock that the weight of overburden will be safely in excess of the water pressure; the tunnel being carefully lined with concrete and its backing pressure-grouted, to a point within a relatively short distance from the power house, from which point several steel penstocks can be run side by side in close contact, tightly embedded in concrete, within about the same cross-sectional area as that of the tunnel, and with thickness of shell adjusted to distance and depth of cover.

A small relief pipe should rise at the downstream end of each penstock back up the hill, or rise like a chimney, to the hydraulic grade with spillway at its top. An emergency valve may be placed just outside the power house, and just outside the power house should be placed also a nest of small relief valves. A large number of small valves gives much better and smoother action than one large valve.

The failure of a certain steel-lined pressure tunnel in California some ten years or so ago seems to have created some prejudice against this general type of pressure tunnel, which is not justified.

The failure cited was plainly due to improper design and inadequate precautions in construction. The success of the vast systems of pressure tunnels of the Catskill aqueduct and beneath the City of New York in use for ten years past should give satisfactory practical proof that such structures can be made safe.

ICE TROUBLES AND A CURE.

In northern latitudes, as in Canada, Maine, New Hampshire, northern New York, and Minnesota, a cure has now been found for the serious troubles of twenty-five years ago.

There were two kinds of ice that caused most of the trouble, cake ice and frazil or anchor ice. The floating cake ice can be guided off to one side of the turbine intake, by ice booms set deeply and inclined at a sharp angle to the current approaching the intake; although this involves more or less waste of water in carrying the ice over the raceway. The ice boom is a simple common-sense device, with no mystery about its principle of operation, but needs engineering design. For meeting extremely difficult conditions on the St. Lawrence River, Mr. B. F. Groat, M.Am.Soc.C.E., has worked out by means of models a more elaborate device than the ordinary ice boom, which appears to meet conditions well by taking the water from the bottom under extremely low velocity, through a series of transverse channels, as far as possible below the surface current which carries the ice.

Slush ice comes chiefly from snow blown into the ice-cold water during severe storms, and is after all similar in action to floating crushed ice, and differs greatly from frazil and anchor ice by having no strong tendency to agglomerate.

The problems of frazil and anchor ice are far more difficult than those of surface ice. Their capacity for causing trouble at a water power plant is unbelievable to one who has not been up against it. Anchor ice and frazil are of much the same nature. Both are composed of loose collections of needle-like crystals, lying at all sorts of angles, like nails in a keg. These are formed when water is under-cooled a few thousandths of a degree below the nominal freezing point of 32° F., and the distinctive quality of both anchor ice and frazil is their tendency to agglomerate and quickly freeze together into a shapeless mushy mass, which will build up rapidly against screen inlets or turbine inlets. It will bridge across and clog a broad passage-way, and when broken out or cut apart, will instantly re-unite, so that a paddle may be pushed through the mass with small

expenditure of force and leave hardly a mark behind. A broad gateway may be blown clear of frazil by dynamite, and a moment later the parts of the frazil mass will be found re-united and the opening again closed.

The only important difference between anchor ice and frazil is that of a different origin. The crystals of anchor ice are formed in attachment to the river bottom mostly on clear nights in open water without ice cover, particularly in rapids, by the radiation of heat into space. This anchored ice is released on the following morning soon after the sun has warmed up the water close to the river bed by not more than half the one-hundredth part of a degree.

Frazil seems to be composed of similar crystals formed within the flowing water because of a similar under-cooling of the water by radiation on cold cloudless nights. Each crystal forms around some small nucleus of sand in suspension, commonly of microscopic size.

Frazil or anchor ice never forms beneath an ice cover, or upon cloudy nights.

The researches of Prof. Howard T. Barnes, physicist, of Magill University, Montreal, which may be found partially described in his excellent book, "Ice Formation," begun as a study in pure physics, have come to be of the highest practical importance, through their discovery of the nature and cause of these phenomena, and in showing that a complete remedy can be had by warming the water which contains these crystals by less than the one-hundredth part of a degree F., or by warming the turbine casing very slightly.

After thus removing the under-cooling, the separate crystals lose their tendency to stick together and will no longer agglomerate into a clinging mass any more than so much sawdust. Prof. Barnes' precise temperature measurements were in terms of less than the thousandth part of a degree and these showed that in difficult cases an economical remedy may be had by the discharge of a small steam jet into the water upstream from screen or turbine, or by expending in electrical heating coils at the power house intake less than 5 per cent. of the power derived from the water wheels.

At one important plant a substantially complete cure for serious interruption by ice has been obtained by dredging out the canal so as to give a large cross section and a surface velocity slow

enough to permit the maintenance of an ice cover. In order to permit a quick freeze-over at the beginning of the ice season the water must be slowed down during the first cold nights to about 1 foot or 1·5 feet per second; but after the ice cover has been made complete, turbine gates may be opened further under favourable conditions, and the velocity raised to 2·0 feet per second and more, as the ice becomes thicker and stronger, or to the highest velocity which the ice cover can resist without rupture.

GENERAL LAY-OUT OF PLANT.

Electrical distribution of power has completely changed the general lay-out of large power plants from the current practice of former years. Formerly the water was distributed by canals to separate turbines, placed at the particular building where power was needed.

It is of interest to note that the change to the vertical turbine was not universal in the early stages of hydro-electric practice even for large plants. For example, at the St. Lawrence Power Co. at Massena each large electric generator was mounted near the end of a long horizontal shaft, extending back into a forebay and upon this long shaft were mounted six separate turbine runners divided into three pairs, all for the purpose of obtaining compactness of design, and at two of the Niagara plants each great generator was set on a short horizontal shaft between horizontal turbines each set in a strong iron chamber that was fed by a tall steel penstock. At Hale's Bar, Tennessee, two vertical turbines were mounted on the same vertical shaft, one above the other in separate chambers moulded in a mass of concrete.

Mounting upon a horizontal shaft had certain advantages apart from that of avoiding the troubles incident to step bearings, for certain cases and heads, by giving higher rotative speed when the discharge was sub-divided between two turbines each of small diameter, which have in part disappeared with the design of runners adapted for higher speeds. There were various modifications of mountings on both vertical and horizontal shafts prior to the perfection of top suspension and disc bearings; since which almost the one and only method where the power is to be used for generating electricity is that of the single runner, vertical shaft and top suspension, already described.

Different conditions prevail at water power plants where the power is directly applied to machines such as pulp grinders, or

is applied to main shafts lines by belts. For such situations current practice still puts turbines on a horizontal axis, commonly set in opposite pairs.

For high heads and large units when a horizontal axis is required the best practice is to use turbines of the same standard Francis type used on vertical shaft, each within a scroll case of cast-iron fed from a separate penstock and to run each turbine discharge into a quarter-turn pipe which units with a corresponding quarter-turn receiving the discharge from the opposite turbine so that both discharge into a vertical draft. Thrust along the shaft is thus equalised by subdivision of the power between pairs of opposite turbines. Tests have demonstrated that placing the opposite discharge pipes too near together lessens the efficiency by an important percentage, and it now seems important that the draft tube run as nearly vertical as practicable and with more attention to the divergence and shape at bottom than formerly.

This arrangement of the pair of turbines with their discharges convergent, commonly works out better for high efficiency and for convenience of access to gate mechanism than feeding from a common forebay with divergent discharge into separate draft tubes, but for small or medium heads and discharges, the opposite arrangement, with two turbines set inside a common forebay, can often be worked out at smaller cost and is still recognised as good practice. For smaller water powers which serve their factories directly without electrical conversion, the standard stock turbines of some half dozen different manufacturers, made at remarkably low cost, still serve a most useful purpose in hundreds of power sites, and their designers are entitled to great respect for having developed types that could be cheaply built, cheaply set, and which could withstand neglect and abuse; for it is by refining their details that the magnificent giant turbines of to-day have been produced and standardised.

Summarising current water power practice in the fewest words, it may be said:—

(a) That current practice has now become highly standardised.

(b) That there is no limit to the head and fall which may be used in a single stage turbine, between eight feet head and 800 feet head, except the extreme limits of size and weight of parts imposed by machining and by railroad shipment.

(c) In power that can be applied to a single turbine, there is

practically no limit under 60,000 H.P. at 300 feet head, or 15,000 H.P. at 30 feet head, and here the limits are fixed only by the size and weights of turbine runners, which can be shipped over ordinary railroads.

(d) For heads above 500 feet or 800 feet, the impulse wheel is in operation with 15,000 H.P. per single wheel, and with a pair driving a single 30,000 H.P. generator under 1,100 feet head, while somewhat smaller units of impulse water wheels in three widely separated parts of the world—California, Norway and the French Alps, are working at heads up to about 3,300 feet.

(e) The standard lay-out is a sub-division into fewest practicable units, commonly three to five, all in a single power house, placed as close to the dam and pond as the lie of the land will permit and set to use the maximum head direct from the pond through a pressure pipe or a pressure tunnel, without needless sacrifice of head in forebay or head gates. Each turbine runner is suspended at the bottom of a vertical shaft which carries the rotor of the electric generator at its top, the entire weight of runner, shaft and rotor being supported by disc bearings floating on a thin film of oil placed near the top of shaft, or above the turbine. The turbine is of the Francis type, set in a scroll-chamber, with all water passages carefully proportioned so as to permit high velocity with least possible eddy or shock, anywhere from forebay to tail-race. The turbine is set about 10 to 20 feet above tail-race level and provided with a divergent vertical draft tube, flaring at its base and carefully designed to recover the largest practicable amount of velocity head. The result is that the turbine of standard design thus set delivers to the electric rotor about 90 per cent. of the theoretic power of the water over a wide range of power demand and will run twenty-four hours per day seven days per week, and year after year with remarkably small expense for care or repairs. There are well authenticated tests of 93 per cent. efficiency, and when one considers that the remaining 7 per cent. covers mechanical and fluid friction and air friction, it is plainly impossible to hope for much further improvement in efficiency.

THE SIPHON SPILLWAY.

The siphon spillway for about twenty-five years past has been

slowly coming into notice and general approval, as the simplest, cheapest and best means for holding the flood height down to the normal height in the millpond above the dam, on a river subject to sudden floods. The writer believes that it is worthy of much wider use and in units of far greater capacity than those yet built, and has recently presented designs for a line of such spillways with throats 10 feet high by 12 feet wide under 30 feet head, each probably capable of instantaneously discharging about 3,500, or perhaps 4,000 cubic feet per second without human attention if a sudden rainfall or a sudden shut down of the turbines tends to raise the reservoir level too high. These extremely large sizes have not yet had the test of use, and it is evident caution must be used in the design to avoid severe shock from the coming together of the two parts of a broken surging water column with no air cushion between.

Looked at from a different point of view, the siphon spillway increases the water power, sometimes to a very important percentage, by permitting the ordinary working level of the head water to be kept up close to the highest admissible flood level.

THE DESIGN OF DAMS.

It has not been the requirements of water power so much as those of municipal water supply and the need of high dams for great storage reservoirs, that has within the memory of many engineers still active, led to closer study and to the development of standard designs of dams for heights up to 200 feet or more, of whose absolute safety no skilled engineer has now any doubts.

The present general standard is a massive dam of rubble concrete, having a so-called " gravity cross section," and given an additional factor of safety, or given at least a pleasing appearance and a sense of superior safety in the mind of the public, by arching the dam in plan on a radius of anywhere from 400 to 1,000 feet. Uplift pressures are carefully designed against, and their possibilities are lessened by drainage bore-holes and tunnels. The writer happens to have been one of the earliest to introduce large longitudinal drainage tunnels set as deep as practicable in the base of the dam of gravity section with drill holes from this extending 10-20 or 40 feet below, as local conditions demand, and with pipe-like openings extending upward from the tunnel at about 10 feet intervals, to near the top of the dam, and from observing several structures where these

have been introduced is well assured of their utility, and notes that they are coming into current practice. It is also of interest to note that in great dams, and, in fact, in most hydraulic structures of concrete, carefully designed shrinkage joints at intervals of not more than 50 feet are coming to be "current practice."

For situations where funds are scanty, various other types of dams are being perfected, which there is not space here to discuss.

A better realisation than heretofore is now current about the need of providing against uplift pressures and for stopping seepage as near to the upstream face of the dam as practicable, before it permeates the mass of masonry, and in course of time weakens the concrete, particularly where exposure to frost is severe.

SOME HISTORICAL NOTES.

We may recognise at least three distinct epochs or stages in current practice. (1) The Colonial Stage, (2) The Industrial-City Stage and (3) The Electrical Transmission Stage; in the midst of which we now are.

The changes in methods and standards from those current in water power development a few years ago have been so vast and revolutionary, that it seems worth while very briefly to refer to the development of the earlier current practice, and to the causes of change as seen by the present writer, who happens to have entered the service of one of the most noteworthy old-time water power companies, as a junior assistant engineer, fifty-two years ago, and was thus brought into intimate personal contact with some of the most notable pioneers, Charles S. Storrow, James B. Francis and many others, at a time when the second stage of American water power development was in its prime at Lowell, Lawrence, Manchester and Holyoke, and as yet unsurpassed at any other place in America or in the world.

The Colonial stage of American water power development was found in small grist mills, saw mills, carding mills, fulling mills and forges; all on small streams. Its water wheels were mostly slow-moving breast, or over-shot wheels built up with heavily timbered frames, and flat or "pitch-back" wooden buckets, all operating not by reaction or impulse, but by simple force of gravity on the water contained between bucket and apron.

More rapidly rotating "flutter-wheels" were also in use. These were crude impulse wheels, with straight wooden blades, and were

mostly set on a vertical axis and thus well adapted for direct connection to the mill-stone of country grist mills.

Some were set on a horizontal axis and thus adapted to drive " up-and-down " saw mills, and sometimes they were geared to a horizontal main shaft.

Seldom was one of these Colonial power units of more than 10 or 20, or perhaps at most 60 H.P.

The American practice of these early days is well reflected in a book popular nearly a century ago, called " The Millwrights' Guide " by Oliver Evans, of Philadelphia.

The European practice of early days and up to 1850 may be found in such books as Belidor's " Hydraulic Architecture," (in French), and in other books collected nearly a hundred years ago in the remarkable library of Loammi Baldwin, of Boston, Mass., who has been called " The father of civil engineering in America," which library now reposes at the Massachusetts Institute of Technology, and may also be found in the library collected at the office of the Locks and Canals Company in Lowell, by James B. Francis, about seventy-five years ago.

The first great impetus to water power development on a larger scale in America, followed the successful introduction of cotton manufacture at Pawtucket, Rhode Island, on the Blackstone River, early in the nineteenth century. Many small mills were built, one after another, between 1815 and 1840 on the smaller rivers of New England.

The " Mill-power," equivalent to 30 cubic feet of water per second, falling 25 feet, gave 85 Theoretic H.P., which, allowing 70 per cent. efficiency for the best water wheels of the time, less the gear friction, yielded about 60 H.P. on the Main Shaft, became established first at Waltham, Mass., and later adopted at Lowell, Lawrence and elsewhere, as a convenient unit of water power, sufficient for driving the individual cotton factory of those days.

One of the new hydraulic turbines recently put into service at Queenston, Niagara, yields about one thousand times the amount of power given by the largest water wheel of a hundred years ago!

The second great era in American power development began under the leadership of the great old-time Boston merchant houses of the Lawrences and the Lowells, with Appletons, Jacksons and Amorys as their associates. The primary object was cotton manufacture with a great machine shop as auxiliary. This era in power development was begun about ninety years ago by

transforming an old Navigation Canal at Pawtucket Falls on the Merrimack River, and this was followed about seventy-five years ago by a similar development ten miles further downstream. The cities thus founded on farm sites were named Lowell and Lawrence in honour of the leaders above named. Manchester N.H. and Nashua N.H. and Hoylake, Mass., were similarly founded at about the same time, and the Merrimack River, with water-power developed at Lowell, Lawrence and Manchester, and on its tributaries at Nashua, Fitchburg, Clinton and some smaller towns, became known as " the hardest worked river in the world."

Its three great water power cities of Lowell, Lawrence and Manchester could muster altogether only about 40,000 water H.P. in nearly 200 turbines, or less than that found to-day in a single turbine, started a little more than a year ago at Pitt River, California, and altogether could produce only about two-thirds the power given out by one of the recent Niagara turbines at Queenston.

In the second great epoch of water power development in America, the city of Lowell, being the home of three or four men of peculiar genius, became the birthplace of many of the great improvements.

The first of these men of genius in water-wheel design was Uriah Boyden, a self-educated engineer and mechanical genius of rare quality, and possessed of an inborn love of exactness. Before Boyden's time the larger water wheels were mostly of the " High-Breast " type, ponderous structures of heavily framed timber, about 20 to 30 feet in length and of from 15 to 30 feet in diameter, according to the fall.

These were set on a horizontal axis in great cut-granite wheel-pits, and revolved slowly and carried cast-iron segments of gearing on their outer corners, which engaged small pinions, which in turn drove the great drum carrying the main belts.

In time of flood these water-wheels wallowed in the backwater, with much reduction of power and speed; nevertheless, they were the choice for one of the first large factories built in Lawrence in 1847, and continued in successful operation there more than a quarter of a century, until replaced by Boyden turbines, under the writer's immediate supervision, about forty years ago. These high-breast water-wheels were a common type in others of the early New England factories.

Boyden became impressed with the need of something better

and more compact than the Breast Wheel or overshot Wheel and re-designed the reaction turbine of the French engineer, Fourneyron, and by successive steps refined it to a remarkable degree. He introduced spiral approach and conical form in some of his turbine casings in order to lessen the shock and eddy-loss, as the water entered the guides. He suspended the revolving turbine from the top of its vertical shaft by various ingenious devices in one design after another, such as suspension from a cylinder floating in a pot of mercury designed with thin clearance so that a small quantity of mercury sufficed. This trial design was replaced in a later model at Nashua by a series of grooves in the top of the shaft, into which thrust collars engaged, and had their individual loads equalised by a series of cords and pulleys in a way not very practical. Later he adopted a simple thrust block of rings and collars similar to the thrust blocks on marine propeller shafts, which survived, and which I recall often seeing in successful operation after nearly fifty years of use at the Atlantic Mills in Lawrence, Mass. He added a so-called " diffuser " at the turbine outlet, for the purpose of extracting so much as possible of the energy lost in the high velocity of discharge.

In his contracts of seventy-five years ago he based his price upon the percentage of useful effect obtained in carefully made tests, and for an instrument to be used in these tests he invented the Hook Gauge.

After accumulating a competence from his inventions, he retired from business and devoted his old age to researches in physics, bequeathing much of his fortune† for scientific research, and offering valuable prizes for determination of comparative velocity of transmission of various kinds of radiant energy.*

It was a tradition at Lawrence that Boyden claimed an efficiency of 92 per cent. for each of the four large turbines that he furnished the Atlantic Mills, in 1848; this 92 per cent. being based upon tests made on site by means of weir and proney brake, and that upon this high result being doubted, the test records were placed for confirmation in the hands of a committee composed of Professor Benjamin Pierce, the great mathematician of Harvard College, and James B. Francis, the chief engineer of the Locks and Canals Co., and that finally a compromise settle-

† This, with accumulations, amounted to $232,599.90.

* The executors of his will turned this over to Harvard College, which has devoted it largely to establishing an astronomical observatory on a mountain peak in Peru.

ment was made on the basis of about 88 per cent. The high percentage of the Boyden turbine was obtained only with the speed gate wide open. The part gate efficiency of the Boyden turbine was poor, like that of all turbines with plain cylinder gates.

It is also a tradition that the doubts of Mr. Francis about the accuracy of data for estimating the weir discharge, led to his famous " Lowell Hydraulic Experiments."

The Boyden turbine became for many years the commonly accepted standard of the larger New English factories, in units of seldom more than 200 H.P. and for heads of seldom more than 30 feet. The Boyden turbine was in many ways a costly machine. It was limited in capacity and speed and its efficiency fell off rapidly as the gate was partly closed, and Mr. James B. Francis and others recognised the need of something better and cheaper.

Mr. Francis to the end of his life was recognised as the great leader in all that pertained to water power engineering in America. As Chief Engineer of the power corporation at Lowell he gave much thought to these matters of turbine design, making extremely accurate tests with proney brake and weir, tracing analytically the path of a particle of water through the turbine on carefully plotted diagrams, measuring direction of outflow and testing the performance of venturi tubes in order better to understand the action of the Boyden diffuser in regaining energy.

In the course of many experiments, and following somewhat on the lines of the " Howd " wheel, he built a model of a re-action turbine in which the direction of flow was opposite to that of the Fourneyron and Boyden turbines and thus evolved what he called a " centre-vent " or vertical inward-flow turbine, with downward discharge. In describing his experiments, he gives due credit to the work of the earlier designer, Howd, of Geneva, New York, whose inward flow turbines never obtained more than local popularity. He described the course of its evolution briefly in his book, "The Lowell Hydraulic Experiments."

In a test upon his somewhat crudely built model Mr. Francis obtained a percentage of useful effect near enough to that of the best outward flow turbines to prove that the principle of the inward flow was correct. Its structural advantages in economy of setting were obvious from the beginning.

The book named above, in which Mr. Francis describes some of his many experiments on turbines, measurement of discharge by weirs, and by float measurements in canals, etc., etc., was

first published more than sixty years ago, but in precision of method and in clarity of description it remains one of the great classics of hydraulic experimentation.

The third man of peculiar genius in turbine design became conspicuous about 1870. This was Mr. A. M. Swain; by trade a maker of foundry patterns, but possessed of clear vision as to the need of guiding the current of water through the curving passages of the turbine so that it should be led gently around corners; and so that eddies and shock should everywhere be avoided; he perceived that the reaction of the current of water against the bucket of the runner might profitably be continued from the inward to the downward course, and that the discharge might be spread outward by the well-rounded surfaces of a short draft tube, which was crudely similar to the modern "hydraucone."

Mr. Swain had small knowledge of hydraulic theory, and engaged Mr. Hiram F. Mills, who had formerly been an assistant of Mr. Francis, to make his tests of efficiency. Mr. Mills assisted Mr. Swain with much good scientific counsel about proportioning the relative areas of water passages, at both inlets and outlets. At Mr. Mills' suggestion the height of the turbine was increased, with much advantage in increase of power and increase of efficiency.

At about this time (or from 1865 to 1875) the demand for cheap turbines that could be set with maximum economy by country millwrights in cheaply built wooden flumes, for all sorts of small factories, caused the proprietors of several machine shops which were competing for miscellaneous work, to add to their lines of manufacture a series of cheap stock sizes of turbines, built chiefly of cast-iron and with a minimum of costly work in the machine shop.

This crop of turbines was more the product of the practical mechanic desirous of competing in cost, than the product of men skilled in the theories of hydraulic design, but the work of Boyden, Francis, Mills and Swain had made high efficiency a popular requirement, and a talking point among the salesmen, and each maker of turbines was soon forced to compete as much in efficiency and durability and general good qualities, as in cheapness of price; and a healthy evolution and a survival of the fittest resulted and laid the foundation for the magnificent turbines of to-day.

A fourth man of peculiar genius, although of limited scientific knowledge, next entered the lists and was for several years very helpful in promoting efficiency of design. This was Mr. James Emerson,* an ingenious mechanic, said to have possessed great physical strength and much skill as a rigger, who because of those qualities had been called in to assist Mr. Francis on some of his tests. Being a shrewd Yankee he saw a good opening for business in establishing a turbine-testing flume of his own, and in widely advertising that all turbines of whatever make, be purchased subject to guarantee and test.

The first Emerson testing flume was in an old disused navigation lock on one of the Holyoke canals. The second was on a small stream near Holyoke, Mass., and the advertising these received was doubtless one of the factors that induced the accomplished hydraulic engineer, Mr. Clemens Herschel, who had recently come to administer the works of the Holyoke Water Power Company, to build something better and bigger, in the Holyoke Turbine-Testing flume; which now for about forty years has been aiding many makers in the improvement of one turbine model after another, until low cost and high efficiency have been combined to a most remarkable degree in the stock American turbines of small and medium sizes, built mostly in the foundry, but giving excellent service and long life in hundreds, or perhaps thousands, of the smaller American water powers.

A fifth man of peculiar genius should not be omitted from our list. This was McCormick, a country mechanic and many-sided genius from Pennsylvania, with an inborn sense akin to the genius of Swain for leading water around easy curves, and for avoiding eddys—who is said to have whittled out his wooden patterns of water passages until "they looked right." He is said to have desired to economise and lessen the discharge of an old inward flow turbine in a small mill that had come into his possession, and so started experiments with some spoon shaped extensions to the bucket of the old wheel, which gave such good results that he made patterns for a new turbine, cast his turbine in the iron foundry, finished it off in the lathe and brought it to the Holyoke flume for test. Not being bound by precedent, he had given his runner much greater depth and relatively smaller diameter than that found in previous turbines, and he put more of the discharge

* A sea captain in his early years, who later invented an excellent modification of the Prony Brake dynamometer.

through the outward flare of the bucket than previous experimenters had dared to do.

It has been suggested that the remarkable success of his first model was more by happy accident than by way of superior knowledge. Be that as it may, he produced a model which made a sensation with the experienced observers at the testing flume, by reason of its combination of high rotative speed and high efficiency with small diameter and small weight.

The inventor, McCormick, proved his genius and the fact that he possessed more than good luck by continuing to repeat these good qualities through a wide range of sizes, and gradually improve upon his earlier designs.

This success led gradually to a similar re-shaping of most of the current models of other makers, and is reflected in all of the recent turbines of giant capacity and high efficiency.

It is worthy of remark that these remarkable attainments in perfecting the turbine have so largely been the result of "cut and try" methods. In the early days, James B. Francis and John C. Hoadley, in designing turbines of the Boyden type, laboriously computed a mean path of a particle of water in its course through the turbine runner, as a guide to giving the bucket its best angle and curvature, but after this path had been twisted in three directions by inward, downward and outward discharge, it became impossible of description in equation or diagram and the solution was found chiefly by scale models in the hands of men with sound mechanical instinct in leading water without eddy round gentle curves, and who then tested their new models in the hydraulic laboratory, otherwise called the testing flume.

The giant turbines of the recent great hydro-electric plants, a hundred or a thousand times more powerful, are largely the product of the magnifying and the refining of these slowly perfected modest products of the small foundry shop and the testing flume by designers perhaps better skilled in hydraulic science and of broader experience, but who still seek the assistance of a hydraulic laboratory.

Certain of the leading builders of the great modern turbines have recently built testing flumes or hydraulic laboratories of their own.

The present standard speed gate of the largest turbines has been refined through superior accurate workmanship and stronger

design from the so-called "wicket-gate" found in the old-time Leffel turbine, which was popular half a century ago in small country mills of the Middle West, and the standard design of runner has come, through half a century of development, from the successive advances of Francis, Swain and McCormick, and their successors, until now it seems that nothing more of importance can be added.

To-day the modern hydro-turbine stands in performance as one of the most wonderful products of the hand of man. Consider how, within the short space of from two feet to five feet of travel, and within about one-tenth of a second of time, it extracts from a mighty jet of water, upward of 90 per cent. of all the energy contained, although this may amount to 25,000 or even 50,000 H.P.

Some months ago I was thinking of these marvels while I stood inspecting a power house where the generation of 30,000 kW. was being wholly cared for by two men on each twelve-hour shift. I tried to think of a 40,000 mule team, fed, groomed, and managed by two men; and a few hours later I persuaded the superintendent to open a spillway gate on top of the dam, that I might see the energy made manifest from a similar quantity of water as it fell nearly 200 feet, with a great show of energy in foaming surges, and I compared this with the quiet outflow from the near-by turbine tail race.

It is only in such ways that one can visualise and measure the wonderful things accomplished in the manufacture of power, and in harnessing these great forces of nature for the use and convenience of man.

CHANGES IN PLANT LAY-OUT.

Thus far we have been discussing only the water wheel. The general lay-out of water power plants as a whole also has been changed greatly in passing from one to the other of the three periods into which on a previous page we have divided water power development in America.

In the colonial period and down to the beginning of building small cotton mills in New England about 1815, the plants were so small and so simple that the design was simply that pertaining to a small dam, often made of timber-cribs, weighted with field-stone, and backed with an embankment of gravel. A "trench" or canal led along the contour of the valley until a fall of from 15 feet to seldom more than 20 or 30 feet was obtained, and this

canal fed into a wooden flume leading to a water wheel, which commonly was set in the middle or at one end of the mill building, in order to simplify and shorten the distribution of power by shafting and belts. A separate water wheel in each factory building was the common practice and not infrequently there was a separate water wheel for driving each principal machine.

On a series of rapids in a small river, or at the outlet of a lake, the saw mill, the grist mill and the carding and fulling mill, each had its own dam across the stream, and together they formed the nucleus of a small industrial community, developed in the midst of agriculture, with power units planned with extreme individuality, often with much ingenuity, and seldom of more than from 10 H.P. to 50 H.P.; and as a whole presenting wholesome conditions that have never been excelled for community life and for the development of character in the individual, all centring around the development of water power.

The writer has several such communities in mind to which childhood memories attach a mild halo, as of a golden age of New England industry.

Within the later years of this period and in the earlier days of New England textile manufacturers, nearly all of the mills were water driven. Steam power was expensive; the automatic cut-off for using steam expansively had not been invented, and mill sites on the smaller streams were in demand and were the chief factors in the founding of a score of communities.

In this period of early textile development the dams were somewhat higher, the mill-ponds larger, and the water wheels somewhat more powerful, but otherwise the general lay-out was not changed materially from conditions of the colonial period. The development of power was still the work of the millwright, rather than that of the hydraulic engineer.

The engineer, scientifically educated, as distinguished from mechanic or millwright, may be said to have first fairly come into the water power field about 1835, with the damming of the Merrimack River, and the building of the canals for the systematic distribution of water for power to the great industrial communities at Lowell, Lawrence, Manchester and at Holyoke on the Connecticut River. The highest engineering development of the industrial city epoch was found on the Merrimack River at Lowell and Lawrence, although Holyoke, Nashua, Cohoes and a score of other water power developments must not be overlooked.

Charles S. Storrow, who planned the Lawrence water power, was doubtless the best educated engineer of his day and generation in America, and was the author of one of the earliest treatises on hydraulic theory in the English language. After graduating at the head of his class at Harvard College in 1829, and reading for a season in the remarkable library of Loammi Baldwin, he had studied several years in the best engineering schools of France, and had worked under Stephenson on the Manchester and Liverpool railroad, and had been chief engineer of New England's earliest railroad.

James B. Francis and Uriah Boyden stood foremost in their respective fields for many years.

We may therefore take their works as representative of the best current practice of the period from 1840 to 1880, and until somewhat later, when the scale of development became greatly increased by the long distance electrical transmission and distribution of power.

Current practice of that period, for large developments, may be thus summarised :—

(a) An overfall dam across the river; seldom more than 30 feet high and having its top flashboards from 2 to 4 feet high, so supported by flexible iron pins that the crest would be automatically lowered in time of dangerous flood.

(b) A long power canal for distribution of the water to the individual turbines in the various factory buildings, this canal being provided with " guard gates " or head gates for holding down the water level in the canal in time of flood, or for employing the canal in emergencies or for repairs.

(c) A working head on the turbine of seldom more than 30 feet, greater heads than this being subdivided between two or sometimes three different canal levels.

(d) Turbine water wheels of seldom more than 200 H.P. set on a vertical shaft, which was most commonly supported on a foot-step bearing of Lignum Vitæ, and carrying at its top huge bevel gears for driving the horizontal jack-shaft which carried the main belt drum.

(e) It was gradually recognised that the water current could be turned through an angle of 90° with less loss by friction and less noise and trouble, than found in these bevel gears, and there was a gradual change after 1870 to inward flow turbines mounted on a horizontal set 10 feet to 25 feet

above the tail-race level, and provided with a divergent draft tube.

(f) The inward and downward flow turbine of Swain, Hunt, McCormick, Risdon, Leffel and other makers began to supersede the Boyden type, and there was a gradual increase of capacity of single units, up to even 500 and 750 H.P. The turbine runners mostly had vanes or buckets of these thin-rolled plate metal cast into iron runs by placing thin plates in the foundry mould and pouring the molten metal around their edges so that in solidifying the cast metal firmly grasped the edges of the plates. This construction was borrowed from the designs of Boyden, who had used rolled bronze plates about 3/16th inch thick, for both guide and bucket as a means for obtaining smoothness of surface and thereby increasing the percentage of efficiency. Obviously, this type of construction was not well adapted to the stress of high heads, and when about 1878 a Swain turbine of 80 inches diameter, and supposed to be the "most powerful in the world," yielding about 750 H.P., was set at work under about 30 feet head, the stresses tore it asunder after few years.

The water power developments of this second period were nearly all made at sites convenient to main pathways of commerce and to cheap transportation. A waterfall or power site in the remote wilderness had little or no commercial value or appreciation until the invention for grinding of wood pulp first from poplar and later in far larger quantity from spruce logs, for the making of newspaper called for large amounts of power and emphasised the advantage of the draft tube and of the horizontal turbine axis, which permitted the direct coupling of the grind-stones to the turbine shaft.

The distant power sites in the forest or on rivers down which logs could be floated, came into great demand and much higher heads were utilised. The number of employees per horse-power to be housed and fed was not large, and could be readily cared for at remote sites. The product to be taken away was large and regular and valuable, and made excellent railroad freight so that it was profitable to build a branch railroad into the mill in the forest, and developments of remote power sites of large potential capacity became very active. Also, these pulp mill turbines were worked twenty-four hours per day, and at times

subjected to rough usage from water containing chips and ice and to run-away speeds at high heads. This pulp-mill experience in the backwoods all helped greatly to prepare the way for the successful design of the giant high head turbine runners of to-day.

Stoppages were expensive; there was scant time for repairs; turbine design was further developed in the "school of hard knocks" by many skilful ingenious mechanics. Water passages through the guides and buckets were enlarged by the use of fewer buckets, turbine runners were greatly strengthened in design, entrance edge of buckets was cut back, thickened buckets were cast integrally, and the testing flume showed how all of these changes could be made without loss of efficiency.

THE ELECTRICAL TRANSMISSION EPOCH.

The greatest changes of all in water power practice have been caused by improvements in the electrical transmission of power and within the past twenty-five years this has revolutionised current practice in the design of both general lay-out and of machinery.

The power canals of Lowell, Lawrence, Manchester, Holyoke, Lewiston and certain other important industrial cities, may now be regarded as survivals of a bygone age.

In new designs water is not distributed to factories so that each may manufacture its power on the premises.

To-day, the power is all manufactured as closely as possible to the dam site, in the fewest possible turbine units, is combined in a common stock at the station bus-bar, is stepped up in A.C. transformers to a voltage appropriate to the distance of transmission, and "all limits are off," and practice standardised in nearly every direction at the hydraulic end.

Many of us remember when turbines at Niagara and at Rochester, N.Y., utilised only a fraction of the total head, and remember how their waste ways discharged at a relatively short distance down from the top of the canyon wall. To-day, there is no such waste of energy. Reaction turbines are designed to work under more than 800 ft. head, and impulse water wheels in Norway, America and France are operating under heads of more than 3,000 ft., with no particular difficulty found in giving proper strength and durable wearing quality to every part. The efficiency of both types has been brought so near to 100 per cent. that further important advance in economy seems impossible.

Speeds have been increased to meet the economics of generator design while the vast weight of the modern turbine runner shaft and rotor floats steadily on a film of oil, continually dragged beneath the load by its own viscosity. The dimensions of certain parts have attained the maximum size that railway transportation will permit, and no good reason appears for further increase in size. In brief, it now seems certain that, under the tremendous impetus of electrical transmission of water power, current practice in lay-out of power plant and in turbine design has, within the short space of about twenty years, been so far perfected that no further important development seems likely to be called for, and that the state of the art is now ready for extending the complete standardisation of all turbine parts to larger units, with promise of economy.

In electrical generation, transformation and transmission, while efficiencies are now wonderfully good there are said to be possibilities of further economies; perhaps by the larger use of direct current, but these are in the field of the electrical, rather than of the hydraulic engineer and it is hard to see how any possible changes at the electrical end can largely change current water power practice.

RIVER VALLEY RESERVOIRS.

Outside the power house, as already stated, the science and arts of building great dams has made most remarkable progress, nearly all within the past thirty-five years, or since the days of the discussions over the proposed great dam at Quaker Bridge on the New York water works. The studies of dams for municipal water supply have led to this progress more than studies made for water power dams. The Hydraulic Fill Dam, the Rock Fill Dam, and the Multiple Arch Dam are becoming standardised and the weak points of earlier designs becoming well recognised and efficiently guarded against; and means are now available by which sufficient spillway capacity for flood discharges double the greatest ever recorded (or with factor of safety of 2) can be given for almost any situation. There is an attempt here and there to discredit the standard "gravity-section" Ogee type of massive rubble concrete dam as "antiquated and wasteful" by certain younger engineers of mathematical genius, who seem to forget secondary stresses, and are possessed of a desire to make money out of some novel shape containing less concrete, on which they can get a patent, but the

engineers of broadest experience appear generally to hold fast to the massive gravity section for important works.

One of the most noteworthy items of progress by means of higher dams, and one which holds promise in many places; where expensive prior railroad re-location does not block the way, is in creating storage within river valleys by building high dams at favourable points, thereby permitting the equalisation of the weekly and monthly hydrograph, by storing those portions of the 24-hour seven-day run-off from the watershed which are not immediately required for use at peak loads, and by also conserving the run-off from the smaller floods, for use in periods of low discharge, by drawing down the reservoirs thus created, 10, 20, or perhaps 40 feet. On several large rivers of extremely variable flow, it has been found that this storage in the river valley greatly increases the commercial value of the opportunity for power development by greatly equalising the delivery of water to the turbines.

By adapting the design of the turbine runner to the maximum efficiency near the lowest head, and by selection for it of a proper characteristic curve the same turbine runner can be made to operate with good economy at the higher head and a good average adjustment worked out for all stages, by reference to hydrograph and reservoir depletion diagram, notwithstanding much variation in reservoir level.

RELATIVE COST OF WATER POWER.

The cost per horse power hour of both water power and steam power, considered broadly, remains to-day in America just about what it was fifty years ago, and there is no substantial ground for hope that it will ever be materially cheaper.

The only hope of preventing higher costs lies in the present tendency to a closer union between water power plants and steam central power stations, each supplementing the other in equalising the load.

While water wheels and steam engines and steam turbines have been improved in the percentage of efficiency with which the theoretic foot pounds, or the total thermal units in water and coal, respectively, are delivered to the main shaft, and while the costs per horse power of plants for creating power, as measure in the number of pounds of iron, and the quantity of masonry in cubic yards required in the structures

have been lessened by use of larger units and higher pressures for both water and steam, these reductions have been offset by the increasing cost per unit of labour, and per pound of metal, and per barrel of cement.

Moreover, the water power sites first developed were those which could be most cheaply developed. The developments of the later years have been driven farther away from easy access to railroad transportation, and have required constantly increasing distance and cost for electrical transmission to the point of consumption or sale. Thus, gains have been met by losses and costs remain about as before, and with expectation for the future of larger, rather than smaller costs, particularly in future water power, except as its cost can be borne in part by improvements in navigation.

For a fair example of current practice of about fifty years ago, Lawrence, Mass., may be taken. At Lawrence about fifty years ago the current price of the right merely to draw water for power from the canal was $1,200 per mill power per year, equivalent to about $20 per net effective horse-power per year, for the right to draw this water not exceeding sixteen hours per day. It was used chiefly in textile industries, which actually drew it only about ten hours per day.

It may be supposed that the management of the power company had shrewdly put the price of water at about all that the traffic would bear. The factory managers sometimes argued that steam power was cheaper than water at this rate, but unless they had use for exhaust steam in a dye house, the writer observed that they continued using the water power while letting their large and excellent emergency steam plants stand idle, until the water power that could be delivered to them was reduced by flood or drought.

The cost of steam coal at the mine, and the cost of transporting it by water and rail to the factory have so increased in recent years that now the relative cost of steam and water power remain much the same as twenty-five or fifty years ago. Wages in mine and upon railroad have doubled, and seem not likely to return to anything like the old levels. Therefore, it seems that present relations of cost of water power and steam power are likely to continue.

Up to about 1865 or 1875 the early American factories all sought water power sites; but after that time there were about

as many textile mills built to be run by steam as by water, for by this time the cost of steam power had been lessened by the invention of the automatic cut-off, and steam engines had come to be built of such excellent quality that they could be relied upon to deliver their power day after day, and year after year with seldom or never an hour of lost time due for breakdown or repair in plants working ordinary hours; moreover, it was becoming recognised that quick access to markets and to an abundant labour supply were quite as important as cheap power, and at Lawrence, within twenty-eight miles from the great commercial centre of Boston, some small amount of water power remained unsold, about twenty-five years ago, at the price above-mentioned.

As to present day costs of water power production, it is difficult to generalise. There may be a few large developments highly favoured by nature where all costs of production, including interest operation, supplies management, and overhead for "primary" or "firm power" at the power house, under, say, 75 per cent. load factor, does not exceed one-third of a cent. per kilowatt hour, but any new projects of more than 5,000 potential horse power, which can show a cost at the power house of, say, in general one and a quarter cents. per kilowatt hour for primary power, under 40 per cent. load factor, may be considered worthy of development, if there is a certain market for all of its product in the very near future.

At present, the maximum value of water power near all commercial and industrial centres in the eastern United States is measured by the cost of competing electric power, generated by steam. This now costs in the best plants of central stations of 100,000 kW. capacity, located at tidewater, from coal costing $6.25 per short ton, at switchboards under 35 per cent. load factor, about one and one-eighth cents per kilowatt hour for coal alone, and adding for distribution, overhead and profit, the delivery in large blocks at convenient points in New England can hardly be at a less price than 1.50 cents per kilowatt hour. While this fixes a maximum value for water power, and of itself would prevent many prospective developments, there are other causes that detract from the apparent value of large developments where flow of water is variable.

The large companies in California interchange hydro-electric power at about 0.75 cents per kWh., and are understood to have

offered the city of San Francisco one cent. per kWh. for about 60,000 H.P. developed in connection with its Hetch Hetchy water supply.

Of course, the value and the price of a water power varies greatly with proximity of the water power to centres of commerce and industry and with the remoteness from supplies of cheap fuel for competitive steam power, but most of all its value depends upon certainty of use.

VALUE DEPENDS ON IMMEDIATE DEMAND.

Most of the early large American water power developments suffered great hardship or bankruptcy, while waiting for customers for the last half of their available power. An undeveloped and unmarketed water power is at a great disadvantage compared with steam, because substantially all of the expenditure for a large water power development has to be made in dam, flowage rights and power house, before any power can be delivered; whereas steam can be added, a unit at a time, and only the coal burned has to be paid for; and all this has been reflected in current practice in the delay in developing certain great powers as at the Great Falls of the Potomac within 16 miles of the Federal Capital and Moores Falls on the Merrimack between Manchester and Lowell.

Electrical transmission opened a new era in water power development, largely because it permitted all of the power developed at a new site to be sold in advance to great users of energy in distant cities.

While this has hastened the development of water power, it has checked the opening up of new communities centring around a fall of water.

CENTRALISATION OR DIFFUSION.

Looked at from this point of view, many of the recent water power developments have set very few men at work and have built very few new homes, compared with the accomplishments in developing water power under the old regime.

But there is another point of view, in the aid that may be given to industry by the central power station where water power and steam power supplement each other, and where present and future convenient distribution of power by electricity permits the founder of a new industrial plant to put more of his ready capital into productive machinery, and meanwhile stands ready

to furnish him with whatever power he needs at smaller cost than that at which he could produce it himself.

The electric wires can take power out to scattered industries created in smaller communities favourable to happy homes just as well as they can centralise it and increase the congestion in the great cities, and we can see evidences for hope that this may soon become current practice in water power development, to an increasing proportion.

POWER SURVEYS.

An extremely valuable review of present day power conditions in New England was published in April, 1924, by the "Associated Industries of Massachusetts" (950, Park Square Building, Boston), which forms one of the most valuable surveys of this kind ever attempted. It was financed by fifty-five of the leading industries of Massachusetts and the data were collected by a committee of five of New England's most eminent power-engineering specialists, working diligently with competent assistants for about twelve months.

It is not practicable, here, to do more than refer to these 183 pages as a storehouse of facts showing present costs of steam power and water power, and showing the developed and undeveloped water power resources of New England and the trend of development in both water and steam and the tendency toward the central station.

A somewhat similar survey is now in progress for Pennsylvania, under the auspices of the Governor and a special staff of experts, and doubtless other similar regional surveys will soon follow, for the subject is now very much alive.

CONSERVATION OF CAPITAL.

In some of the recent popular demands for water power development it seemingly has been overlooked that conservation of capital is quite as important as the conservation of power from water which now runs to waste. Also it is hard for the engineer to sacrifice efficiency in order to keep down the initial cost, but often this must be done, and can be done wisely and with profit after it has been computed on the sinking fund basis that the saving of interest in say twenty-five years, if compounded with the principal saved, will at the end of that time permit tearing out and building anew with the benefit of all advances in the art that have occurred meanwhile. The chief point is to keep the

maximum development and the maximum economy always in view and to guard most carefully the opportunity for attaining them when the time arrives.

PUBLIC RELATIONS.

At present in the United States the public at large, and legislators in general, need further education about water power.

Many look on water power as an ever-flowing stream of gold, ignorant or forgetful of the vast amount of capital required, and ignorant of the risks involved in its development, such as those of bad conditions for foundations, and unappreciative of the great fact that cost of power can be lessened to the ultimate consumer, and that dependability of power against interruption, can be safeguarded most effectively by vast inter-connected systems, each reaching over many communities and to many plants, with generation both by water and by steam; by which interconnection advantage can be taken of the "diversity factor" of loads for different uses, coming at different hours, and by which the surplus capacity of a new plant can be most fully put into immediate service and earning, and the safeguards against interruption most effectively provided.

It can be abundantly proved, to those who will listen, that the public can be most efficiently served, and most cheaply served, by these great inter-connected public service corporations.

Education now seems to be progressing, although at times slowly, so that through the wise adminstration of such public service-commissions as have come into existence in several states and in several municipalities, the public can receive proper protection against extortionate prices or against arbitrary regulations, and against the delay of improvements sorely needed; and the man who risks his money in the enterprise can, at the same time, and by the same commission, be protected; so that in course of time and after perhaps more real proof of the fact, capital will be satisfied with less than the present return of 7 or 8 per cent. per annum for dividends on market price of stock, all of which now has to enter the cost of service.

There is to-day less opportunity to lessen the cost of water power and electric current produced therefrom, to the general public, by means of further improvements in engineering of power plants, than there is by removing from investors of capital the fear of unfair treatment in taxation and rate-making by public officials, such as have been suffered by certain railways and other public

utilities. It is hard to conceive of a safer investment than in a good water power enterprise, and it is easy to see some of the benefits that would follow if capital could be attracted at 4 per cent. instead of 8 per cent.

There is, now current, much popular misunderstanding of the value of an undeveloped water power site, and a lack of full appreciation that value comes only through use, and a lack of understanding of the large cost of structures and of the expenditure of business skill required for setting the power site at work, and lack of general knowledge of the risks and disappointments often involved in both bad conditions for dam or conduit or power house, and in unexpectedly slow sales of product. Financial disasters have come far more often from slow sales than from mistakes of engineering. Every engineer in active practice in water power development comes to have high appreciation of the courage of capital in many instances of which the public knows nothing, for commonly those at the head of a great enterprise are slow to tell the story of their errors of judgment. The engineer has a large field in which to aid in all these matters of education of public and of legislative officials.

With a better understanding there will come an earlier and better development of our water power resources, and so it may not be improper to refer to these facts of public relations, as matters in which "current practices" in water power development may be improved. Signs of recent great progress are found in the passage of the United States Federal Water Power Bill and in the annual reports of the Federal Power Commission, but of this we can here only make this brief mention.

RÉSUMÉ.

L'auteur passe en revue la pratique hydroélectrique courante au point de vue hydraulique plutôt qu'au point de vue électrique.

Il examine en détail chaque élément de machine et ses accessoires, il cite en particulier la turbine moderne à grande vitesse, dans laquelle on a mis en pratique la question d'économie réelle en sacrifiant un petit pour centage d'effet utile dans la turbine, en vue de réduire les frais de premier établissement.

Une attention toute particulière a été donnée à la question des perturbations apportées par la glace et les moyens de les éliminer. La glace flottante en morceaux et la neige fondue sont relativement faciles à combattre, Mais les aiguilles de glace avec leurs qualités d'agglomération présentent des difficultés qui demandent une connaissance de la formation physique de la glace avant qu'une solution convenable puisse être obtenue.

L'auteur conclut par une étude détaillée de l'histoire du développement de l'énergie hydraulique.

POWER DEVELOPMENT ON NAVIGABLE RIVERS

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For readers not familiar with conditions in the United States, it seems well to begin this discussion with a clear definition of what with us constitutes a "navigable river." Under our Constitution, all powers of government are reserved to the several states except such powers as the states have agreed to surrender to the Federal Government. Among the powers thus surrendered is the power to regulate commerce with foreign nations, and commerce between the various states, the latter briefly called with us "interstate" commerce. As a consequence, only such rivers as are or can be used for the transportation of foreign or interstate commerce are subject to national control. These are the only streams that with us have had or possess now any importance in respect to vessel traffic and these alone are therefore regarded as "navigable rivers." This article will limit itself to consideration of power development upon streams that are under Federal regulation and control, those that are usually classed as "navigable waters of the United States."

Prior to 1890, there was no general legislation regarding the construction of dams in navigable rivers. Where any legislative authority was secured for the construction of power dams before that time, it was in the form of a special Act of Congress relating to the particular project under consideration. Power developments were, however, rare in those days, the art was in its infancy and such developments as were made were on a scale so insignificant as to deprive them of any great interest. In 1890, a general requirement was set up that any dam, for power or otherwise, constructed in a navigable river by private parties must receive the prior approval of the Secretary of War; and in 1899 an Act of Congress was passed which provided that the consent of Congress must be had before such a dam might be constructed; that is,

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a special Act of Congress covering each particular case was again required, but no policy was announced as to the scope of such acts. This omission was in part supplied by the general dam act of 1906, which amplified previous legislation by stipulating not only that the consent of Congress must be had before beginning work but also that the specifications, plans and location must have the prior approval of the Secretary of War and the Chief of Engineers of the Army. The grantee was further required to construct, maintain and operate, without expense to the United States, booms, sluices or any other structure which the Secretary of War and Chief of Engineers at any time deemed necessary and to light the locks, furnish the power to operate them, and extablish such fishways as the Secretary of Commerce might demand. The grantee might, under the Act, also be called upon to construct locks without expense to the United States. Under the terms of this Act of 1906, only six power projects were completed, and for reasons not necessary to elaborate here, the Act was amended in 1910 so as to overcome certain objections that had been raised by President Roosevelt and had caused him to veto a number of bills passed by Congress authorizing the development of power. Under the amended Act of 1910 only two dams were constructed so that under the two acts of 1906 and 1910, only eight power projects, having a total installation of 140,000 H.P., were completed. This slow progress in developing power on our navigable rivers was due on the one hand to presidential objections to laws which failed to protect the public interests and on the other to unwillingness of financial interests to subject themselves to the uncertainties of tenure involved in the laws that were approved.

To overcome these difficulties in the way of utilizing a valuable natural resource, Congress finally adopted what is known as the Federal Water Power Act which became a law on June 10, 1920. It is unnecessary to dwell upon this Act further than to say that it represents the final result of discussions that had raged for nearly twenty years as to the correct principles and limitations under which to permit private initiative to take possession of and to exploit a natural resource of permanent and increasing value. Briefly stated, the Federal Water Power Act lays down, among others, the following important principles governing the development of water power on navigable rivers as well as in other places where the United States has jurisdiction:

1. That authority to develop power will be granted only upon the presentation of plans that are best adapted to develop, conserve

and utilize in the public interest the navigation and water resources of the region as part of a comprehensive scheme of improvement and utilization.

2. That all grants or licenses shall be for a definite term not to exceed 50 years, at the end of which the power development may be recaptured by the public in a manner clearly described in the Act.

3. That every licensee shall begin construction within the time fixed in the license, which shall not be more than two years from its date, and complete his development and put it into operation before the expiration of the period also stated in the license.

4. That every licensee shall pay to the United States, reasonable annual charges to cover the cost of administering the Act.

It is evident that only the first of these principles has any technical value or bearing. The economy and propriety of requiring that any power development shall be so planned and constructed as best to promote all public interests that may be involved are, of course, obvious. Such interests may include not only navigation, but drainage, irrigation, sanitation and the like. The conflicting requirements of these various uses are often difficult to reconcile and decision on a really comprehensive scheme of improvement and utilization may involve the exercise of a more or less speculative judgment as to future conditions. However, the requirement is a sound one and as time goes on, experience in its enforcement will gradually establish precedents to serve as guides in debatable cases.

It was not with the deliberate purpose of establishing a principle or a policy to govern the relations between navigation and water power that the foregoing principle was adopted but rather with the idea that all uses of water should be protected, conserved and co-ordinated. In our country the courts had always upheld the prior rights of navigation in Federal navigable waters and, during a time when power development was as yet small and unimportant, a vast body of court decisions had placed the rights of navigation in so strong a position as to subject every other aspirant to privileges of any kind in navigable rivers to limitations and restrictions calculated to prevent interference with the ease, safety and convenience of navigation. Such a policy, often involving added expense in the development of power or in putting into effect other uses of water, was defensible as long as the navigable streams furnished really important and economical transportation

routes, more important in the daily lives of the people than water power or drainage or irrigation.

The Federal Water Power Act gives protection to navigation by prescribing "That no license affecting the navigable capacity of any navigable waters of the United States shall be issued until the plans of the dam or other structures affecting navigation have been approved by the Chief of Engineers and the Secretary of War" and also provides that, if the Federal Power Commission deems it "reasonably necessary to promote the present and future needs of navigation and consistent with a reasonable investment cost to the licensee" it may require "that such licensee shall to the extent necessary to preserve and improve navigation facilities, construct, in whole or in part, without expense to the United States in connection with such a dam, a lock or locks, booms, sluices or other structures for navigation purposes, in accordance with plans and specifications approved by the Chief of Engineers and the Secretary of War." Provision is also made that in case such structures are not thus required, then whenever the United States shall desire to complete such navigation facilities, the licensee shall convey to the United States, free of cost, such of its lands and rights as may be required to complete such navigation facilities. In the interest of the public, it is to be hoped that no merely technical or traditional right of navigation will cause the Federal authorities to place onerous burdens on power development and especially it is to be hoped that any demand for the construction of locks at private expense will be supported by the existence of a prosperous water traffic that the construction of a dam across the river without a lock would destroy.

With the advance of the railroads and of other agencies of transportation, such as the motor truck, there has come about a decline in the importance and value of river transportation and, with the increasing complexity of our culture and civilization, it has become necessary to reconsider our attitude as to river transportation and to ask ourselves whether, in the interest of society, the time has not arrived for the promulgation and acceptance of a broader doctrine. It is not unlikely that such a doctrine is already tacitly accepted by the War Department and by the navigation interests themselves, but it ought, at any rate, to be clearly stated, and I therefore do so. This principle is as follows:

In every case in which the development of water power on a navigable stream is under consideration, the relative value and importance of the use of the stream for navigation and of the power that may be

developed should be judged in the light of existing and reasonably probable future conditions. Navigation should be given the preference only if it is of substantial character with strong probability of permanence and of future growth. If, however, there is no commercial navigation, and experience shows that it is unlikely to develop in the future, then power should be given the preference and every opportunity afforded to develop the greatest possible amount in the most economical way.

This rule seems simple and fair but the long established priority hitherto conceded to a sometimes shadowy navigation may create difficulty and delay in its acceptance and by some of those who still believe that navigation near the headwaters of small streams is an asset of value to the scattered populations of their banks. Up to the present there are no cases known, in which the demands of navigation have been unfair to the extent of causing impossibly onerous conditions to be interposed in the way of power development.

As already stated, after modern and efficient methods and apparatus for the development of power had come into use there were comparatively few plants constructed in navigable waters, partly because of the difficulties in the way of securing the necessary legislation from Congress and partly because good power sites are somewhat rare in navigable waters and when they exist are usually expensive to develop. Obviously, the best power sites are those having a rapid fall, a rocky bed and ample flow and these are conditions that tend to make navigation impracticable. Such sites are usually found near the headwaters of rivers rather than further downstream; and yet there are a number of sites where power has been developed as an accompaniment to navigation or where navigation exists and it is proposed to develop power. Since the passage of the Federal Water Power Act an increased interest has been manifested in such power sites and proposals for the development of a considerable number of them have been before the Federal Power Commission. A few of the more important cases may be worth describing.

The first development that will be described is on the Hudson River at Troy, New York, about 150 miles above New York City. In 1913, an open river channel with a depth of 12 feet was available practically from just below Troy to New York City. The New York State Barge Canal was under construction and approaching completion, also with a channel 12 feet deep, extending from just

above Troy to Buffalo and to Lake Champlain. At Troy, there had formerly been a lock and dam, part of the old Erie Canal system, but the lock was too small for the 12 foot channel. In 1913, therefore, the United States began the new lock and dam shown in the accompanying drawings and, as water power had formerly been developed in connection with the old dam, it seemed desirable to plan the new one so as to permit the eventual development of power. Accordingly, the bulkhead or head wall shown on the drawings was constructed at the right, or west, end of the dam so that at some future time, a power-house might readily be built. The lock and dam were finished late in 1916 and while, from that time until the passage of the Federal Water Power Act in 1920 there was much local discussion regarding development of power, nothing could be done because of lack of enabling legislation from Congress. On the other hand, the government itself had no need for the energy and was without the agencies necessary to dispose of it.

After the passage of the Federal Water Power Act which, under specified conditions, authorizes the issuance of licenses to utilize surplus water or water power from any Government dam, a licence was issued by the Federal Power Commission to develop power at the Troy dam in accordance with the general plans shown. It will be seen that the lock is on the left or east end of the dam, remote from the power house, thereby contributing to the safety of navigation while avoiding any possibility of interference between these two activities. This is, in fact, the general rule of arrangement, the only conspicuous exception being known at Keokuk, as will be seen later.

The head available for power development varies not only with the tide, which has a mean range of 2·55 feet below the dam, but with freshets and becomes practically nothing at high freshet stages. At lowest mean stages of the river below the lock and dam, the lift or head is 16·3 feet. The elevation of the crest of the main spillway of the dam is 14·33 and of the auxiliary spillway 16·33 feet above mean sea level and provision exists for placing flashboards two feet high on the main spillway. The extreme minimum flow, which rarely occurs, is 1,000 c.f.s., but 2,100 c.f.s. is officially assumed as the flow at ordinary low stages. Ordinary freshets run from 60,000 to 100,000 c.f.s., and an estimated freshet of 260,000 c.f.s. is on record.

The power capacity of the river at this locality may be approximated at about 2,700 kW. With the flashboards in use, this

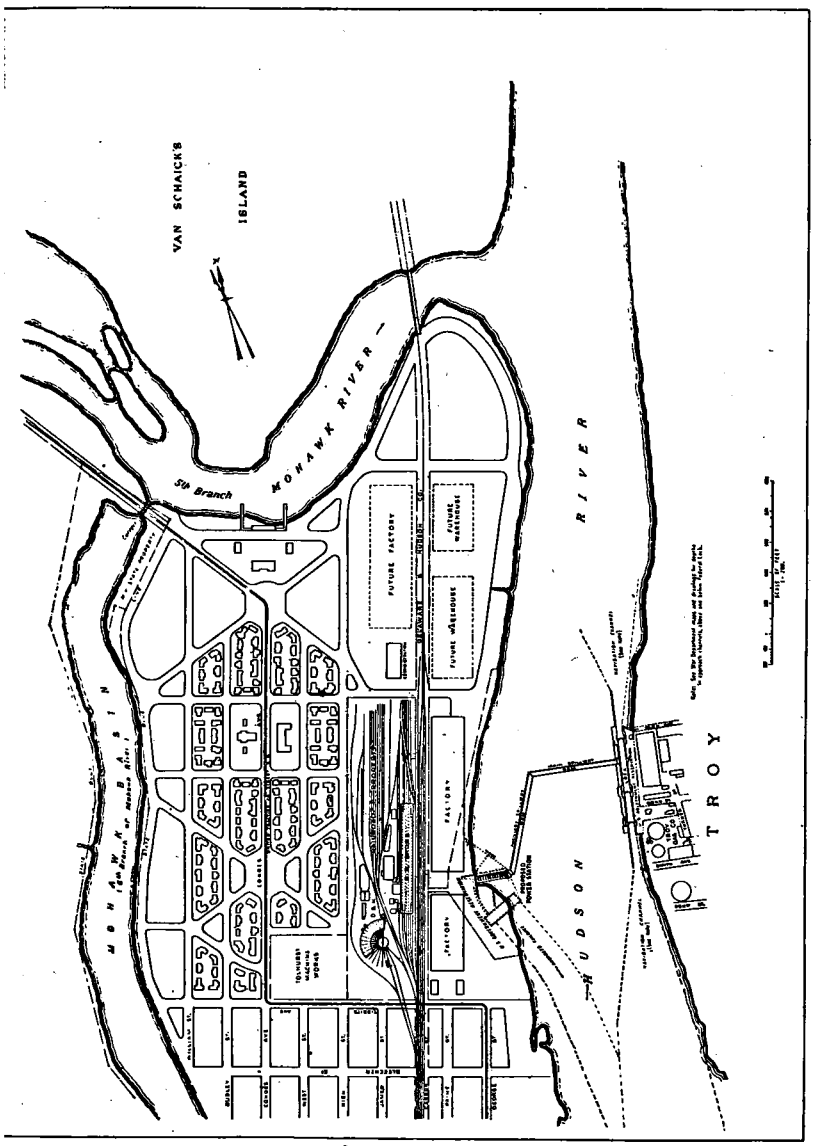


Fig. 1.
General location of power and navigation project on Hudson River, Troy, N.Y.

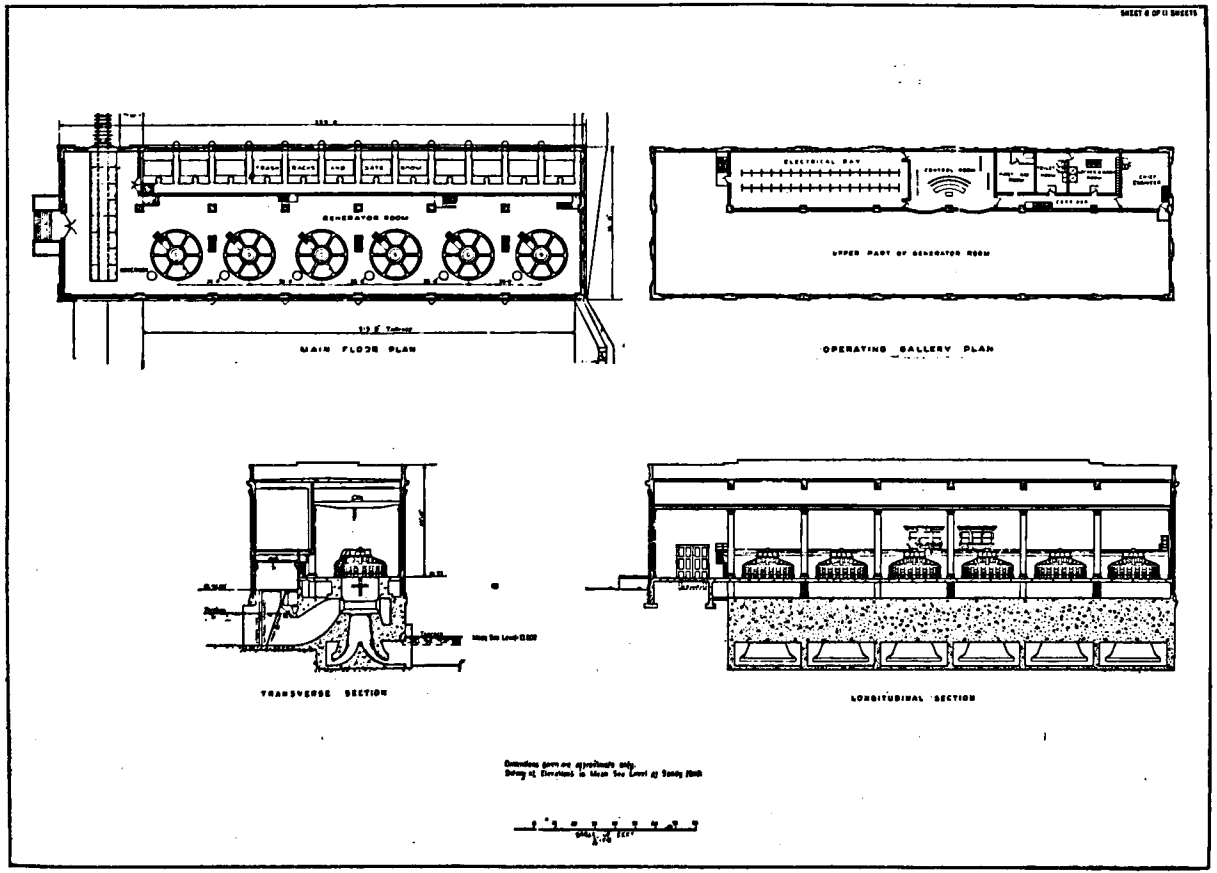


Fig. 2.
General plan and elevation of power house on Hudson River at Troy, N.Y.

becomes about 3,000 kW. It should be emphasized, however, that the power output varies over quite a wide range because of the conditions as to head and flow, and the power is better suited to incorporation in a system having a considerable base load than to independent base for purely industrial purposes for which much of the intermittent power would be valueless.

The dam and locks as installed by the Government cost $1,593,200 and the power installation cost $1,765,000, divided as follows: power-house, $700,000; intake works, $35,000; forebay and tailrace, $415,000; turbines, $265,000; and electrical equipment, $350,000. The power-house contains four vertical, Francis type turbines rated at 2,000 H.P. each, which are direct connected to unusual generators designed to generate direct and alternating current and rated at 1,000 kW. D.C. and 800 kVA. A.C. For the use of the Government dam and adjoining lands a yearly rental of $5,000,000 is charged.

The navigation of the Hudson River between Troy and New York is a prosperous one and that between Buffalo and New York by way of the New York State Barge Canal, the Troy lock and the Hudson River amounts to several million tons annually. The construction of the lock and dam was a necessary connecting link in the latter route and little, if anything, was spent in providing for the development of power that would not have been necessary in completing the dam to the west bank of the river. The co-ordination of power development with navigation was, so far as the original structures are concerned, efficient and economical. It remains to make sure that all energy susceptible of development is absorbed either for manufacturing or for other uses. It is possible that, as experience accumulates, it may be necessary to establish regulations as to the ponding of water during periods of low flow.

A second example is Government dam No. 17 on the Black Warrior River in the State of Alabama.

The Black Warrior, Warrior and Tombigbee Rivers constitute virtually a single stream and unite with the Alabama River, 45 miles above Mobile Bay to form the Mobile River. Beginning at a point about 110 miles above Mobile, the Tombigbee, Warrior and Black Warrior Rivers have been canalized by the construction of 17 locks and dams, affording a depth of eight feet, and there is an open river channel of practically the same depth between Mobile and the first lock. This channel affords access to the rich coal fields of northern Alabama, 400 miles and more from Mobile.

All the locks and dams are of ordinary lift, varying between 10 and 21 feet, except the uppermost, No. 17. Originally it was proposed to construct in place of No. 17 three dams, with accompanying locks, each with a lift of 21 feet but, to permit developing power, Congress authorized the construction of a single dam with two locks in tandem and a total lift of 63 feet since reduced to 61 feet by the installation of flashboards on Dam 16 immediately below. These works were finished in 1915. To permit power to be developed when Congress had sanctioned it, the original construction included a power-house foundation. This is on the right or west side of the river, the locks being on the opposite side. Since 1915 a fair traffic in coal from the mines to Mobile and New Orleans has developed and there is a certain amount of miscellaneous freight carried by river barges to the three larger cities on or near the river, Demopolis, Tuscaloosa and Birmingham. The present traffic is not such as to warrant the cost of the original navigation improvement, over $10,000,000, or even the amount that has been expended in maintaining the locks and the connecting channels, nearly $3,500,000. As a navigation project, the work is, nine years after its completion, still a disappointment.

Dam No. 17 and its two locks cost about $3,175,000, whereas three dams and locks, each of 21 foot lift would have cost about $1,600,000, the difference of nearly $1,600,000 being, of course, due to the relatively greater volume of masonry in the single high structure as compared with three low ones. The excess cost was incurred solely to conserve the power.

Due to the difficulty of securing Congressional sanction, but also in part to the exceeding variable flow, 150 c.f.s. at low water and 153,000 c.f.s. during extreme freshets, and to the further fact that the dam is in the midst of a region where coal of high thermal value abounds, no effort was made until about a year ago to secure from the Government the right to develop this power. It was evidently regarded as uneconomical compared with power derived from the modern Gorgas steam plant, situated a few miles away at the mouth of a mine.

Application was, however, recently made to the Federal Power Commission for a license to develop this power, the applicant, being the owner of the Gorgas steam plant, as well as of excellent water power plants on the Coosa River in eastern Alabama. The plans herewith show the locality and the character of the proposed development. It will be seen that the proposal is to install a unit

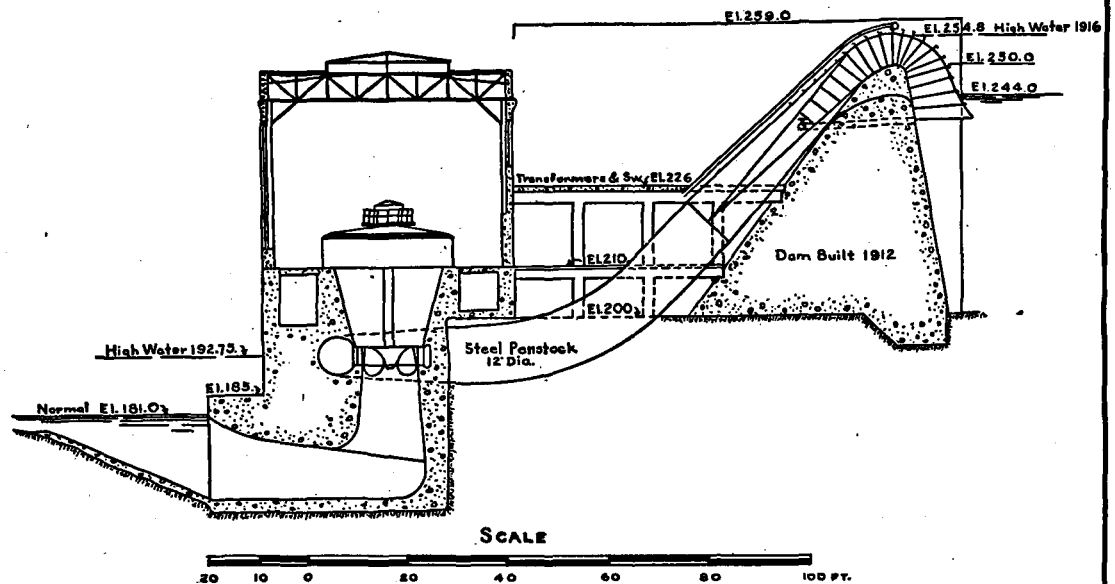


Fig. 3.
Cross section of dam, penstock and power house, Black Warrior River, Alabama.

of 7,500 kW. capacity with the possibility of a second unit in the future. It is understood that action on this application has been deferred.

Figuring reasonable interest since 1915, the original investment for conserving the power has nearly doubled. In this effort to conserve a natural resource was the failure to appraise correctly the underlying conditions, a thing that could have been done, however, only by full discussion and previous complete understanding with the local power interests, whose knowledge of power costs and of market possibilities would have enabled a decision to be made on the basis of full knowledge of all the economic conditions. Moreover the power is so variable as to be unsuited to development by any but the large power system now asking for the license which alone can use every kilowatt hour. The dependable flow for 90 per cent. of the time is only 200 c.f.s., of which the greater part is needed for navigation. Though the average flow is estimated at 5,200 c.f.s., expensive storage is necessary to improve discharge conditions so as to enable the power possibilities of the stream to be utilised in a really comprehensive way. Until this storage has been created, it is doubtful whether the power ought to be developed and it is believed that it was for this reason that action on the application for a license was deferred by the Federal Power Commission.

There is a third instance in which the United States has, during the course of an improvement for navigation, sought to preserve the incidental water power and to create conditions favorable to its economical development. The plan for the improvement of the Mississippi River between Minneapolis and St. Louis contemplated a channel six feet deep. At the upper end, between Minneapolis and St. Paul, for a distance of about five miles, the project in effect in 1910 called for canalization by the construction of two locks and dams, each of about 16 feet lift. In 1910 one of these locks and dams, the upper one, had been completed at a cost of nearly $740,000. In that year Congress adopted a new plan under which the upper lock was to be abandoned and the lift of the lower one increased to 33·5 feet so as to carry the desired depth through to Minneapolis while at the same time permitting the development of power. This change was made largely at the instance of Twin Cities, St. Paul and Minneapolis, with the idea that they would develop this power jointly to supply their public needs.

Approximately $2,000,000 was spent on the enlarged lock and dam, which were completed in 1917. Roundly, about $1,000,000 more was spent on this work than would have been necessary for

navigation alone. The power remained without hope of development during the three years that intervened before the passage of the Federal Power Act. After that date, it became a bone of contention between the two cities for whose joint benefit its development had been rendered possible at national expense. In the end they composed their difference by withdrawing in favor of a private corporation, to whom, in June, 1923, six years after the completion of the dam, a license was issued by the Federal Power Commission on general plans shown herewith. This development is now in progress. The original power-house installation was intended for a maximum development of 15,200 H.P., whereas the plans of the licensee are reported to provide for four units of 3,600 kW. each or about 19,000 H.P. The head varies from 33·5 feet at low water to 24 feet during freshets. The discharge usually varies between 1,800 c.f.s. and 54,000 c.f.s., although an extreme low flow of 600 c.f.s. occurred in the winter of 1923-24. The development is predicated on the availability of an average low discharge of 6,000 c.f.s. The above figures show that the output of this plant will be variable, much of it considered by itself not being really commercial power. Arrangements have, however, been made with a public service corporation serving Minneapolis, St. Paul and adjacent territory with power derived from large steam plants and from numerous water power plants, so that the surplus intermittent power of the new development will be absorbed and rendered useful. Such an arrangement is, of course, possible only when the output of the commercial company that absorbs the surplus is relatively very large. In this case, the public utility company generated in 1923 about 636,000,000 kWh., whereas the entire output of this new water power is likely not to exceed 76,000,000 kWh. annually, of which the primary portion should be about 40,000,000 kWh., leaving only 36,000,000 kWh. of secondary power to be absorbed.

No navigation of commercial character exists between this dam and Minneapolis and there is at present no long distance traffic between St. Louis and Minneapolis or St. Paul. This condition is in part because the six foot channel is not yet completed. Moreover there are no suitable river terminals above St. Louis and no proper connections between such terminals as exist and the railroads on the banks. Evidently therefore, the extension of the channel to Minneapolis has not yet justified itself and the co-ordination of navigation with power development here serves merely to reduce the cost of developing the power. On the other hand it may be said that had the two locks originally planned been built, there would,

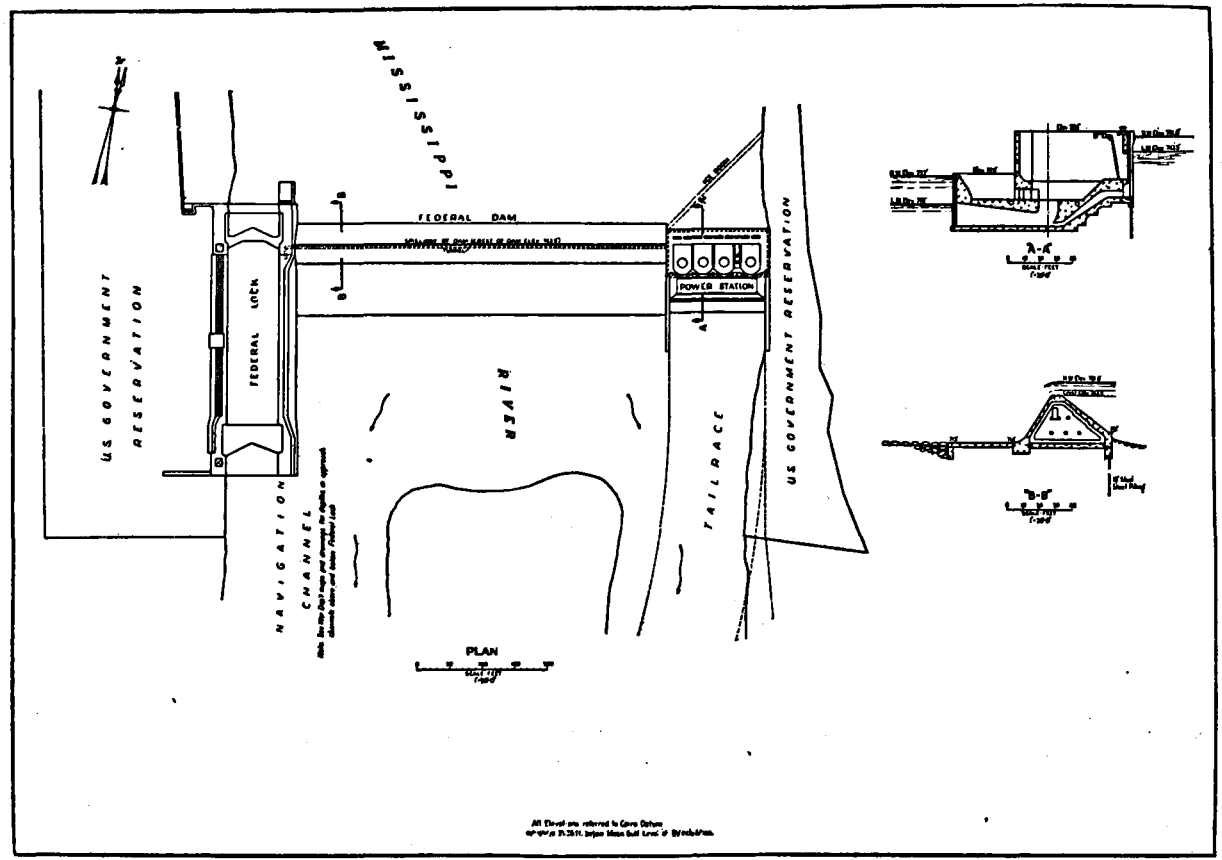


Fig. 4.
General plan of locks, dam and power house, Mississippi River, between St. Paul and Minneapolis, Minnesota.

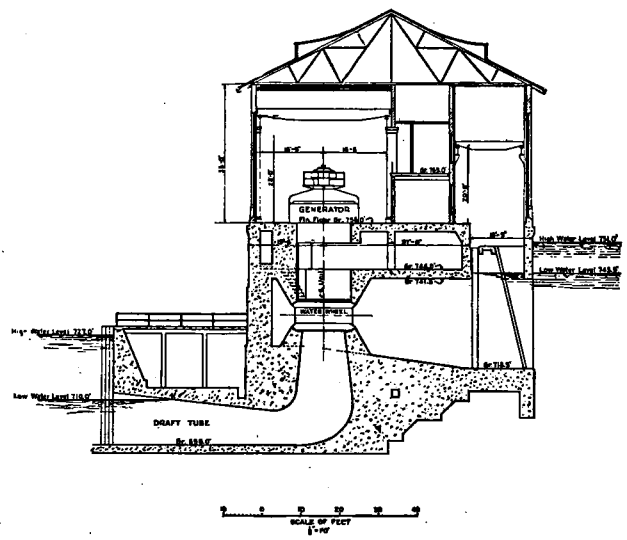


Fig. 5.
Cross section of power house being constructed on Mississippi River at St. Paul, Minnesota.

however, have been a large expenditure and the operating cost would have been doubled with no advantage of any kind to the public. The improvement of the river between Minneapolis and St. Louis, may in the long run prove commercially useful. As an experiment in large scale, long distance, shallow draught river transportation it is instructive and should be brought to a definite conclusion. In the meantime reasonably cheap power has been developed and rendered generally available, to the unquestioned benefit of the public.

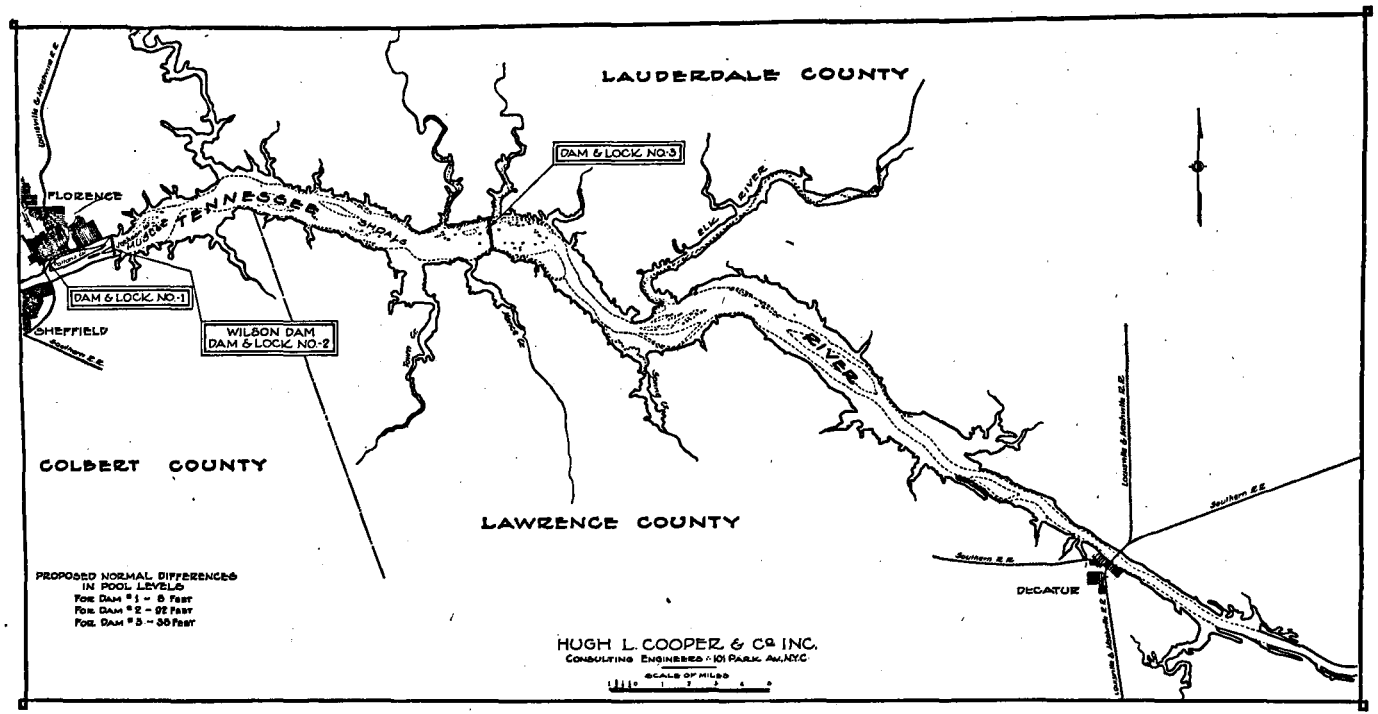
As a final instance of public intervention in the construction of combined navigation and power facilities, the Muscle Shoals development now in progress may be briefly described. Muscle Shoals are a series of rapids on the Tennessee River in northern Alabama and they extend over a distance of approximately 24 miles, terminating at a point about 260 miles above the junction of the Tennessee with the Mississippi. The total fall is about 135 feet. These shoals interrupt the navigation of the river and about 40 years ago two lateral canals were built around the more serious of the obstructions. The river is a large one, its flow varying

between 8,000 and 450,000 c.f.s. at these shoals, and the power possibilities presented by this liberal flow and the considerable head are obvious. For ten years or more, attempts were made to induce Congress to sanction some plan under which the power might be developed by private capital in co-operation with the construction of locks by the United States, and in 1916, at the request of Congress, the Chief of Engineers presented a project in which such a plan for developing both power and navigation by the construction of two dams, one of 95 and the other of 40 feet lift, with accompanying locks and power-houses was worked out in great detail. At that time, the cost of the dams, the locks and the substructures only of the power-houses, was estimated at $19,000,000. This plan proposed that the Government build the locks, dams and power-house sub-structures, while a power company operating in central and northern Alabama should, at its own cost, build the super-structure of the power-houses, install the machinery and utilise the power. The Company agreed to contribute $3,000,000 in cash toward the cost of the dams and in addition was to make certain annual payments. These payments in the aggregate would have reduced the portion of the cost chargeable to navigation to about $9,000,000, while the power company proposed an eventual expenditure of some $80,000,000 in the progressive development, distribution and marketing of the power.

Before this proposal had been placed in the hands of Congress the latter on June 3, 1916, passed the so-called National Defence Act which contained an appropriation of $20,000,000 for the establishment of plants for the fixation of atmospheric nitrogen and stipulated that " the plant or plants provided for under this act shall be constructed and operated solely by the Government and not in conjunction with any other industry or enterprise carried on by private capital."

With its possibilities for the development of a very great amount of energy combined with its favourable geographic location, remote from the seaboard and close to supplies of coal, iron, phosphate rock and other valuable natural resources, Muscle Shoals was one of the most suitable places for establishing a great nitrogen fixation industry not only for the manufacture of high explosives but also for making fertilizers of which large quantities are needed by the cotton growers of the surrounding states.

No action was taken by Congress on the proposal of the above power company and in fact nothing whatever was done until early in 1918 when, by order of President Wilson, Muscle Shoals



Location of proposed navigation and power developments, on the Tennessee River, in the State of Alabama, including Dam No. 2 now under construction.

Fig. 6.

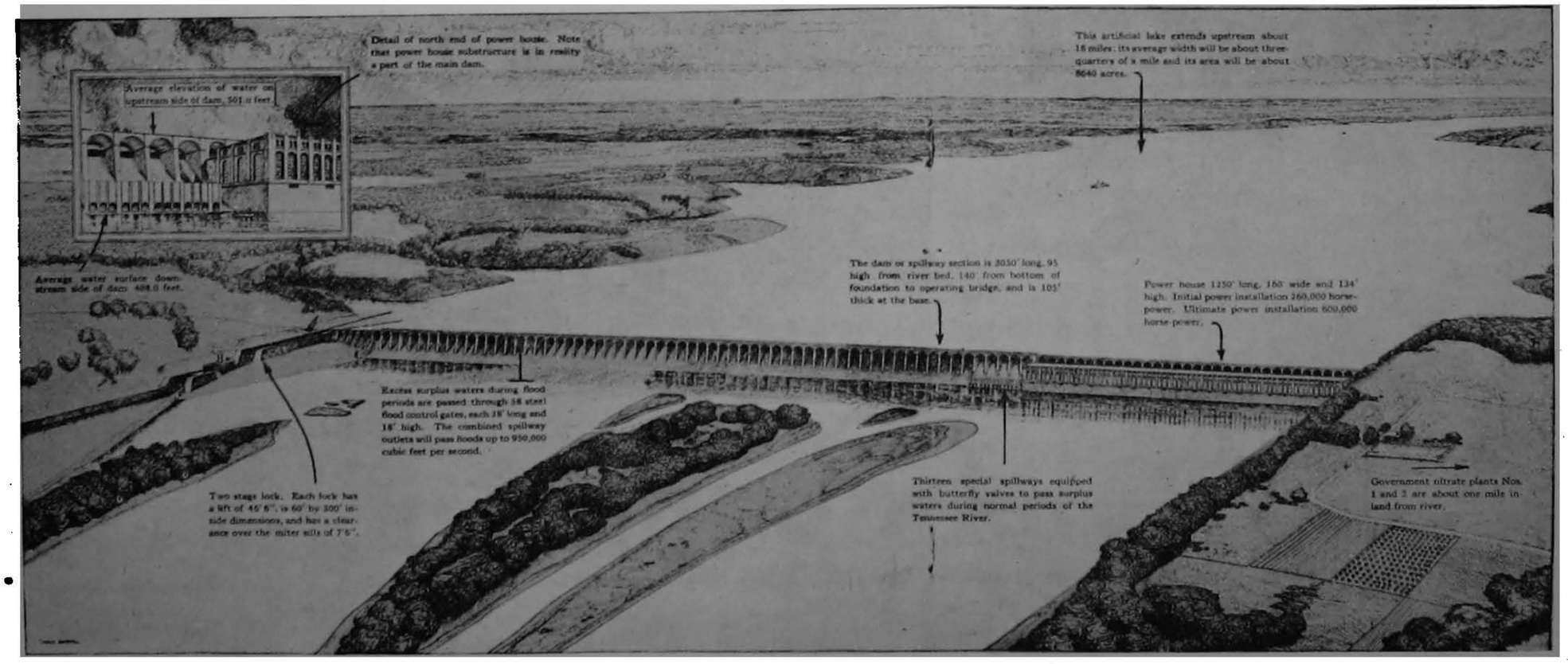


Fig. 7.
Drawing of dam, locks and power house, Muscle Shoals, Alabama, as they will appear when complete.

was formerly selected as the site for the nitrogen fixation plant authorized by the National Defence Act, and for the development of the water power needed for that purpose. The organization of the working forces and the assembling of the necessary plant and construction materials were begun in February of that year and field work was pursued until August, when it was suspended by order of the War Industries Board because the project could not be completed in less than four years and it was thought that the men, money and materials involved could be better employed on something that would more immediately contribute toward winning the war. With the Armistice, work was resumed and since the spring of 1919, it has been steadily in progress except for interruptions due to freshets and the lack of funds, one of the latter lasting over a year.

Under the plan presented in 1916, the combined navigation and power development of Muscle Shoals would extend 6 feet navigation a distance of 82·5 miles from its present head at Florence, Alabama, leaving about 100 miles of river to be improved in the completion of a 6 feet channel from the Mississippi River to the city of Chattanooga, over 630 miles. The improvement of the Muscle Shoals section was to be accomplished by the construction of three dams with corresponding locks. Of these, No. 1, the furthest downstream, of only about 10 feet lift, a structure purely for navigation, was to be built at Florence. The other two structures were intended to be for power development as well, No. 2, 2·7 miles above No. 1, having a lift of about 95 feet above low water, and No. 3, with about 40 feet lift above the pool of No. 2, being about 15 miles further upstream. Dams No. 2 and No. 3 will drown out the existing old lateral canals and substitute for them unrestricted navigation in the pools they create.

At present, however, work is in progress only at dam No. 2. It includes a flight of two locks 60×300 feet with normal lifts of about 45 feet each, a fixed dam about 3,050 feet long equipped with movable crest gates 18 feet high and a power-house section about 1,250 feet long to contain 18 units of about 35,000 H.P. each. This work will require the excavation of about 1,200,000 cubic yards of earth and rock and the placing of over 1,252,000 cubic yards of concrete. Its cost, which now includes the completion of the power-house and the installation of hydraulic and electrical machinery, as well as certain other work not included in the original plan, was $32,258,410 up to July 1, 1923, and at that time it was estimated that $13,000,000 more would be needed to complete it.

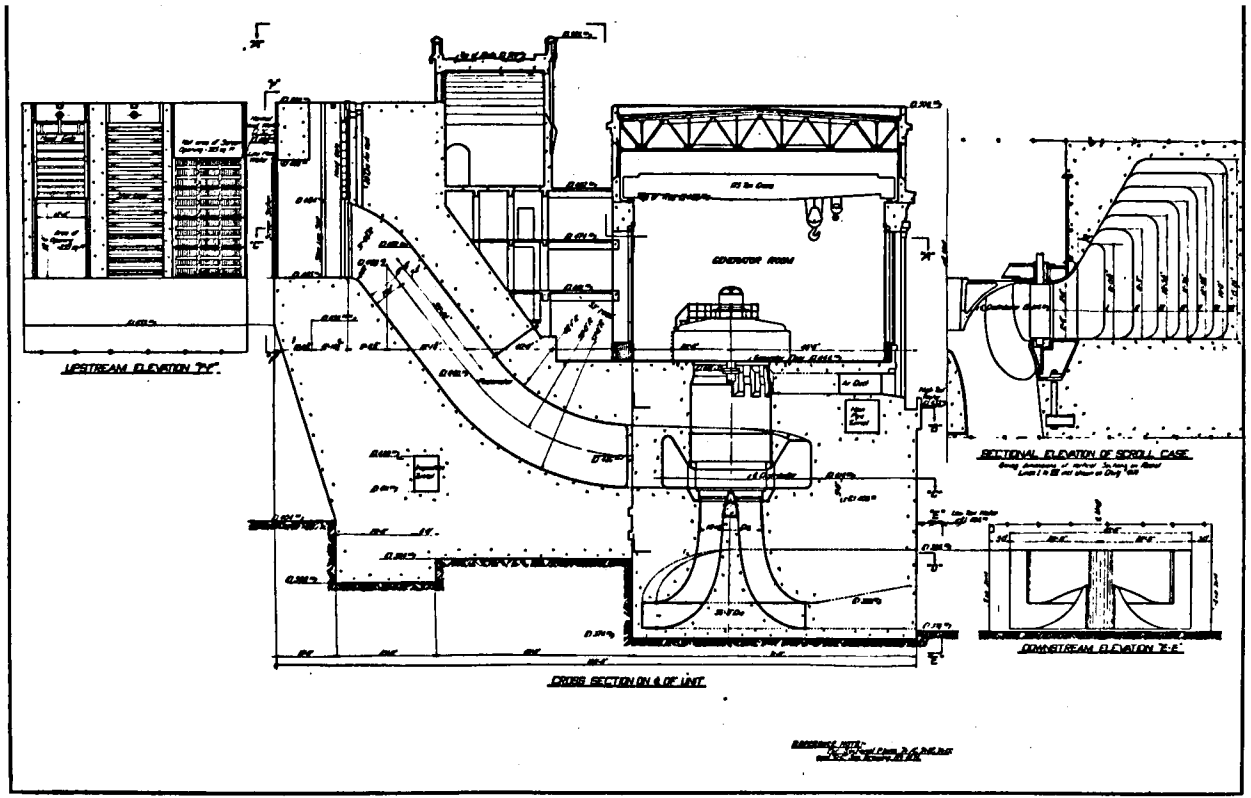


Fig. 8.
Cross section of dam and power house, Muscle Shoals, Alabama.

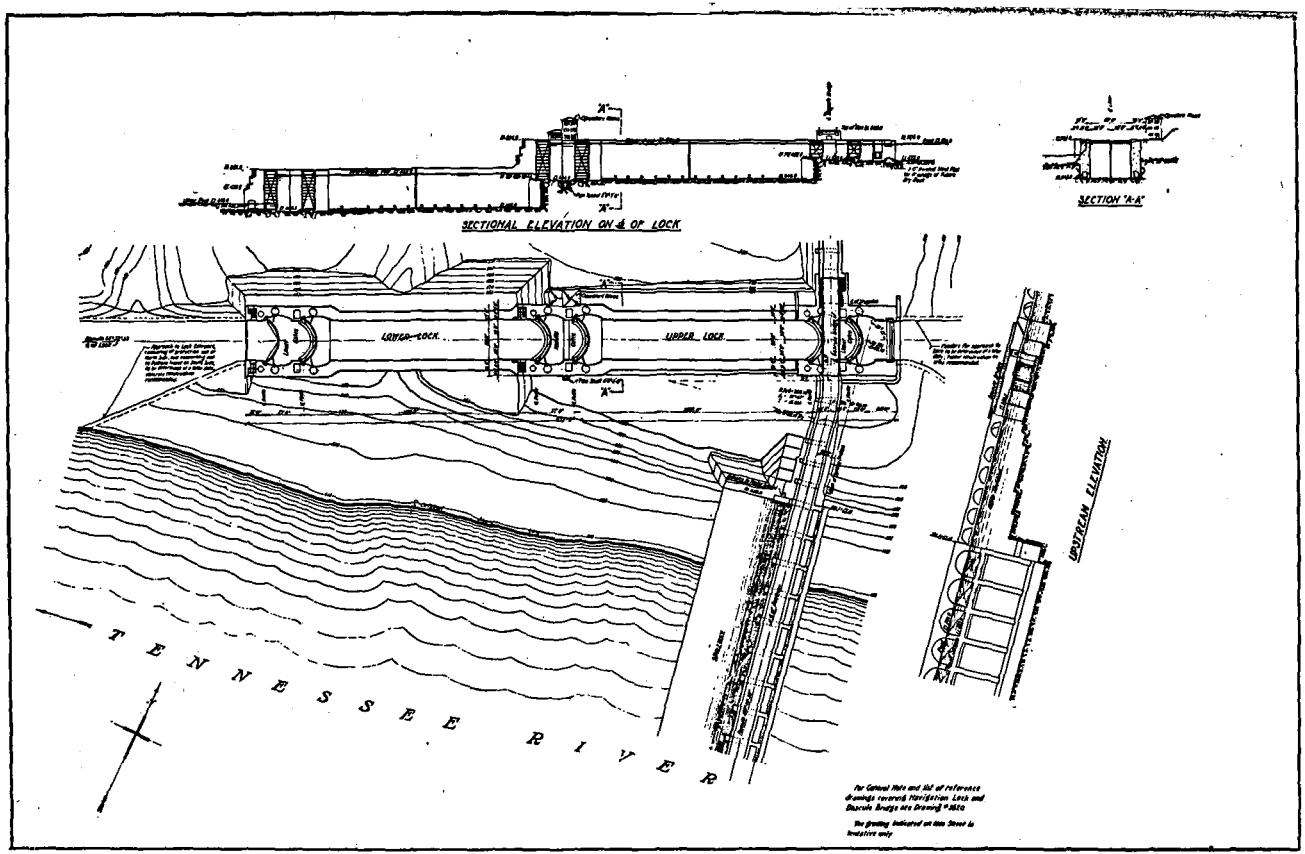


Fig. 9.
Plan and elevation of locks at Muscle Shoals.

This total of over $45,000,000 for Dam No.2 compares with a pre-war estimate of $19,000,000 for all the masonry and equipment of two sets of locks, the masonry and gates of both Dams No. 2 and No. 3, and the masonry substructures of their two power-houses. The war has thus very seriously increased the cost of this project. Dam No. 2, is at present about 70 per cent. complete and all the work on it should be done in 1925.

The amount of power susceptible of development in the two power-houses is indicated by the magnitude of the river flow already stated as varying between 8,000 c.f.s. and 450,000 c.f.s. under extreme conditions, and by the proposed installation, namely, 624,000 H.P. at Dam No. 2, and 250,000 H.P. at Dam No. 3. At 90 per cent. efficiency the primary power, based on the minimum daily discharge of record at the Florence gaging station, is 110,000 H.P., equivalent to 722,000,000 kWh. per annum. The power which would be available for 90 per cent., 75 per cent. and 50 per cent. of the time during a period similar to the 25 years of record, is as follows: 90 per cent., 192,000 H.P.; 75 per cent., 290,000 H.P.; 50 per cent., 530,000 H.P. The output of secondary power per annum, in excess of the 722,000,000 kWh. of primary power, for each of these periods would be 512,000,000 kWh., 1,042,000,000 kWh. and 2,229,000,000 kWh. respectively. These figures assume the full utilization of the water supply for the several periods, an assumption which will be correct if, as appears probable, the pondage at the dams is adequate to meet the daily load fluctuations, and if the load factor is not less than 60 per cent. At 75 per cent. average daily load factor a total yearly output of 3,127,000,000 kWh. could be produced; but as much of this energy would be available for short and uncertain periods, it would be of questionable value if the plant were to be operated as a run-of-river plant developing only the natural flow with no seasonal storage. If, however, the 60,000 kW. steam plant, which was built by the United States for war purposes and is located near the site of the hydro-electric plants, is used as a reserve, the amount of primary power would be increased to 190,000 H.P.

The output available at Dam No. 2, which alone is under construction at the present time, based on the same assumptions of operation and flow as in the preceding paragraph are: primary H.P. 75,500; primary kWh. 510,000,000 H.P. available 90 per cent. of time, 134,000; 75 per cent. 206,000; 50 per cent. 373,000; Secondary kWh. 90 per cent of time, 360,000,000; 75 per cent. 734,000,000; 50 per cent., 1,426,000,000. The total annual output

at this dam of primary and secondary power at 75 per cent. daily load factor and with an installation of 624,000 H.P. in the average year is estimated as 2,200,000,000 kWh. With the 60,000 kW. steam plant used as a reserve, the primary power would be increased to 156,000 H.P.

No decision has yet been made as to the application of this energy. Obviously the best method would be to join it with a system that already has large water power and steam output, a good base load and a rich and productive territory in which to build up a market for the added energy. Such a combination could be made to convert a large part of the short term secondary power into commercial power. A system of this kind actually operates in the adjoining part of Alabama, and was the proponent of the plan for co-operative development first described. It has now made the Government an offer for the power and other offers have also been received, notably one from Mr. Henry Ford.

It will be seen that the Muscle Shoals situation differs from the examples already cited in that, until a considerable amount of additional work has been done, navigation will not benefit. To make a six feet channel available from the Mississippi River to Chattanooga, the principal city on the river, will require the construction of locks and Dams Nos. 1 and 3 and also the improvement of the river for a distance of about 100 miles from the head of the backwater above Dam No. 3 to the Hales Bar lock and power dam, about 33 miles below Chattanooga. Until the through channel has been provided, the navigation facilities at Dam No. 2 are practically useless.

The work should not have been resumed after the Armistice before determining what part of the power, if any, was to be used for Government purposes and the best manner of disposing of the surplus. It is also regrettable that nothing has been done to assure the completion of the through channel within a reasonable length of time. In reality a promising project is being delayed and the Government is making a very large expenditure in a way that puts the financial outcome in doubt.

This is a case in which the terms of the Federal Power Act have not been applied. The work was started before that Act was passed. Since then controversy as to the power has been so acute and the decision of such financial importance as to place the matter outside the class to be decided by executive action. Moreover the large cyanamide plant and other property near by are also involved and these could not be regarded as coming within the scope of the Power

Act. The case is, therefore, a special one, though there seems no good reason for departing from the principles set forth in the Federal Water Power Act and uniformly observed in licenses issued under it.

As a final illustration of the co-operative development of power and navigation, I cite the well known plant of the Mississippi Power Company at Keokuk, Iowa.

It has already been explained that between Minneapolis and the mouth of the Missouri River, the Mississippi River is under improvement for the purpose of creating a channel six feet deep. Except at the Twin City Dam (dam No. 1) and at the Rock Island and the Des Moines Rapids where canalization has been necessary, the improvement has been made by the use of contraction works and bank revetments and the greater part is now completed.

The Des Moines Rapids, rocky reefs extending across the river channel at intervals for a distance of 12 miles above Keokuk, were originally made navigable by a lateral canal, built between 1870 and 1880 and provided with three locks to surmount the low-water fall of 21 feet. In 1905, Congress passed an act to authorise the Mississippi River Power Company to develop the power of the Des Moines Rapids. Among other conditions to the grant, the company was required to replace the navigation facilities to be destroyed with others satisfactory to the War Department. These included a new lock, a dry-dock and shops, and an office building.

Work was begun late in 1910 and was completed in 1913. The new development is shown in the accompanying plates. It consists of a dam of the abutment type averaging 30 feet in height and provided with spillway gates 11 feet high. The dam extends from the left (east) bank of the river, a distance of 3,600 feet and it has 120 spillway openings. At its right or west end it joins the power-house, a structure about 1,600 feet long, only half of which has, however, been provided with a superstructure, in which there are fifteen units of 150,000 H.P. capacity. At the lower or south end of the power-house substructure, there is an ice sluice which in turn connects with the single lock, on the land side of which is the dry-dock. The head at low water is 40·35 feet and at high water 20 feet.

Keokuk is 173 miles by river above the mouth of the Missouri and about 200 miles from St. Louis. The greater part of the power is transmitted to St. Louis, an air line distance of about 160 miles, where it is employed in public utility service.

The cost of this improvement, exclusive of transmission lines

and sub-stations, amounting to $20,230,000 was defrayed by the company. Of this total $1,160,000 is chargeable to the lock, dry-dock and other structures connected with navigation and large sums were also expended to elevate the tracks of the railroad on the west bank and to pay for overflowed land. The pool of the dam extends nearly 50 miles upstream and for practically this entire distance, channel improvement has been rendered unnecessary, the consequent saving to the United States being for this item estimated at about $1,000,000. In addition there is now one lock where there were formerly three and, in contrast to 12 miles of shallow canal requiring restricted speed for safe navigation, the pool affords a wide deep channel where good speed can be maintained by vessels. The saving of time to vessels is considerable while the single lock costs perhaps $20,000 less annually to operate than the old canal.

The location of the lock with reference to the power-house is unusual. It appeared preferable for a number of reasons to have the power-house near the city which is on the west, or Iowa, side and the lock was required to be there because the opening of a draw-bridge, just below the dam, was on that side. No difficulty has been experienced due to the nearness of the power-house to the approach to the lock.

The low water flow of the river is about 17,000 c.f.s. and the high water discharge about 300,000 c.f.s. The low flow occurs during the late fall and early winter, when navigation is either impossible because of ice or unprofitable because freight and passenger traffic are light. At such times, it would be possible to permit the pool above the dam to be regulated in the interest of power production, and night ponding and peak load discharge could take place without any disadvantage. However, it has been necessary, in the interest of navigation, to forbid ponding when the natural flow of the river is declining or when it is less than approximately 64,000 c.f.s., which corresponds to a normal stage of 6 feet above low water at Keokuk. The War Department has, however, wisely given to the officer of the Corps of Engineers of the Army, locally in charge, discretion to make written exceptions to this rule. In the long run, as experience demonstrates the possibility or the necessity of altering this rule, it may therefore be expected to be changed either by the exercise of this discretion or by the formal action of the War Department.

Navigation was formerly much more active on the portion of the Mississippi affected by this improvement than it now is, the

GENERATOR

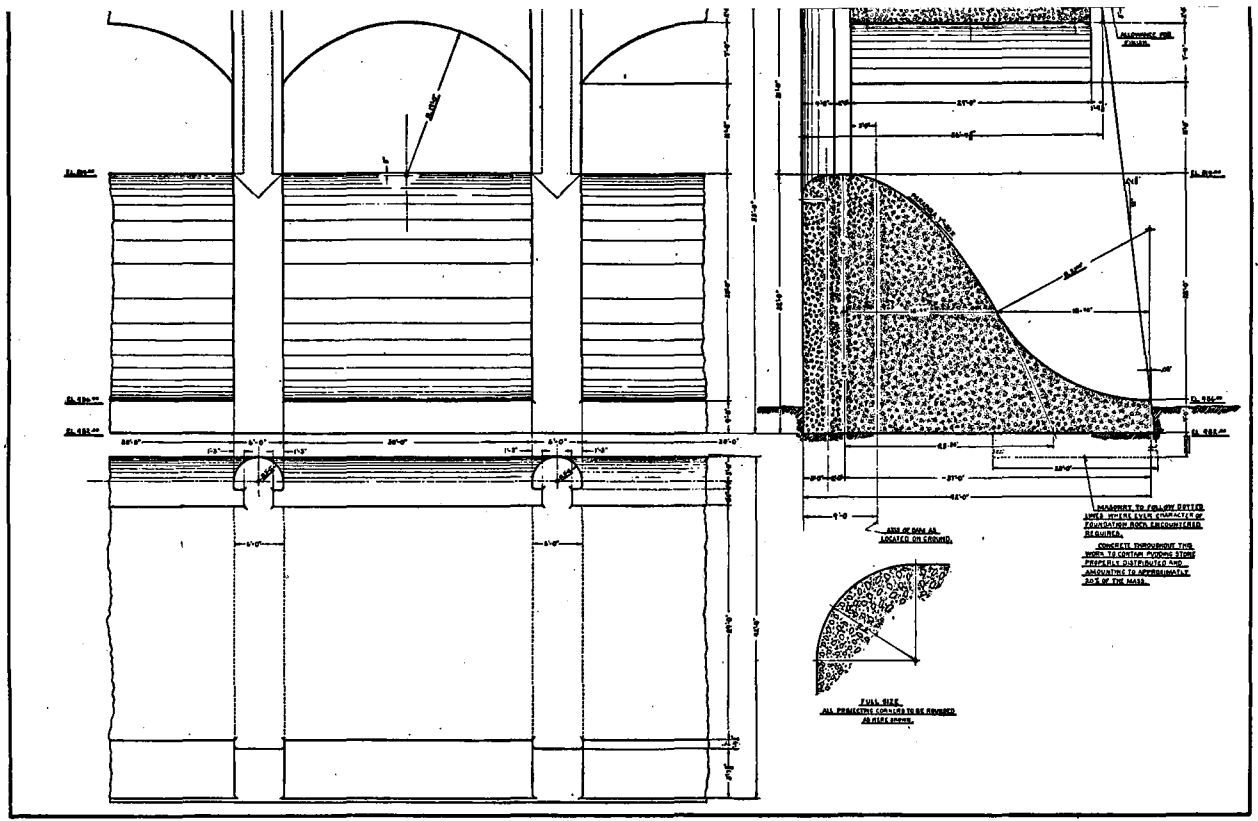


Fig. 11.
Cross section through water wheels and draft tube, plant G., Mississippi River Power Company, Keokuk, Iowa.

principal traffic then being lumber and logs, usually towed for considerable distances in rafts. These are a thing of the past and to-day the traffic is mostly a local or short haul business in miscellaneous freight and there is an enormous excursion passenger traffic. The 6 feet channel is not yet completed and there are no modern facilities for handling river freight. With the completion of the 6 feet channel and the progressive increase of wealth, population and output of the rich and busy region tributary to this channel, there will come an opportunity to judge as to its eventual usefulness as a transportation route and to work out permanently, in the interest of the public, a judicious system of control of the flow at Keokuk.

Many other examples of power development on our navigable waters might be mentioned, some completed long since and others now in progress. For example, there is another large private development at Hales Bar on the Tennessee River, 33 miles below Chattanooga. Here the dam and power-house were, under a special Act of Congress, built between 1905 and 1913 by private capital and the United States paid for the lock, whose cost was about $236,000. Other completed projects are on the Mississippi above Minneapolis, on the St. Croix, a tributary of the Mississippi, and on the Fox River in Wisconsin. Among all that have been mentioned, Keokuk is the best example of proper co-operative development of power and navigation in that money has been expended only to furnish actually useful facilities. Even at Keokuk, there has been some idle investment in power-house substructure, and it is to be regretted that the salutary provisions of the Federal Water Power Act were not made applicable to the project.

Our experience goes to show that there is no real difficulty in harmonizing the needs and interests of navigation with the economic development of power. It is true that run-of-river plants may find the natural low flow too small to maintain a satisfactory commercial output but it will generally be possible, without material damage to water traffic, to permit some ponding and regulation of flow and usually the shortage of water power will be anticipated and auxiliary power provided. Eventually this difficulty will, in many cases, be alleviated by recognition of the fact that such navigation as exists is of less importance to the community than the water power that must be sacrificed, and fuller storage at headwaters may also help to ameliorate low flow and uncertain power output. The real remedy for the weaknesses inherent in run-of-river plants, on streams as variable as are most of our

navigable rivers, is recognition of the inability of such plants to function economically as independent units and of the consequent advisability of incorporating them as parts of large electric systems, whose power resources are sufficiently varied and whose output and base load are of such magnitute as to cause the variability of the run-of-river plant to become a thing of little or no importance.

With the recognition of this fact under the encouragement and protection of the Federal Water Power Act, we may confidently expect a progressive utilization of the power resources of our navigable waters, beneficial alike to the power industry and to the promotion of economic river transportation.

RÉSUMÉ.

L'auteur donne une brève description sur les conditions qui ont présidé à l'adoption de la loi Fédérale sur les forces hydrauliques (Federal Power Act), et discute les données diverses de cette loi, concernant l'utilisation de la puissance hydraulique des cours d'eau navigables aux Etats-Unis. Il décrit dans ses grandes lignes le principe général concernant de telles installations à savoir que la priorité simplement technique des droits de navigation ne doit pas majorer indirectement le coût d'installation de la puissance hydraulique et conseille de solutionner les conflits entre les intérêts de la navigation et ceux de l'utilisation de la force hydraulique en considérant avant tout l' intérêt Public.

Plusieurs types d'installation de force motrice en combinaison avec la navigation sont décrits au point de vue de l'état général des forces hydrauliques et des relations entre la navigation existante et future. Il est indiqué que la plupart des cours d'eau en question, présentent une grande marge de débit et que la puissance primaire est relativement faible et peut être onéreuse si elle est installée indépendamment, tandis que la grande proportion de puissance secondaire peut ne pas avoir de valeur commerciale. Le remède éventuel est d'incorporer de telles forces hydrauliques dans un vaste système pouvant absorber sans pertes toute l'énergie que peuvent produire ces forces motrices

En résumé on émet l'opinion que l'installation de ces forces motrices tend à se développer et que, dans chaque cas les démarches nécessaires seront prises pour que toute l'énergie primaire et secondaire puissent être utilisées dans l'intérêt public.

POWER IN ITS RELATION TO IRRIGATION

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and
EDWARD C. BEBB,
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Broadly speaking, all that part of the United States lying west of the 100th Meridian of longitude, or about one half of the entire area of the country, is deficient in rainfall at elevations suited to agriculture and throughout this area irrigation must be resorted to for profitable crop production. Below elevations of 6,000 or 7,000 feet, where the growing season is long enough for successful farming, the precipitation varies from two to sixteen inches per annum, while the normal precipitation in all the United States lying east of this region exceeds twenty-five inches per annum. A narrow belt between the Pacific Ocean and the Cascade and Coast Ranges in Washington, Oregon and Northern California, where the annual precipitation varies from 30 to 150 inches per annum, is the only area of importance within this great domain to which the general statement does not apply.

In this so-called "Arid West" are the Rocky Mountains, the Sierra Nevada and numerous lesser ranges and mountain masses rising to elevations of 10,000 to 14,000 feet and from the snow-capped peaks and abundant precipitation of these high altitudes come streams with lavish fall that call for power development before they reach the thirsty plains below to be consumed by irrigation. Thus, we have the anomaly of the arid west, with only a fraction of the run-off of the eastern states, presenting the best opportunity for water power development in the country, and thus it is that anyone contemplating power development in this region is immediately confronted with the question of its relation to irrigation.

Lengthy explanation is unnecessary to bring out the importance of irrigation to the West. It is the foundation upon which practically all the *permanent*, prosperous, growing communities are built. The mining, oil and lumber industries have their centres but they are in the main ephemeral, subject to serious ups and downs of prosperity and add relatively little to the permanent population

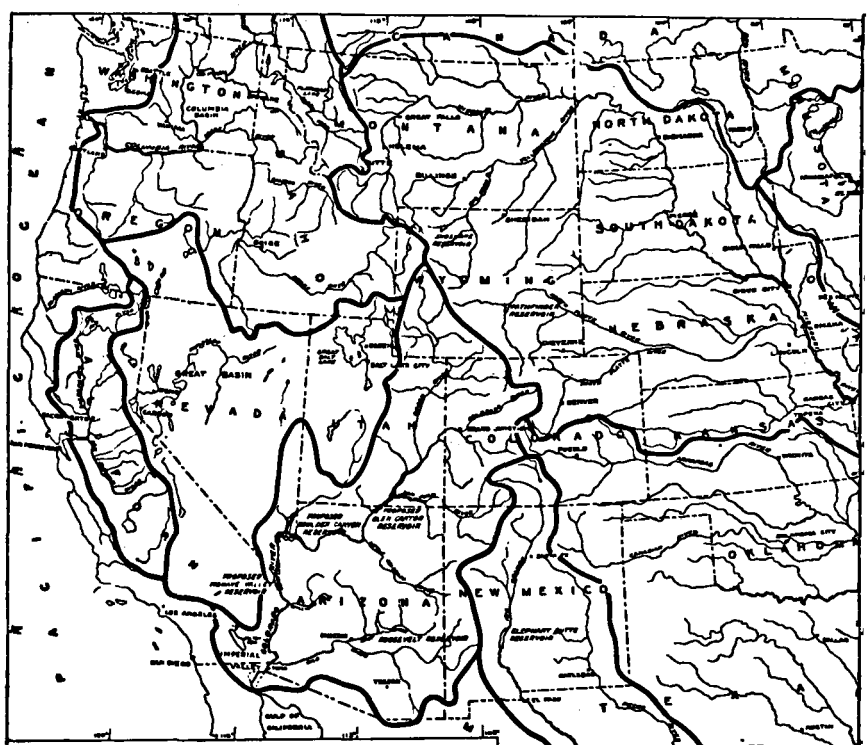
and wealth of the region. Stock-raising on the open range and "Dry farming" reached their fullest development some years ago and are on the decline. Communities supported by irrigated lands, on the other hand, continue to grow and thrive in a healthy manner notwithstanding depressions such as we have had in all agriculture during the past few years. For this basic reason public opinion in the West permits no interference with irrigation and the principle has become well established in state laws that use of water for irrigation is superior to all other uses except domestic.

Here it should be explained to those not familiar with the subject, that in the United States each state controls the waters within its borders. In the humid area of the Eastern and Central States riparian rights based on the old English Common Law are in full force. In the Western or arid States, there has become dominant, through the requirements imposed by nature and the influence of the early Spanish settlements in the Southwest, the "doctrine of prior appropriation for beneficial use" which has come down from early Roman law. In some states the old Spanish water laws remain almost intact, in others there are varying degrees of compromise with the riparian system, but in all the right to appropriate the waters of any stream for irrigation, power or other non-domestic use must be obtained from the state authorities. The Federal Government exercises control over the use of the public lands for water storage and other irrigation and power development and controls similar development on navigable streams in the interest of interstate and foreign commerce but in no case is there any usurpation of the State's right to the waters within its borders.

Bearing in mind the natural conditions and fundamental policies mentioned and the added fact that lack of market is the greatest obstacle in the path of power development in the West, the person seeking to develop and dispose of power as a commodity would be shortsighted indeed if he permitted restrictions imposed in the interest of irrigation to lead him into opposition to such development or into antagonism toward those who are seeking to lay the best foundation upon which to build a stable general utility load.

Having frankly accepted irrigation then, as an industry to be fostered, and having conceded it a superior right to water when confined within justifiable economic limits, let us see in what respects water power and irrigation conflict, in what lines their interests run parallel and how conflicting interests can be harmonised to best advantage.

PLATE 1.



DRAINAGE SYSTEMS OF THE WESTERN UNITED STATES

Watershed	Area* (Sq. miles)	Area irrigated 1920 (Acres)	Water Power	
			Installed, H. P. 1924	Estimated Maximum H. P.
Missouri River	4,147,000	814,000	347,000	8,370,000
Western Lower Mississippi and Gulf	1,836,000	479,000	49,800	930,000
Rio Grande	1,294,000	130,000	1,100	690,000
Colorado River	9,218,000	942,000	81,300	8,760,000
Great Basin	2,215,000	201,000	431,000	630,000
Columbia River	3,679,000	890,000	667,400	17,700,000
Central California and South Pacific Coast	2,365,000	85,000	896,000	5,301,000
North Pacific Coast	263,000	40,000	625,000	3,800,000
Totals	19,843,000	3,851,000	3,107,700	38,170,000

*Areas here given are for the United States only and do not include portions of watersheds in Canada or Mexico

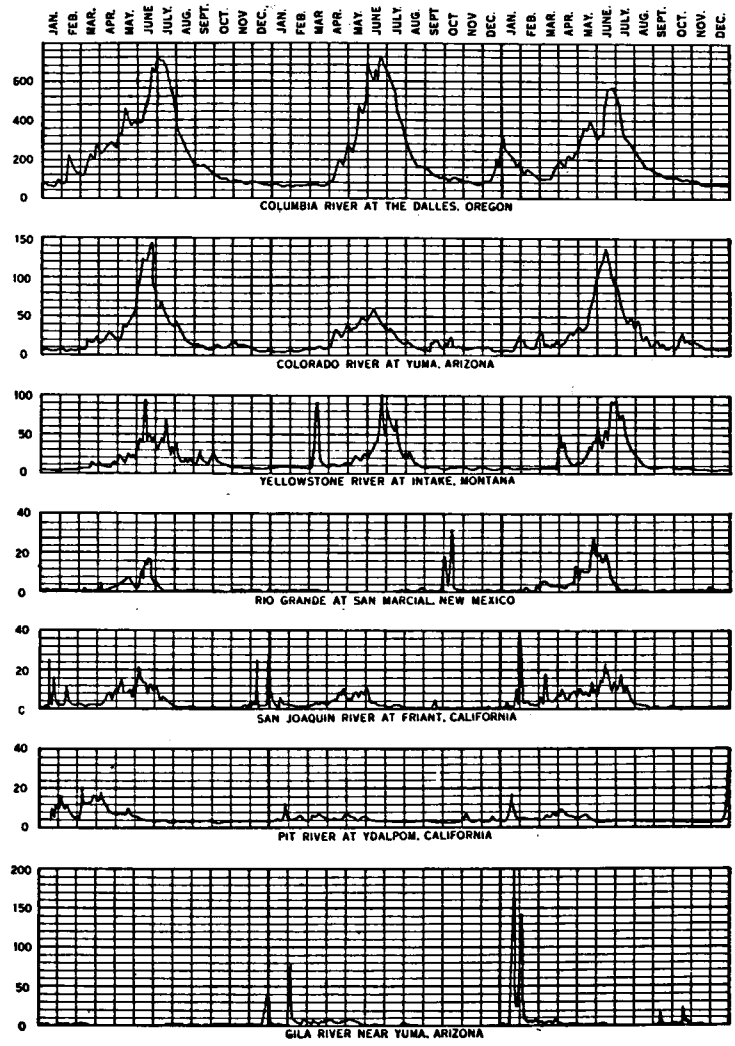
On Plate 1 are outlined the main drainage systems of the western United States and a table gives the total area, area irrigated in 1920, developed water power and estimated maximum available power in each main watershed.

Plate 2 shows the typical, seasonal discharge curves for the Colorado, the Columbia, the Yellowstone and the Rio Grande, representing the four largest drainage systems of the West; also the Gila in Arizona and the San Joaquin and Pit Rivers in California. The Colorado, Yellowstone and San Joaquin possess the characteristic flow of streams fed by snows of the high altitudes and are typical of perhaps 90 per cent. of the more important streams. On some of these streams the annual peak discharge or "June rise" occurs with quite surprising regularity. The Columbia differs in that its peak is retarded and flattened by a considerable number of lakes serving as regulating reservoirs and because a large part of its drainage area lies at high altitudes in British Columbia, where the run-off from snows and glaciers does not occur until midsummer. The Rio Grande is a sample of the erratic streams which are fed mainly by rains on lower altitudes of arid and semi-arid character, its snow run-off from the mountains of Colorado being almost entirely used by irrigation near its source. The Gila is an example of the most extreme desert type of stream. It is of only limited value in its upper reaches and little but a flood menace below. The Pit, an eastern tributary of the Sacramento, is an exceptional type, regulated by a great underground reservoir formed by the volcanic rocks which form its watershed. A few other streams in north-eastern California and southern Idaho are similarly affected in less degree.

The diagrams on Plate 3 have been prepared to show the relation between the monthly discharge of several characteristic western streams and the monthly demand for irrigation water in the region served by each.

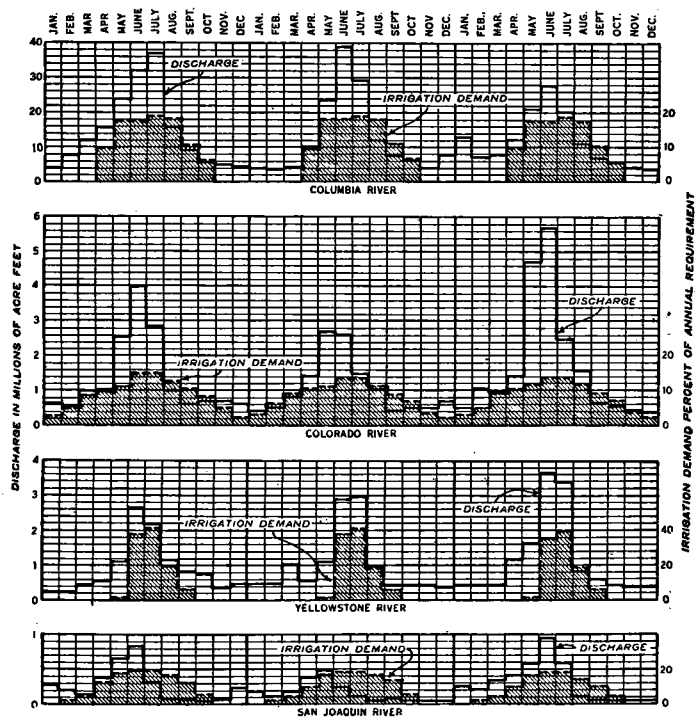
The curves on Plate 4 show actual recorded deliveries of power in kilowatt hours per month by certain prominent utilities for various uses. They are presented to illustrate the characteristics of these types of power load and their adaptability to stream flow. The same three successive years are used in all cases. It will be observed that the manufacturing and mining loads possess no regular seasonal fluctuations. The demand rises and falls in a general way with the industrial conditions of the country but has little relation to the seasons. The railroad load also is responsive to business

PLATE 2.



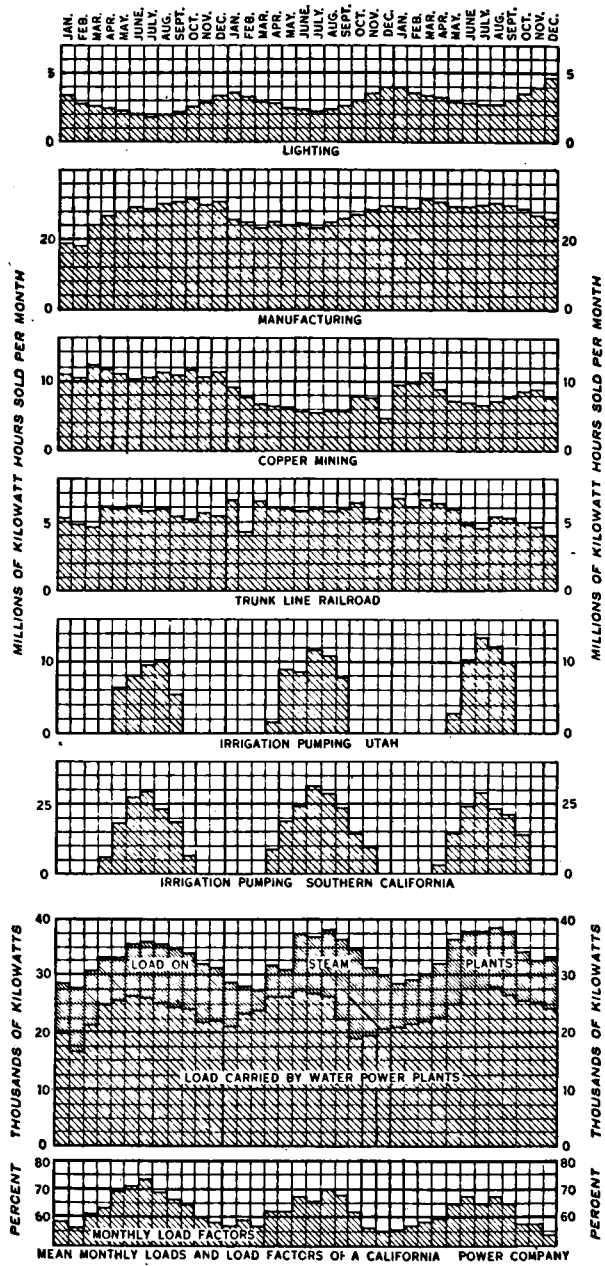
Discharge curves of typical western rivers in thousands of second-feet.

PLATE 3.



Monthly discharge of typical western rivers in millions of acre feet compared with the average monthly irrigation demand in the region of the stream measurements; demand expressed in percentage of total annual requirement.

PLATE 4.



Consumption curves showing characteristics of various types of load. Also the mean monthly loads and load factors of a typical California power company.

conditions but has no recognisable seasonal characteristic, though this particular road is one of the trunk lines where such fluctuation might be expected. Irrigation pumping is the only load that can be relied upon to fill the summer trough produced by the lighting load and to utilise the summer peak discharge of streams that are unregulated, only partly regulated or regulated primarily for irrigation.

Below these type curves is shown the load curve of a California power company to illustrate the advantage of irrigation pumping load when it is built up in proper proportion. In this case the utility was able to make use of the full hydraulic power of its plants on partly regulated streams and at the same time maintain a fairly even load on its steam plants. Note also the monthly load factor curve for the same period showing an increase of 10 to 15 per cent. due to the pumping load. Irrigation pumping forms about 25 per cent. of the connected retail power load of this system and during the height of the irrigation season many pumping plants operate continuously day and night, thus producing a very marked effect on the monthly load factor of the entire system.

If comparison of the various discharge and load curves is made, foundation for the following statements will be evident :—

1. On every stream all interests would benefit greatly by " hold-over storage " or the provision of a reserve supply for low years.
2. On typical western streams the monthly discharge follows in a general way the irrigation demand, so that much less storage is required to regulate the stream for irrigation than to equate the flow for ordinary power use. The maximum irrigation demand occurs in most cases, however, about a month later than the peak of stream discharge and the regulation most needed for irrigation is the storing of the flood peak for use in late summer.
3. In seasonal regulation there is sure to be some conflict of interest between irrigation and power, the conflict being the more pronounced the shorter and more concentrated the irrigation season.
4. Development of irrigation pumping load, which follows the same curve as irrigation water demand, is the best means of synchronising the requirements in seasonal regulation of the two interests.

The development of pumping load and the determination of where irrigation by pumping should be undertaken or encouraged is a matter for the closest economic study. Of the 19,000,000 acres

estimated to be at present under irrigation in the United States, water is supplied by gravity canals to about 16,000,000 acres, the remaining 3,000,000 acres receiving their supply from water pumped from streams, from gravity canals and from wells. While no authentic figures are given, it has been roughly estimated that through utilisation of flood waters available for storage about 15,000,000 acres of now desert land can be reclaimed by gravity water and that in addition possibly 10,000,000 acres may be irrigated economically through water pumped from adjacent streams, largely by means of hydraulic power latent in those streams. Opportunities and importunities to extend this area of irrigated land supplied by pumping present themselves on every hand, but we must be cautious. A prosperous irrigated region is the greatest blessing that can be bestowed on an arid country, but judgment permitted to swing too strongly to the side of optimism is likely to produce its greatest curse—a hopeless and helpless community and a set of disillusioned investors who will make financing difficult for future projects of a similar nature, no matter how worthy.

We must weigh carefully the construction cost and annual pumping and maintenance charges against the value of the crops that can be produced. A fair estimate of cost of pumping can be arrived at without much difficulty. Table I. gives some reliable data on energy consumption in pumping both from surface bodies of water and from wells. These figures have been obtained from records of the United States Reclamation Service. Their value lies in the fact that they are actual performance records for an entire irrigation season of plants which have been in operation for some years and are in good ordinary condition, and that the records show overall efficiency from electric meter to water in the outflowing canal. In other words, instead of records of new motors and pumps tested under favourable conditions we have an approximation of what we may reasonably expect of well maintained pumping plants operating under actual irrigating conditions over a period of years. Comparing the energy consumed with the potential energy of the water raised it will be seen that the overall efficiency of these plants ranges between 40 and 70 per cent. and that in pumping from wells 50 per cent. is the best record.

We must next consider the amount of water required by character of soil, climate and crops and determine the monthly and peak demand for water. This is more difficult. To indicate the water requirements which may be expected with certain combinations

TABLE 1.—ENERGY CONSUMED IN PUMPING.

Pumping Plant	Water pumped from	Type of pumping units	No. of units	Plant capacity (horse-power)	Net lift (feet)	Quantity pumped during season (acre ft.)	Energy used for pumping (kW.-hrs.)	Energy used per acre ft. per foot lift (kW.-hrs.)
Robinson Flat, Okanogan, Wash. ..	River	*H.C. 2-Stage	2	400	188	1,008	426,340	2·24
"B Lift," Yuma, Arizona	Canal	V.C.	3	1,100	69	4,788	665,100	2·02
Duck Lake, Okanogan, Wash.	Lake	H.C.	1	50	55	1,150	98,984	1·56
High Line, Salt River, Arizona	Canal	H.C.	4	900	47	33,927	2,880,618	1·81
No. 1, Minidoka, Idaho	Canal	V.C.	5	2,760	29·2	196,445	8,799,847	1·50
No. 2, Minidoka, Idaho	Canal	V.C.	4	2,400	30·2	160,350	13,674,646	1·75
No. 3, Minidoka, Idaho	Canal	V.C.	3	1,560	29·9	99,188		
West End Minidoka, Idaho	Canal	H.C.	2	150	21·2	9,144	385,600	1·99
Boersch Lake, Minidoka, Idaho	Drain	V.C.	2	200	19·8	11,450	431,320	1·89
No. 3, Williston, N. Dak...	River	H.C. on barge	3	405	12–32	2,386	140,057	2·68
Phœnix Division, Salt River, Arizona ..	Wells	V.C.	18	365	57·2	12,447	1,904,243	2·68
Tolleson Division, Salt River, Arizona ..	Wells	V.C.	20	650	38·1	33,311	2,663,000	2·10
San Francisco Div., Salt River, Arizona	Wells	H.C.	1	100	38·0	1,236	97,251	2·07
Chandler Division, Salt River, Arizona ..	Wells	V.C.	11	795	35·9	26,656	2,209,436	2·30
Salt River Division, Salt River, Arizona ..	Wells	V.C.	21	760	29·0	44,031	2,997,274	2·29
Mesa Division, Salt River, Arizona ..	Wells	V.C.	16	600	22·4	26,096	1,590,953	2·72
Nos. 1 and 2, Okanogan, Wash.	Wells	V.C.	2	30	35	448	71,620	4·56

* H.C. = Horizontal, motor driven centrifugal pump.
V.C. = Vertical, motor driven centrifugal pump.

TABLE 2.—WATER REQUIREMENTS FOR IRRIGATION WITH VARIOUS COMBINATIONS OF SOIL, CLIMATE AND CROPS.

Project	Soil	Average elevation Feet above sea level	Length of irrigation season Days	Annual rainfall Inches	Principal crops Ranked by acreage	Average annual water delivery at farm Acre feet per acre of land.	Maximum monthly demand Acre feet per acre of land.
Colorado Drainage.							
Salt River, Arizona	Sandy loam	1,200	365	8·3	Cotton, alfalfa, grain, vegetables, fruit	2·8	0·45
Yuma, Arizona-California	Rich alluvium	100	365	3·1	Cotton, alfalfa, grain	2·8	0·50
Grand Valley, Colorado	Sandy loam and clay	4,700	214	8·3	Alfalfa, beets, grain, fruit, vegetables	3·7	0·80
Uncompahgre, Colorado	Sandy gravel, clay and clay loam	5,500	214	9·5	Alfalfa, grain, potatoes, beets, fruit, onions	5·0	1·15
Great Basin and Northern California.							
Strawberry Valley, Utah	Sandy loam, clay, alluvium	4,600	169	15·1	Alfalfa, beets, grain, vegetables	1·5	·45
Newlands, Nevada	Sand, sandy loam, clay, volcanic ash	4,000	198	4·6	Alfalfa, grain, beets, vegetables	3·0	·70
Orland, California	Sandy, silty and clayey loams	250	267	18·4	Alfalfa, grain, almonds, fruit, vegetables	3·0	·55
Klamath, California-Oregon	Disintegrated basalt, volcanic ash	4,100	168	12·7	Alfalfa, grain, vegetables	1·2	·40
Columbia Drainage.							
Umatilla, Oregon	Sandy loam, sand	470	210	7·9	Alfalfa, fruit, grain, vegetables	4·4	1·00
Yakima, Wash. (Sunnyside)	Volcanic ash and decomposed basalt	700	214	6·5	Alfalfa, apples, grain, potatoes, fruit	3·2	0·60
,, ,, (Tieton)	Volcanic ash and decomposed basalt	1,700	164	8·1	Alfalfa, apples, grain, potatoes, fruit	2·5	0·55
Okanogan, Washington	Volcanic ash, sand and gravel	1,000	153	11·5	Apples, alfalfa, fruit	2·9	0·80
Boise, Idaho	Clayey and sandy loams	2,500	184	13·7	Alfalfa, grain, clover, potatoes, fruit	3·4	0·85
Minidoka, Idaho (Gravity)	Sand, sandy loam and clay loam	4,225	198	11·7	Alfalfa, grain, beets, potatoes	3·4	0·75
,, ,, (Pumping)	Volcanic ash				Alfalfa, grain, potatoes, beets	2·3	0·65
Missouri Drainage.							
North Platte, Nebraska-Wyoming	Sandy and clayey loams	4,100	183	14·7	Alfalfa, grain, beets, potatoes	2·2	0·70
Lower Yellowstone, Montana	Sandy loam	1,900	163	14·9	Grain, alfalfa, beets	1·2	0·55
Huntley, Montana	Sandy loam and clay	3,000	153	13·1	Alfalfa, grain, beets	1·2	0·55
Shoshone, Wyoming	Sandy loam and clay	4,500	204	5·6	Alfalfa, grain, beets, potatoes	1·4	0·40
Sun River, Montana	Sandy loam, clay and alluvium	3,700	163	10·9	Alfalfa, grain, vegetables	1·5	0·60
Rio Grande Drainage.							
Rio Grande, New Mexico-Texas	Alluvium and sandy loam	3,700	245	10·0	Alfalfa, cotton, grain, vegetables, fruit	2·6	0·45
Carlsbad, New Mexico	Sandy loam	3,100	260	14·4	Cotton, alfalfa, grain	2·4	0·55
Southern California.							
Modesto Irrigation District	Sandy and clay loams	100	273	11·3	Alfalfa, fruit, corn, beets, melons, beans	2·6	0·50
Riverside Water Company	Sandy loam and clay	850	365	10·7	Fruit, alfalfa, vegetables	3·0	0·45
Imperial Irrigation District	Sandy loam and clay	−100	365	3·0	Alfalfa, grain, cotton, vegetables, fruit	3·0	0·40

Note.—Data for all but last three projects obtained from reports of the Reclamation Service; data for last three from reports of California Department of Public Works. The large consumption of water on the Umatilla Project is caused by the very porous sandy character of the soil. On the Uncompahgre Project there are some porous soils but the excessive use of water is mainly due to wasteful methods of irrigation employed on several old systems now consolidated in the project. With revision of lateral systems and operation, gradual reduction of water consumption is taking place.

TABLE 3.—CROP VALUES ON IRRIGATION PROJECTS INCLUDED IN TABLE 2.

Project.	Principal crops ranked by total value of each on entire project.	Average crop value per acre.							Average value per acre-foot of water used.
		1917	1918	1919	1920	1921	1922	Mean	
Salt River, Arizona	Cotton, alfalfa, fruit, vegetables, grain	$72·60	$98·70	$126·27	$96·00	$59·87	$81·90	$89·22	$31·86
Yuma, Arizona-California	Cotton, alfalfa, corn, vegetables	105·47	113·32	134·00	61·09	40·04	49·70	83·94	29·98
Grand Valley, Colorado	Beets, alfalfa, grain, fruit, vegetables	44·00	64·87	64·12	48·80	31·32	30·88	47·33	12·79
Uncompahgre, Colorado	Potatoes, alfalfa, grain, beets, fruit, onions	57·89	57·62	56·76	53·30	41·10	25·14	48·64	9·73
Strawberry Valley, Utah	Beets, alfalfa, fruit, grain, potatoes	50·37	55·13	67·50	66·50	32·52	30·22	50·37	33·58
Newlands, Nevada	Alfalfa, grain, vegetables, potatoes	51·36	53·15	56·59	28·70	35·57	51·59	46·16	15·39
Orland, California	Alfalfa, grain, almonds, fruit	56·57	58·73	71·90	49·80	43·30	47·92	54·70	18·23
Klamath, California-Oregon	Alfalfa, grain, potatoes	25·73	28·92	26·30	25·65	13·20	16·30	22·68	18·90
Umatilla, Oregon	Alfalfa, fruit, vegetables	56·15	58·75	74·83	50·00	29·62	50·99	53·39	12·13
Yakima, Wash. (Sunnyside)	Alfalfa, apples, potatoes, fruit, vegetables, grain	121·67	102·36	167·07	105·50	96·65	78·13	111·90	34·97
,, ,, (Tieton)	Apples, alfalfa, fruit, grain, vegetables	72·80	97·36	154·10	127·40	116·40	95·80	110·64	44·26
Okanogan, Washington	Apples, other fruit, vegetables, alfalfa	96·88	141·85	367·23	87·70	385·00	332·45	235·18	81·10
Boise, Idaho	Alfalfa, grain, potatoes, clover, fruit	49·44	56·80	63·12	46·20	40·68	36·80	48·84	14·36
Minidoka, Idaho (Gravity)	Alfalfa, beets, grain, potatoes, clover	55·15	52·64	58·95	35·00	28·59	27·18	42·92	12·62
,, ,, (Pumping)	Potatoes, beets, grain, alfalfa, clover			61·32	49·00	40·81	34·43	48·89	21·26
North Platte, Nebraska-Wyoming	Beets, alfalfa, potatoes, grain, vegetables	41·92	36·35	45·71	47·10	28·12	21·74	36·82	16·74
Lower Yellowstone, Montana	Grain, alfalfa, beets, potatoes, vegetables	29·35	31·85	40·82	30·60	15·23	21·68	28·26	23·55
Huntley, Montana	Beets, grain, alfalfa, vegetables	36·16	39·00	49·14	27·10	23·90	29·33	34·10	28·42
Shoshone, Wyoming	Alfalfa, grain, beets, potatoes, vegetables	33·63	41·59	49·98	27·00	16·24	18·81	31·21	22·29
Sun River, Montana	Alfalfa, grain, potatoes, vegetables	29·43	31·39	42·07	21·62	13·72	16·35	25·76	17·17
Rio Grande, New Mexico-Texas	Alfalfa, cotton, grain, vegetables, fruit	56·50	66·20	53·00	59·60	32·11	53·06	53·41	20·54
Carlsbad, New Mexico	Cotton, alfalfa, grain	39·66	60·74	106·04	47·75	42·53	53·41	58·35	24·31

of these elements which affect irrigation demand, Table No. II. has been prepared. It shows the characteristics of soil, climate and crops and the average annual deliveries of water at the farm in acre feet per acre of land irrigated for the six years 1917-1922 on each of a number of projects selected to give as wide a range of conditions as possible.

Last, but by no means least, is the estimate of value of crops that can be raised, cost of production, availability of market and necessary investment to be carried by the settler. It would be unwise to attempt to generalise on these points. Each locality has its own combination of factors and each project is a distinct problem. Table III., which gives average crop values per acre for the years 1917-1922 for each of the projects included in Table II., should prove of some interest and value in this connection. The high prices of the war period and sudden drop in 1920 to pre-war values and below is here clearly reflected and should be given due consideration.

It is quite generally recognised among irrigation engineers that for ordinary agricultural crops, such as grains and alfalfa, we are treading upon dangerous ground when we undertake lifts above 100 feet. With crops of high acreage value, such as fruit, garden products, sugar beets and cotton, this limit can be safely raised.

Projects in which power development and irrigation have been successfully combined in the United States fall naturally into four classes :—

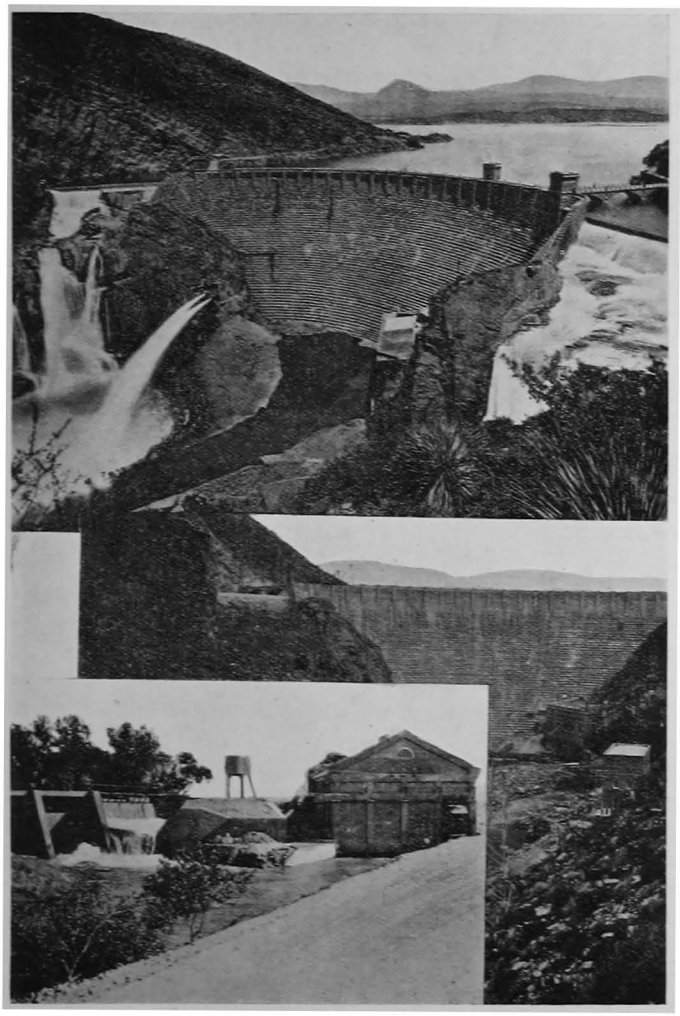
1. Irrigation projects in which power is developed as a by-product.
2. Projects in which power is developed primarily for irrigation pumping.
3. Cases in which independent power and irrigation interests have combined in reservoir construction and stream use for mutual benefit.
4. Power projects in which irrigation pumping serves as a profitable market for secondary power.

An understanding of the practical application of these different phases of co-ordination can be obtained from the brief discussion of one example of each class which follows.

POWER AS A BY-PRODUCT OF IRRIGATION.

Numerous cases of the first class can be cited but perhaps the most striking example is the Salt River Project of the United States

PLATE 5.



Two views of Roosevelt Dam and Power House, Salt River Project, Arizona. Height of dam, 280 ft. Capacity of plant, 11,750 kVA. Two 54-inch needle valves discharging.
Inset shows one of the four power plants installed at drops in the canal system of this project.

Reclamation Service in Arizona. For the adequate water supply of this 215,000 acre project surrounding Phoenix, the State capital, a storage reservoir of 1,575,000 acre feet capacity, formed by a dam 280 feet high known as " Roosevelt Dam," was constructed about 60 miles upstream from the irrigated lands. To run construction equipment, a cement mill, etc., during erection of the dam, 19 miles of canal and a 1,300 H.P. temporary hydraulic plant were built. After completion of the dam a plant of 11,750 kVA. capacity was built to utilise the energy of the water discharged into the stream bed at variable reservoir head.

Power plants were then installed, one after another, at drops on the main canals as follows :—South-Consolidated, 23-ft. head, 1,600 kVA. ; Arizona Falls, 19-ft. head, 950 kVA. ; Crosscut, 111-ft. head, 5,250 kVA. ; and Chandler, 40-ft. head, 600 kVA.

The project water users are now constructing a second storage dam 200 feet high at Mormon Flat, below Roosevelt. The re-regulating capacity of this reservoir and head added at Roosevelt Dam by placing gates on the spillway will make it feasible to install an additional 7,500 kVA. generating unit at Roosevelt. All plants are interconnected by high tension transmission lines and the power is used for pumping and commercial purposes.

The project is underlaid by a porous formation, and as irrigation progressed year after year the ground water rose in the lower areas to a proximity to the surface that threatened plant growth. To prevent deterioration of these lands by rise of ground water and to serve the equally valuable purpose of augmenting the water supply, this underground reservoir has been tapped by wells scattered over nearly half the area of the project, and there are now in operation at these wells 8 pumping plants with an approximate capacity of 9 sec. ft. each and 81 pumping plants with capacities ranging from 1 to 4 sec. ft., the lift varying from 20 to 60 feet. In addition there is a plant with 100 sec. ft. capacity for lifting water to a high line canal 45 feet above the gravity system. Power not needed for pumping is disposed of at wholesale rates to public utility companies and a few large industries in the project towns and to large copper mines in the vicinity of Globe, Arizona.

The development of power on this project has been not only a highly profitable by-product, relieving the farmers of a large part of the operating costs of the entire system, but it may also be considered almost indispensable in maintaining the productivity and adequate water supply of thousands of acres of very valuable land.

Fig. 1.
Minidoka Power House—Intake of north side gravity canal in foreground. Part of 2,385 ft. spillway shown by dark line in distance.

Fig. 2.
Interior of Minidoka Power House. Five 1,400 kVA. units.

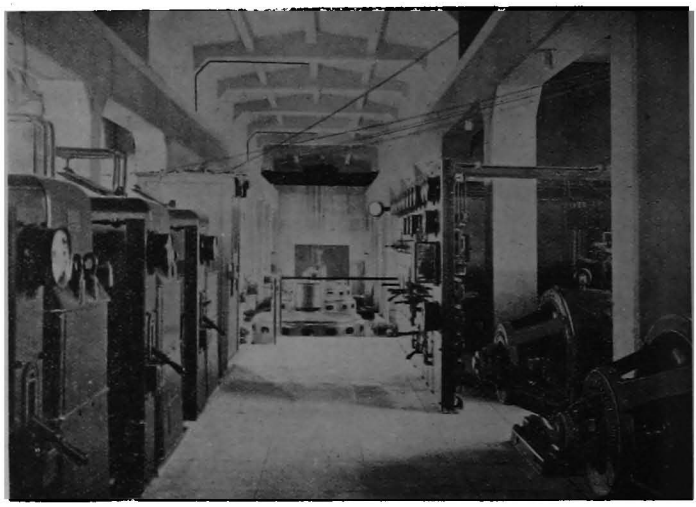


Fig. 3.

Interior of pumping station No. 1, Minidoka Project. Five motor-driven centrifugal pumps. Motor capacity 2,760 H.P.; pump capacity 732 c.f.s.; net lift 29·2 ft.

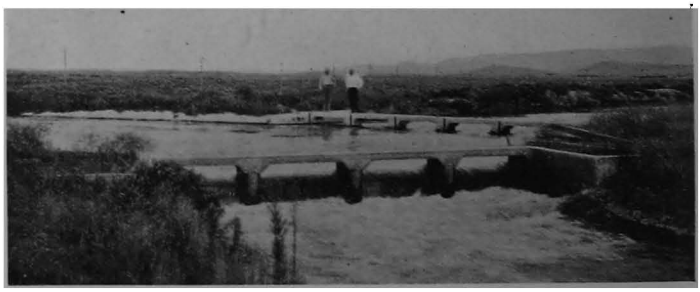


Fig. 4.

Discharge from above station. The first lift canal, in foreground, carries about 160 c.f.s. and 570 c.f.s. is passing on to pumping station No. 2.

POWER DEVELOPED PRIMARILY FOR IRRIGATION.

While the area of irrigated land in the United States depending entirely on pumped water is large, as has been indicated, by far the greater part is in relatively small areas where the pumping is done by small steam, oil or gas engine plants or with electric power purchased from power companies. The instances in which hydraulic power has been developed primarily for pumping water for a specific project are not very numerous. The most prominent example is probably the Minidoka Project, constructed by the United States Reclamation Service on the Snake River in southern Idaho. Water for this project of 120,000 acres is diverted from Snake River by a combined storage, diversion and power dam, 86 feet in maximum height, into two canal systems, one on the north side of the river supplying 69,000 acres by gravity and 3,500 acres by low lift pumps and one on the south side carrying water 15 miles to a series of 3 pumping lifts of about 31 feet each, which furnish water to about 49,000 acres. Part of the area is supplied at each step, the capacity of the pumps at the successive lifts being 735 sec. ft., 617 sec. ft., and 433 sec. ft.

Power for this pumping is developed at the dam. Prior rights to a part of the natural flow of Snake River make it necessary to let water pass to projects farther downstream throughout the irrigation season, and with the available head of 46 feet this flow furnishes power for a 7,000 kVA. plant. Power is also used in some parts of the project for drainage pumping, one plant having a capacity of 50 sec. ft.

The large amount of power available in the non-irrigating season and the low price at which it can be furnished as a by-product has encouraged the use of electric appliances on this project to a remarkable degree, and considerable notoriety has been won by the heating of buildings by this method. Extension of this particular use is no longer encouraged as the market for energy in other and more profitable lines will soon equal the supply. The energy is sold to municipalities, distributing companies, mutual companies organised by farmers, and in some cases direct to the consumer.

Another interesting form of development of hydraulic power primarily for irrigation is found in the " direct pumping plants " which have been installed on various projects where a drop in a canal can be utilised to furnish power to pump part of the water to a higher level and turbine and pump are directly connected and practically automatic. Developments of this type on a very

Fig. 5.

Outlook direct pumping plant at drop from Yakima main canal to head of Snipes Mountain lateral; power head 45 ft., pumping head 109 ft.; two turbine driven, centrifugal pump units of 500 and 220 H.P.

Fig. 6.

Two types of well pumping plants. At left, San Joaquin Valley, California At right, Salt River Valley, Arizona.

large scale have been proposed in several rivers where a good dam site has been found at a point favourable for the head of an irrigation system. Such a proposal has been made as one alternative in the construction of the Columbia Basin Project referred to later.

CO-OPERATION OF POWER AND IRRIGATION INTERESTS.

The third class is well illustrated in the South Yuba-Bear River system in north central California. This is a complicated system of canals and conduits receiving water from some 24 large and small storage and regulating reservoirs on the headwaters of South Fork of Yuba River, Bear River and North Fork of American River, eastern tributaries of the Sacramento River. The nucleus of this system was formed 50 years ago by the consolidation under one company of a number of ditches and reservoirs constructed in the early gold mining days for the purpose of supplying water for hydraulic mining. A law passed in 1886, prohibiting the dumping of debris from hydraulic mines into navigable streams, stopped nearly all mining operations in this region, and attention was turned to utilising the water for irrigation. Later, when transmission of electric power had become a commercial success, four small power plants were built on the two main canals. Below these plants the water was rediverted or conveyed direct by canals to foothill areas for irrigation, mining and domestic use. In 1910 one of the large power companies of California acquired the entire system and at once began re-modelling it for the greater production of power. A new 275 foot dam was built to increase the storage at Lake Spaulding, which is the lowest and largest reservoir on South Yuba River. A power canal was constructed from this dam to the head of a chain of 5 power plants to be built on Bear River and Bear River Canal, three of which are now constructed. A plant was installed at Spalding Dam and still another at a drop from the power canal to the South Yuba canal. Sufficient water is still supplied through the old canals and power plants to meet all irrigation and mining rights, but all water not so required is sent through the new and more efficient plants on Bear River.

This operation of the system has benefited both irrigator and power consumer, and it is understood that one of the irrigation districts will be enabled to provide further storage and reclaim more land largely through the power value of the additional supply as it passes through the system and the ability to sell such water as they do not need.

Fig. 7.
Places where irrigation pumping pays. Apple orchards on the Okanogan Project, Washington.

Fig. 8.
Orange grove on the Salt River Project, Arizona.

IRRIGATION PUMPING AS A MARKET FOR SECONDARY POWER.

We now come to power projects which make use of irrigation pumping as a profitable market for secondary power. We have already referred to the advantages accruing to one California utility by the use of pumping load. Abundant, cheap power, scarcity of water, ability to raise crops of high acreage value, and encouragement from progressive power company officials have all contributed to a development of irrigation and drainage pumping in central and southern California which is unapproached in any other part of the country. According to credible statements the five largest power companies serving this area are furnishing power to pump for 1,850,000 acres. One company alone has more than 9,000 pumping consumers, and contrary to the attitude of power men in some other parts of the country, they are all reaching out for more of this seasonal load. They have a dual object. As one official puts it :—" The farm pumping load is a big load, but it is from our point of view a factor of development, not development itself. If the power companies were compelled to depend upon it alone they could not exist. It is seasonal.....But the development of agricultural California means the development of an industrial California. It means bigger towns, better towns, more manufacturing, more demand for a steady use of power that will keep our generators turning and thus give us the evenly balanced, diversified demand necessary to economical and efficient operation..... Analysing 1,200 applications for agricultural service we discovered that 600 of them were for the development of new farm lands, requiring new homes.....Analysing still further we found that in Fresno County there have always been approximately two homes in the town for every home in the country, and we have found since that this is the ratio in practically every farming community of our State. It was apparent then that when we had rendered service to the 600 new farms we would be called upon to render service to 1,200 new homes in the cities and towns."

SOME FUTURE OPPORTUNITIES FOR COÖRDINATION OF POWER AND IRRIGATION.

Before closing this discussion it seems appropriate to call attention to the two greatest opportunities for the correlation of power and irrigation in the United States, both of which are now assuming national importance. We refer to the future development of the Columbia and Colorado Rivers.

Fig. 9.
A residence street in Yakima, Washington. A sample of the urban home that rise in the sage brush.

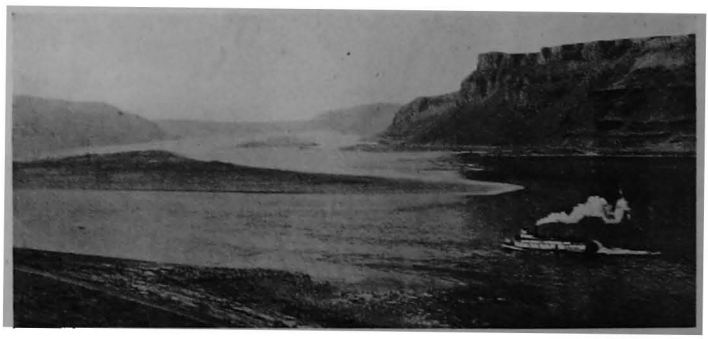


Fig. 10.
Columbia River below Priest Rapids.

COLUMBIA RIVER.

The Columbia River drains an area of 259,000 square miles in the six States of Washington, Idaho, Montana, Nevada, Wyoming and Oregon and the Canadian province of British Columbia. It has an annual discharge exceeded by only two rivers in the United States—the Mississippi and the Ohio. From the headwaters of its two main forks, Clark's Fork and Snake River, in the heart of the Rocky Mountains to near the west line of Idaho both branches have interspersed opportunities for power and irrigation development, many of which have been improved, especially on the Snake. In this section it is generally agreed freedom shall be given to the fullest irrigation expansion, but much opportunity will remain for power and their proper coördination.

From the west line of Idaho until the main river passes through the Cascade Range and out of the arid belt, there is a fall of approximately 2,000 feet, which makes possible the development of over 2,000,000 W.H.P. all the year around and enormous blocks of seasonal power at low cost. The problem is to find a market in this sparsely settled region. We have already noted the characteristics of the Columbia's flow and how remarkable its monthly discharge curve coincides with the monthly irrigation demand curve of that particular section of the country. Nowhere else is there such opportunity to provide very cheap secondary power adjusted to irrigation schedule.

This section of the Columbia Valley is distinctly arid. The rainfall averages but six inches per annum. The soil is a rich volcanic ash which, given water, will produce every crop that can be grown in the temperate zone. Sugar beets, tobacco, corn, all the staple grains and vegetables produce abundantly; alfalfa yields four cuttings to the season; cotton, even the Egyptian long staple variety, has come to full fruition by the middle of September, and apples, pears, cherries, and other deciduous fruits have made the adjoining Yakima, Wenatchee, and Okanogan projects famous.

Throughout this section the banks of the river are too high for feasible gravity diversion, but with lifts of 100 to 400 feet hundreds of thousands of acres can be irrigated. The proposed Columbia Basin Irrigation Project, which is receiving serious consideration, would irrigate some 1,750,000 acres of this land in the "Great Bend," either by gravity diversion above this section and a 20,000 second-foot main canal, or by a huge direct pumping plant. A power company which is planning to develop 300,000 W.H.P. at

Fig. 11.
Sage brush plains of the Columbia Basin.

Fig. 12.
The desert reclaimed by pumping from the Columbia. Mowing alfalfa.

Priest Rapids, a short distance above the junction with Snake River, contemplates the irrigation of 100,000 acres by pumping with very cheap secondary power, and a similar development at Umatilla Rapids, further down stream, is under investigation by the United States Reclamation Service.

The real problem on the Columbia is :—To what height can we pump without overburdening the farmer with operating costs? To what limit is it possible or justifiable to go in relieving secondary power of development costs and other overhead charges in order to provide phenomenally cheap power for pumping and to secure the benefits of a large and prosperous agricultural community?

COLORADO RIVER.

The scenic wonders of the Colorado River and its Grand Canyon are world renowned, but until recent years few persons have had any vision of its potentialities as an empire builder. Its mile-deep canyon and great annual floods inspired awe and respect for the destructive forces of Nature, but no thought of peaceful beneficence or of the role it now seems destined to play in the development of the great southwest. From the head waters of the Green to the Gulf of California, the river is 1,750 miles long and drains an area of 244,000 square miles in the seven States of Wyoming, Colorado, Utah, Nevada, New Mexico, Arizona, and California, and the Mexican States of Sonora and Lower California. The upper section of the river to the Utah-Arizona line supplies about 86 per cent. of the annual run-off, has power possibilities aggregating 2,000,000 W.H.P., and contains 4,000,000 acres of irrigable land 35 per cent. of which is now irrigated. In this section are numerous reservoir sites which can be developed to control the flow of the river and main tributaties either for power or for irrigation in the section.

The middle section furnishes about 8 per cent. of the annual run-off and contains about 250,000 acres of irrigable land, all on tributaries. The main river in its course through 500 miles of almost continuous canyon falls about 3,000 feet and 4,000,000 W.H.P can be produced by utilising the full head and average annual run-off. In this section and immediately above are three available reservoir sites. Glen Canyon, just above the Utah-Arizona line, Boulder Canyon at the elbow where the river turns from a westerly to a southerly course, and Mohave Valley at the lower end of the section near the southern extremity of Nevada. Dams of the unprecedented height of 600 feet above stream bed and corresponding reservoir capacity exceeding 30,000,000 acre feet have been

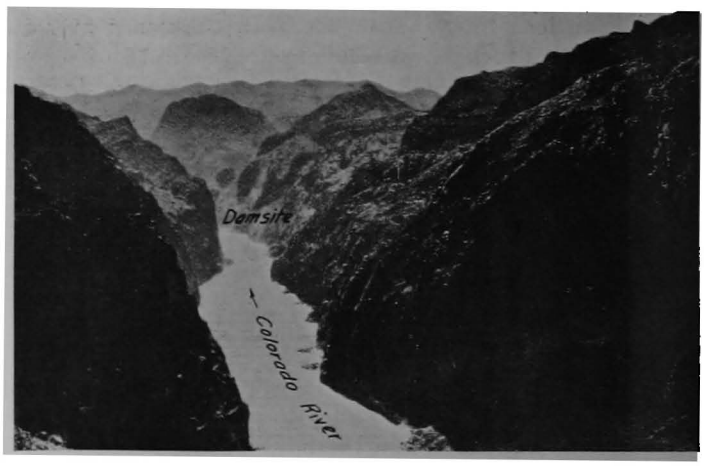


Fig. 13.
Colorado River. Proposed dam site in Black Canyon for Boulder Canyon Reservoir.

Fig. 14.
The lower Colorado in flood. View taken from levee of Yuma Project with swirling counter current undermining the levee at depth of more than 40 ft.

proposed at both of the first two sites. Either would effect complete control of the stream and furnish power for a plant of more than one million W.H.P. installed capacity. Glen Canyon is ideally located for regulating the entire canyon section for power, but the safety of its foundation for so high a dam has been questioned by some. Boulder Canyon is better located for effective control for irrigation and flood protection in the lower section and is nearer the great southern California power market. Mohave Valley can provide 10,000,000 acre feet storage with a 200 foot dam, which would be ample for irrigation and flood control but would be comparatively valueless for power production.

Fig. 15.
The Colorado Delta Country. View on the Yuma Project.

The lower section of the basin, including the Gila watershed and the Imperial Valley, contributes the remaining 6 per cent. of the annual run-off. Its power possibilities are confined to the upper Gila and its tributaries and are unimportant in considering the problems of the main river. It contains, however, about 3,000,000 acres of irrigable land; some say much more—the most productive in the basin, about 1,000,000 acres of which are already under irrigation. Nearly 2,000,000 acres are in the alluvial valleys and delta of the lower river and in the famous Imperial Valley, which, cut off from the Gulf by the delta cone and dried up by evaporation, lies below sea level. All these lands must be protected by levees, and the Imperial Valley in particular lives in dread each year lest the great meandering silt carrier, in building up its delta, will shift its course, break through their lines of defence, and discharge its whole flood into their valley, as it did in 1905 and continued to do until 1907 when it was finally turned back to its channel at a cost of over two million dollars. The insistent demand for flood control,

the pressing need for irrigation storage to increase the late summer supply which is now becoming short, and the realisation by southern California that great as its resources are it must soon look for power outside of its own State—all these have aroused the country to the possibilities of this great national asset.

The seven States in the watershed have framed an interstate compact or treaty designed to avoid litigation over water rights, particularly as between the States of the upper basin and those of the lower. This compact has been ratified by all the States but Arizona.

The Reclamation Service, long engaged in the investigation of storage possibilities in the watershed, urges as the first step in comprehensive development the construction of the great Boulder Canyon dam and reservoir by the Government, its cost to be repaid by sale of power. This plan has the support of many. The Mohave site is favoured by others who would provide at first only for present needs of flood control and irrigation and leave all development of power to be worked out by private corporations under the regulations and licensing method of the Federal Water Power Act. Certain broad principles have received general acceptance.

(1). In the development of the river requirements of flood control shall come first, irrigation second, and water power third.

(2). All developments in the canyon section shall be so located and designed that they will fit into a plan for complete economical development of the head available in the section.

(3). Eventually the river shall be regulated above the canyon section for power and re-regulated below that section for irrigation.

(4). Storage and regulation on the upper river and tributaries shall proceed as the local requirements demand but must not interfere with the general plan for the entire basin.

A Bill embodying the main features of the Reclamation plan is now before Congress. It is too early to say what action may be taken or whether there will be any definite steps for several years, but whenever the initial step is taken and whether by private capital or the Government, we have cause for gratification in the fact that the public has grasped the idea and that haphazard self-centred, wasteful, and frequently antagonistic developments, on a great natural resource like the Colorado will no longer be permitted.

With power and irrigation working in harmony we shall soon see this Twentieth Century Nile serving its people in field, workshop and home in a way never dreamed of by the ancient Egyptian.

RÉSUMÉ.

Le développement de l'agriculture dans la plus grande partie de l'Ouest des Etats-Unis dépend de l'irrigation et de la quantité d'eau fournie par les fleuves et rivières, et tout cours d'eau, abondamment alimenté par les neiges des grandes altitudes. Ces cours d'eau présentent de grandes possibilités pour leur aménagement au point de vue hydraulique. Il est nécessaire, autant pour l'utilisation de la puissance hydraulique que pour l'irrigation, de régulariser les cours d'eau par des réservoirs, mais tant que les besoins saisonniers ne diffèrent pas il y a un conflit d'intérêt entre ces deux facteurs. Cette note essaie de démontrer comment ces différences peuvent être réduites, en employant pour l'irrigation un pompage dans des limites raisonnables. Elle essaie de démontrer également la très haute importance d'une co-ordination de l'irrigation et de la puissance hydraulique dans l'exploitation des cours d'eau, et donne pour exemple de leur relations une brève description de plusieurs types à puissance et irrigation combinée. En concluant l'attention est attirée sur les grandes possibilités de relations réciproques de ces deux facteurs dans la future exploitation des fleuves Columbia et Colorado.

WATER POWER PRODUCTION—GENERAL

DISCUSSION

Chairman: DR. F. A. GABY (CANADA)

Thursday, July 3rd. *Afternoon Session*

The CHAIRMAN, in opening the session, remarked that the papers which were being presented that afternoon were very numerous, being forty-three papers in number, and were presented by various members of the organisations and engineering bodies of the various States in the world. They covered almost every phase of water power production. They dealt with investigations which had been made, and with records which had been compiled by the various States in their hydrographic surveys, and they included technical discussions on the changes in regime, and in flow, due to the development of rivers for power purposes. They dealt also with the design and construction of waterways, and with the design, construction and use of particular novel features in connection with the development of equipment for water power production. The papers also included various descriptions of novel plants, which had been installed by various corporations and public bodies throughout the world. Water power production was a very broad subject, which embraced practically the whole field of engineering design and included the economics of water power developments, not only for the generation of electrical energy for general distribution and transmission, but also for industrial purposes.

CAPT. H. VON HEIDENSTAM *(Sweden)*, in presenting Mr. G. Berg's paper on *Recent Practice in Lake Storage, and What the Storage Means to Water Power Utilisation in Sweden*, said that the problem in general was one of adjusting the varying supply of water to the varying demand, and of making the entire run-off, if possible, available, by storage, for consumption in the turbines, according to varying load and demand during the day, week or year.

A plant, built for only the natural lowest run-off was always much less economical in cost per kWh., than a plant with full storage possibilities (assuming sufficient demand for the power), and the problem assumed the most varied aspects, according to hydrological and natural conditions and the nature of the demand.

With reference to the paper by Lt.-Col. C. M. Norrie on *Factors of Efficiency in Hydro-Electric Development*, he endorsed the author's emphasis on the important part which the civil hydraulic engineer should play in all hydro-electric development, and in the planning and construction of each particular plant. It was absolutely necessary, of course, that all those technical factors of efficiency which lay in various combinations of turbines and generators, and in various types of turbines and generators and machinery, should be looked into properly, but those factors only accounted for a comparatively small percentage of higher or lower efficiency. The actual planning of the plant as a whole must lie with the hydraulic engineer, working in conjunction with the electrical and mechanical engineer. With him rested also the important storage question and the utilisation of the run-off, which might lead to an improvement of 100 per cent. and more in the economy of the plant, and cost per unit produced. The whole question of efficiency in utilisation of the

run-off, by storing during the day, week, or year, was one which gained in importance, the more water power was developed in a country.

DR. H. G. ACRES *(Canada)*, in presenting his paper on *The Generation of Hydro-Electric Power in Canada*, said that if this Power Conference were to stand by itself, they must all look upon it more or less as an episode, which would have some very joyous memories connected with it, but which, beyond that, would have no very great value for the future. If, on the other hand, this gathering should prove to be an inaugural function, and the forerunner of many similar gatherings to come, then it must be regarded as a very important event, and one which was fraught with great possibilities, as having primarily to do with the future advancement of the hydro-electric and steam-electric arts, and therefore with the advancement of civilisation in general. The reaction of these two factors would also beneficially affect the transcendent issue of world peace. Assuming that this latter basis of conception was the proper one, he had prepared a paper which was not a detailed exposition of the art, but a perspective view of the Canadian situation. He had endeavoured to paint in primary colours the story of Canada's advancement in the art since Switzerland had paved the way in 1905, and he hoped his friends from Switzerland would reach the conclusion that Canadians had been apt pupils.

In closing, he suggested that they should endeavour to instil this idea of perspective rather than the discussion of contentious details into the proceedings of this, the inaugural Conference.

MR. J. WILLOUGHBY MEARES *(India)*, emphasised the necessity for a rain gauge which recorded not only the amount of rainfall in a day, but also the intensity. The importance of this was especially noticeable in India, where there was a rainfall of 36 in. in one day, and 500 or 600 in. a year.

He had referred in his paper, *National Water Power Resources of the Indian Empire*, to another paper read before the Institution of Civil Engineers,* in which the problem of the intensity of rainfall was solved in a very simple manner. He had had such a rain-gauge working under monsoon conditions in India, and it had worked perfectly. Water was the absolute lifeblood of Northern India, where the greater part of the enormous rainfall which fell along the Himalayan Range went to the sea unutilised in any way. There was very little developed in India, but there was an immense amount of irrigation. The water which fell, however, fell in such a short time—all in the course of three or four months—that it was quite impossible to utilise the greater part of it.

The Indian Public Works Department had rather smiled at him when, in the Triennial Report of the Hydro-Electric Survey, he had made what might be termed a wild suggestion but it was a suggestion which he gathered had taken practical root in America. The River Indus, which had perhaps as big a flow-off as almost any river in the world, except the Mississippi and a few others, had once suffered from a local earthquake in Gilgit, where there was a gorge rising to a height of 1,500 or 2,000 feet or more. The sides of the gorge had fallen in, and blocked the valley of the River Indus completely to a depth of considerably over 1,000 feet, and for half a mile or so of the valley. A certain amount of the water coming down had been able to get through the debris. It was like a dam built with masonry on modern lines; there had been a certain amount of leakage through it, but it had very soon got sufficiently water tight from the sand, and so on, to allow the water to rise to the full height of that 1,000 feet. Then, of course, when it had gone over the top, the whole obstruction had been washed away, but during that short period it had

* Selected Papers, No. 2, of 1923 (Telford Premium): The Experimental development of an automatic integrating "intensity" rain-gauge without clockwork.

stored up the rainfall of the whole monsoon of four months completely, and the afflux had gone back a matter of 250 miles. The quantity of water stored had been simply inconceivable. If there had been any diversion channel, either through that rockfill, or through the side of the hill, by which the average amount of water coming down the river during any one season could have been diverted round the dam, they might have permanently regulated a great river like that by those means. The sides of a valley could be blown in. It might sound absurd, but it had actually been done by Nature two or three times. Gohna Lake on the Ganges in Garwhal was another well-known instance of recent occurrence.

MR. W. J. E. BINNIE *(Great Britain)*, in introducing his paper on *Problems Relating to Run-off, Storage, and the Allocation of Catchment Areas in Great Britain and Ireland*, said that it was a matter of interest that the conditions in the Straits Settlements, for instance, were very similar indeed to the conditions which prevailed in England with regard to reservoir storage. They were quite different from those in India. In the Straits Settlements, which was very nearly on the Equator, there was an abundant rainfall up to 100 to 120 inches, which was distributed very fairly throughout the year. In many other countries, Governments had taken a great deal of interest in this question of power development. The consequence was that there were many records of the actual flow of rivers; but in Great Britain it had been left entirely to private enterprise to accumulate statistics, and owing to the peculiar nature of British legislation, it was difficult to get those statistics made public. The reason for that was that the statistics had nearly all been accumulated by Municipalities, who were under an obligation to discharge compensation water to the river. That compensation water had been fixed on certain hypothetical figures which had been placed before Parliament; and as time went on, in the majority of cases those figures had proved to be erroneous. At the present time the Ministry of Health were doing their best to accumulate statistics dealing with run-off, and knowledge would be greatly increased in the future.

In the absence of actual gaugings of streams, water engineers in this country had been driven almost entirely to depend upon rainfall records. Having got these fluctuations of rainfall from month to month, there were available a certain number of accurate gaugings in different parts of the country, and their relation in any one month between the rain which fell and the run-off was fairly close. In four or five cases he had compared diagrams, which were based entirely on deductions from the rainfall with actual gaugings established on the river, and had found that they had agreed with a sufficient degree of accuracy to make it possible to arrive at the approximate amounts of storage required to equalise any desired proportion of the average run-off of the river. In order to store the average run-off of a river throughout a very long period, it would be necessary to have a storage reservoir of almost unlimited capacity, and the question, therefore, had arisen as to what was the economic limit.

Taking an average of all Municipal Water Supply cases in this country, the rule had been arrived at many years previously that the economic storage to give was such storage as would equalise the flow of the three driest consecutive years. Generally speaking, the economic limit would depend to a certain extent on the natural conditions which obtained at any particular site, that is, upon the cost of creating storage or augmenting existing storage. Then the question arose as to what economic storage was to be given for a power proposition. When they came to consider the Highlands of Scotland, they would find there, situated at a high altitude above the sea-level, numerous lakes which presented the opportunity of obtaining storage extremely economically. In England and in parts of Wales, they would find that there was a difficulty in obtaining a sufficient amount of storage, and each particular case had to be worked out for itself. The late Dr. Deacon had given a great deal

of consideration to the actual proportion of the run-off—the average annual run-off which would be obtained with reservoirs of different storage capacity. He had spent many years of his life investigating that problem from all the gaugings which were then available, and he had published an article in the *Encyclopædia Britannica*,* which included curves showing the relation between yield and storage for varying mean rainfalls.

Anyone who wished to gain information as to what would be the best design of storage reservoir for Great Britain could not do better than consult that article.

DR. ED. TISSOT *(Switzerland)*, speaking on the economic importance of Switzerland's water power, reminded his hearers that one quarter of the superficial area of Switzerland was taken up by unproductive land. A large portion of the remainder lay at too high an altitude to have more than a limited productive capacity. It had not been till the beginning of the nineteenth century that industrial development had taken place with material benefit to the increasing population.

Up to the outbreak of the Great War, coal had been obtained almost exclusively from Belgium and Germany, but the war had so affected the price of coal (Frs. 30 per ton in 1913 and Frs. 200 per ton in 1920) that the economic situation and transport conditions in Switzerland had been seriously imperilled. Fortunately, however, the country was the possessor of a practically inexhaustible wealth of water power in the mighty network of waterways of the Alps, and the natural regulating facilities provided by the many lakes.

The utilisation of water power in Switzerland had been the result of both technical and economic development. In the middle of the nineteenth century the larger rivers were utilised for the first time. The flourishing industry of the weaving and spinning of cotton and silk owed its existence chiefly to the development of cheap water power.

The introduction of electric transmission of power had marked the beginning of a new era, by rendering the choice of factory site independent of the position of the source of energy.

The study of hydrological conditions in Switzerland had been facilitated by an extensive system of meteorological stations. The average rainfall of the whole of the country was 1,300 mm. Rainfall statistics, however, gave no indication of the suitability of a river for power production; the Department of Waterways of the Swiss Home Office had therefore established measuring stations on their rivers to the number of 659, and had carried out extensive research in the matter of available head.

The exploitation of water power in Switzerland had now reached an advanced stage, 178 out of the 6,870 power stations in existence, having an output of more than 500 H.P. The total output was about 3·2 milliard kWh.

There had been a noticeable increase in the use of electricity for cooking and heating, and industries with large heating requirements frequently produced steam electrically during the night and stored it up for use during the day.

The price of electricity for lighting and power purposes was sufficiently low to oust any other source from the field.

With reference to the railways, Dr. Tissot said that the narrow gauge lines were almost completely electrified, as were various sections of the normal gauge. The power required for the electrification of the entire Swiss Railways amounted to about 1.3 milliard kWh., the maximum power required being in the vicinity of 800,000 H.P., and the average 300,000 H.P. The necessary power stations had been foreseen by the authorities of the Swiss Federal Railways, and had, in some cases, been started on. Single-phase A.C. at 16⅔ cycles had been selected.

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* *Encyclopædia Britannica* (12th Edition), Volume xxviii., page 391.

The utilisable water power in Switzerland was estimated at a minimum of three million H.P., and a maximum of eight million H.P., capable of producing twenty milliard kWh. annually. Barely 15 per cent. of this power was being utilised, so that there were enormous reserves.

Switzerland was exporting about 460 million kWh. annually, part of which supplied only a summer load. This exported power was chiefly used for electro-chemical purposes.

In a densely populated country like Switzerland, where every square foot of ground was made use of, the erection of power plants and the making of artificial storage lakes were fraught with difficulties of a political and economic nature.

Mr D. Halton Thomson *(Great Britain)*, laid emphasis on the fact that the minimum dry weather flow had no reliable relation whatever, either to the size of the drainage area or to the average flow. It was absolutely unsafe to apply an ascertained relation between the minimum and the average flow to another drainage area, even if the watersheds were contiguous and under the same climatic conditions. As an illustration, he quoted the River Exe in Devonshire, in the south-west of England. The minimum flow per unit of drainage area at the lower of two stations on that river, was four times that of the minimum flow per unit of drainage area at the upper station. A further inference could be made from that relation. In order to account for the increase of the minimum dry weather flow from 8 per cent. to 33 per cent., it was a matter of simple calculation to show that in the lower half of the basin taken alone, the minimum dry weather flow must be no less than 60 per cent. of the average run-off. Thus, by comparing the upper and the lower halves of the basin, they could see that the lower Exe had a minimum flow per unit area of no less than 7½ times that of the upper half of the basin. The explanation for this extraordinary difference was entirely geological. The upper Exe basin comprised almost entirely (83 per cent.) impervious rocks, with practically no ground storage whatever. On the other hand, more than half of the lower Exe basin comprised the series known in Great Britain as the New Red Sandstone, which provided an enormous underground storage. He wished to emphasise that accurate and continuous stream gaugings were badly needed, and that it was very important to make a study of the geological conditions. These remarks applied to Great Britain in particular.

Mr. A. E. Kitson *(Gold Coast)*, referred to forested countries with high rainfall, such as the thickly timbered zones of portions of the tropics in West Africa. There the forest was being steadily destroyed by constant encroachments for cultivation. The ground was thus exposed to much more rapid denudation than previously. Assuming that the usual allowance for flow-off was made for an area of this kind, it could be seen that under the changing conditions the flow-off would be progressively increased, owing to the decrease in absorption by the soil and plants.

Again, in certain parts of the tropics, particularly in Africa, in the transition zones between thick forest and open forest or grass lands, and in all the open country, there were seasonal burnings of the grass and annual growth of bushes and shrubs. After the early tornadoes preceding the wet season, the grass and other vegetation grew rapidly in those previously bare-ground areas. With increasing strength of vegetation—especially the grass which grew varyingly to upwards of 20 feet in height, with stalks up to 2 inches in thickness—the flow-off decreased steadily. Thus, from a very large flow-off in the earlier period—varying with the nature of the soil and configuration of the country—there was much less in the later period.

Besides, since in some areas, in abnormally wet seasons, the annual crop of grass did not dry sufficiently to admit of being burnt in the dry season, the flow-off was obviously much less during the year than in

a normal season. Therefore, observations in such country needed to be very carefully made, and at the best the results left much to be desired.

Another factor which needed consideration was the influence of insects upon soils. In some parts of the world, for instance in Southern Gippsland, Victoria, Australia, much of the country had large sub-surface holes (small caverns), some of them upwards of 3ft. by 2ft. by 2ft., made by land cray-fish, and also long deep tubes made by giant earthworms. The soil was a loam, mainly derived from clayey sandstones, sandy shales, and mud-stones. The rain from occasional heavy showers, which in the usual type of undulating country gave a strong flow-off, in this country gave merely a negligible one, for much of the water was trapped, thus causing slow percolation, with increased loss by plant absorption and evaporation. A knowledge of the nature of the rainfall of the country was, therefore, of importance under such conditions.

The same remarks applied to the sandy clay country, riddled with myriads of worm burrows, such as was found in parts of the Gold Coast and elsewhere.

Thus, apart from the configuration of the country and the nature of the soil, etc., the factors mentioned had to be considered seriously in connection with flow-off measurements in certain countries.

THE CHAIRMAN, then called upon Mr. Norsa, of Italy, to present the paper entitled, *The Co-existence of Hydro-Electric and Steam-Driven Generating Stations, as Affecting the Economy of Production and the Necessities of Storage and Reserve.* At that time, when hydro-electric developments were becoming exhausted in a number of countries, it was a very interesting topic to consider in engineering circles the co-ordination of steam and hydro-electric plants and their economy.

MR. RENSO NORSA *(Italy)*, in presenting this paper by Mr. G. Motta, stated that for power economy in Italy, they relied exclusively on water. They had no coal and no oil. They had gone far in water power development, and had made their developments in such a way that they ought to be able to run their plants every month of the year. Unfortunately, however, such conditions were always more or less theoretical. These points had been taken up by Mr. Motta in his paper, in which he had considered what the function of the steam station should be in a country like Italy, where they had necessarily to do all they could with water, and to use as little other power as possible. Mr. Motta held that even in Italy, it was impossible to do without the use of steam stations as reserve stations in the sense he would explain. There were two principal functions of the steam station with regard to the hydro-electric station: first, the integrating function of hydro-electric deficiencies, and secondly, the function of reserve.

MR. J. HAROLD ARMFIELD *(Great Britain)*, said that a previous speaker's references to the River Exe, and the rmarks of another speaker in connection with the run-off of rivers, had brought to his mind some information which he recently obtained in respect of the Wiltshire River Avon. There the whole of the valley was of a very pervious material. It was chiefly chalk in the upper reaches, and gravel in the lower. He had no definite figures, but the same result was noticed—that the minimum flow in the lower reaches was very much more regular than in the upper reaches. The explanation that had occurred to him was that the water sunk into the ground in the upper reaches, and that the underground storage did not become operative until the lower reaches. In other words, the water was absorbed into the ground in the upper reaches and came out as springs lower down, thus equalising the flow.

Another point was in connection with vegetation. He had noticed in gauging the river, that although up to the end of May, 1923, the rainfall had been very well maintained, early in April and in the early part of May, there had been a definite falling off in the flow, due, he supposed

to the rapid growth of the crops, which indicated that evaporation in that case had been the dominating factor.

MR. JOHN R. FREEMAN *(U.S.A.)*, said that there had been three important stages of water power development. There had been, first of all, the small units for driving sawmills and gristmills—seldom more than 30ft. in head, and seldom of more than 50 or 60 H.P. Then had come the cotton mill stage, beginning nearly 100 years ago, with units still small. The quantity of water sufficient to run a cotton factory at that time had been only 60 H.P. net.

Finally he referred to the Pitt River Power Plant, where, in one turbine of 40,000 H.P., there was more power developed than in all the turbines of the great cities of Lowell, Lawrence, and Manchester put together. The modern turbine was a very interesting machine. It was not so much the product of scientific designers as a development through the school of hard knocks. The first of the water power pioneers had been Boyden. He had been a man of wonderful precision, and extremely ingenious. Feeling that something better than the old high-breast water wheels should be found, and after studying the literature on the subject, more particularly the literature of France, he had taken the turbine and improved it in many ways. He had developed efficiencies which were claimed to be about 90 per cent., and, seventy years ago, he had introduced spiral approach and top suspension. It had been the experiments for determining the efficiency of some of those early turbines, for which Boyden claimed 92 per cent. efficiency, which had led to the famous Lowell hydraulic experiment, and the development of the Weir formula, which had been used for sixty years.

Francis had reversed the direction of flow, turning it inward instead of outward, and had called it a centre vent wheel. That had showed up very well in the experiment. Swain had added to the inward discharge, the downward discharge. He had had the good fortune to call on one of the most notable of engineers, Hiram Mills. Mills was a very skilful hydrologist, and had advised Swain on many matters, for instance, about increasing the height of his turbine and improving the relative area of inlet and outlets.

McCormick also was entitled to a great deal of credit. He had not been bound by tradition.

Another man who had played an important part in the development of present-day practice was James Emerson, who had established a business for testing small turbines, which were mostly in use at that time. That, in course of time, had led to the building of the Holyoke Testing School, which for forty years had taken a very high place in the development of the efficiency of their turbines.

When they remembered that a turbine would run twenty-four hours a day, week after week, and year after year, for many years, with hardly any attention, it must seem that standard practice had arrived pretty nearly at the end of the road. He did not see how they were going to get any further than the present 93 per cent. useful effect which they had in some of their large turbines.

They needed a better understanding on the part of the public towards hydro-electric development. Their legislators also needed educating, and he thought that was a point where current practice was not as far advanced as it should be. He found that there was a great deal of popular misapprehension in regard to water power. There were many people who seemed to think that water power development was an ever flowing source of wealth, and that all that had to be done was to gather the harvest. The public at large had very little idea of the risks involved.

With regard to rainfall and run-off, it would seem to be wholly a question of the particular piece of country under consideration. In one part of a country they would get conditions which were very much like those of a slate roof, and they would get conditions in another part of the country which were very much like rain falling on a cinder bed.

He had come across something very interesting in his study in Southern California, in the extreme south-west corner of the United States. He had been studying the question of municipal water supply there. In order to guarantee a sufficient water supply, the reservoirs had to be large enough to carry water in storage for twenty years, and they had to catch the great flood which came with wonderful regularity about once in ten years. Why there should be just that one big flood once in ten years he could not understand. He had examined the old Spanish records for 110 years, and they showed that once in every nine, ten, or eleven years a big flood occurred. He could find no logical reason for that coincidence. A peculiar fact was that these great floods came at about the culmination of the sun spot period.

MR. W. T. HALCROW *(Great Britain)*, referring to Scottish water powers which had already been developed, said that the first station had been construction by the British Aluminium Co., Ltd., at Foyers some thirty years ago, for the production of aluminium, and it had been in use continuously ever since. The second development had been at Kinlochleven where a catchment area of 62 square miles, having an average rainfall of about 80 inches, was made use of with a head of 940 feet. There, power to the extent of 25,000 H.P. from generators had been generated continuously throughout the year. Those works had been in operation since 1909.

The latest development to be undertaken by that Company was known as the Lochaber Water Power. An Act of Parliament was obtained in 1921, and steps had been taken to go ahead with the construction of the works in 1924. This development would be the largest to be undertaken in Scotland. The catchment area was over 300 square miles; the average rainfall some 75 inches, and the head which would be obtained was 800 feet. The average power would be about 72,000 H.P., but in years of ample rainfall it would be possible to develop 100,000 H.P.

One of the main features of this development was a pressure tunnel, 15 miles long and 16 feet in diameter. The British Aluminium Co., Ltd., had no fear for its success, because the nature of the rock through which it would be driven was of the best.

MR. FREEMAN, said that he had been surprised that fear was being expressed about the pressure tunnel. They had one 300 feet deep right under the centre of New York for the whole length of the island. The pressure of that tunnel was such that it would raise water to the tops of the very highest buildings, 300 feet above sea-level. The water was carried beneath the Hudson River from the Catskill Aqueduct in a pressure tunnel which was 1,000 feet and more below the level of the river. They must have had over twenty miles of pressure tunnels in the Catskill Aqueduct supplying New York, and he did not think any engineer connected with that work had the slightest fear about any of them. It was a question of first studying the geology of the country very carefully, making careful borings, and then making very thoughtful engineering designs.

THE CHAIRMAN, said that a good many pressure tunnels had been constructed and had been in use for many years in Canada and in the United States with perfect success, so far as their operation was concerned. It was only in those cases where certain factors had been left out of calculation that the result had been a failure.

MAJOR HJ. JOHANSEN *(Norway)*, referring to Mr. B. Stuevold Hansen's paper on *The Financing of Loans for Power Development*, said that in that paper the author made three proposals for raising loans for development of water power in Norway.

The main feature of one of these proposals was that when raising loans, the credit should be based on water power instead of on gold. There

had been a proposal made to admit bank notes based on water power instead of on gold, but he did not think it would be advisable to go so far as that.

THE CHAIRMAN, expressed a fear that on such conditions those countries which had all the power would have all the money. Canada would be very well off under such a scheme.

In Canada, they had had to do a great deal of very intensive development, because in the central portion of that country for about 1,000 miles in length, they had no natural supplies of coal, and but little oil. In that section, and, as a matter of fact, in the whole of Canada, some 93 to 94 per cent. of the power produced and used for industrial purposes was produced by water power.

Development had been very intensive in the case of the Ontario Hydro-Electric Power Commission. They had approximately 600,000 H.P. in one single plant, having units of 55,000 H.P. capacity. They had had a unique problem to solve in connection with the operation of that plant. In the first place, they had had to contend with a large quantity of ice which, for two or three months in the year, was transported down the Niagara River. In order to have the plant in continuous operation, it had been necessary to separate the ice from the water. This had been successfully done. A new type of intake had been designed by the Commission's engineers, which was approximately a deflecting dam, with tubes which collected the water extending out into the bottom of the river, so that the velocity of the water carried the ice past the intake. They had a canal some 12½ miles in length, of which 4½ miles was a reversed stretch of the Welland River. This had to be excavated to more than 35 feet in depth. Seven miles of the canal were concrete lined with a smooth surface, in order to reduce the co-efficients of friction.

The Commission had installed ten 60,000 H.P. turbines for the operation of this plant. The efficiency of those turbines was some 93½ per cent., which was the highest which had been obtained in turbine design.

THE CHAIRMAN then closed the session.

COL. B. C. BATTYE *(India)* (communicated): Owing to the failure of a pressure tunnel in connection with the Ritom Plant in Switzerland, there appeared to be a certain amount of nervousness on the part of engineers in some countries with regard to the use of pressure tunnels generally. He thought it would be a good thing if the Conference could clear up any cases of misunderstanding of the very important question of pressure tunnels for use in connection with power plants.

There was another suggestion he wished to make: It had been the custom for many years past in India to use the expression "Cusec" for cubic feet per second as the unit of flow. He suggested that this be made an international unit, at any rate amongst those nations using foot pound second units, and also that the unit of storage for power purposes be standardised in the future as a "Cusec-day." In the various reports submitted to the Conference, all sorts of different storage units were quoted, from gallons to millions of cubic feet, acre feet, cubic metres, etc., and in none of those units was it possible to visualise either the amount of storage involved, or what was more important, the resulting flow available. If the "Cusec-day" were standardised, it would always be possible to visualise immediately the possible resulting flow available. For those nations using the metric system, a corresponding unit would obviously be the "Cumec" standing for cubic metres per second as the standard of flow.

To be strictly accurate, the British unit should be "Cufec," and the metric unit "Cumec," but as "Cusec" had now been standardised in many English speaking countries, including India, and was already in use by many thousands of ignorant peasants, who could not even speak English,

it would be impossible to alter this to "cufec." He therefore suggested that the international unit of flow should be:—Cu^{s}_{m} ec $= \frac{\text{feet}}{\text{metres}}$ per second; also that the international unit of storage for power purposes should be:—Cu^{s}_{m} ec-day = a flow of one Cu^{s}_{m} ec for 24 hours. Where one Cu^{s}_{m} ec-day = 86,400 cubic $\frac{\text{feet}}{\text{metres}}$, 86,400 being the number of seconds in twenty-four hours.

This system of units for storage had the great advantage of making it possible to visualise at a glance the value of any quantity of storage named; for example, the storage of 27,000 cusec-days would give a continuous flow of 270 cusecs for 100 days, *i.e.*, approximately three months, which was a very usual storage period for snow-fed projects. It was thus possible, by merely dividing by 100, to ascertain at once the approximate three months' storage flow available from any named storage.

Again—and this would appeal more particularly to pessimists—in the event of a dam bursting, we could at once estimate the probable resulting flow, on the assumption that the dam would take approximately 2½ hours to discharge, *i.e.*, approximately one-tenth of a day, the resulting flow then being one-tenth of its capacity in "cusecs."

WATER POWER PRODUCTION—
CIVIL AND MECHANICAL ENGINEERING

CHAIRMAN: MR. S. KLOUMANN (Norway)
Direktor, Norsk Aluminium Company

RECENT PRACTICE IN CIVIL ENGINEERING WITH REFERENCE TO WATER POWER PRODUCTION

OBERBAURAT Dr. ING. KARL INNEREBNER

(1). INTRODUCTION.

With regard to the water power plants at present in construction or projected in Austria, it must be stated that far more attention than in former years is paid to power plants with storage facilities. In other directions this is also shown by the fact, the " Wasserwirtschafts-Verband der Österreichischen Industrie " appointed in June, 1923, a special Committee to clear up technical and economic questions appertaining to this subject and especially also the utilisation of the waste energy for storage pumping works.

The motive for this is the growing realisation of the extraordinary advantages offered by the combination of water power plants having storage facilities with those without them by electrical interlinking.

Until the time when the Löntschwerk (Switzerland) was constructed, *i.e.*, 25 years ago, the idea of co-operation between such a storage plant (with the Klöntal lake as storage basin) and a power plant which might possibly be provided with a reservoir (the Beznauwerk, distant 85 km.) seemed to be very risky ; to-day the idea is within the reach of all.

The technical and economical advantages of such a co-operation of storage works with power works without storing facilities are so well known that it is superfluous to go further into the matter, though perhaps a number of questions regarding the technical details of installation of storage power works may be reviewed shortly in the following pages.

(2). TAPPING OF EXISTING NATURAL LAKE-BASINS.

In order to use an existing natural lake-basin as a reservoir, the installation for drawing off the working water must be placed below the level of the lake at a depth corresponding to the lowest surface level planned for the future working conditions, adding a sufficient height as a factor of safety. The water is drawn off by pipe lines,

or more often by an adit. To effect the connection of the head race with the lake basin, four ways may be adopted:

(a). Where the local conditions are suitable, the lake surface is lowered as far as necessary to permit of the work being carried out without disturbance from the water. The lowering of the lake may be effected by pumping or by letting the contents of the lake discharge through an emptying gallery. At the present moment, the lowering of the Davos lake (Switzerland) for the erection of the Davos-Klosters Power Station of the Grison Power Company for 34 m. is being carried out by pumping.[1]

On the other hand, a special emptying gallery was constructed for the lowering of the Ritom lake on the occasion of the construction of the Ritom Power Station of the Swiss Federal Railways[2] and for the emptying of the Spuller lake (Austria), used as a storage basin for the Spuller Power Station of the Austrian Federal Railways.[3]

For this method it is necessary to run a gallery towards the lake, at the required depth below the water level; at the Ritom lake the dam was 30 m. and at the Spuller lake, 11 m. below the surface of the water.

(b). Where the lowering of the lake surface becomes too difficult the jointing of the outlet conduit can be effected by piercing through, to the lake, the gallery destined to conduct the water to the prime mover, or in which the actual water conduit is to be installed. This was the case for instance at the Klöntal lake mentioned above (Switzerland)[4], at the Pochard lake (Austria) which was tapped 6 m. below the natural lake surface for driving a power station of the Corporation of Radhausberg[5] and at the Fully lake (Switzerland) with the gallery driven 27 m. below the natural water surface; in that case, however, owing to the unfavourable condition of the banks, it had to be pierced through to the lake at a depth of only 10 m.[6]

(c). Where the depth of the drawing-off point under the lake surface is not too great, or if no solid rock is present, an open trench may be used and the connection to the lake be made by dredging. Such a method was adopted at the tapping of the Walchen lake

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[1] Schweizer Bauzeitung 81 (1923) page 84.
[2] Schweizerische Bauzeitung 69 (1917) page 238.
[3] Zeitschrift des osterr. Ing. u. Architekten-Vereines 72 (1920) page 197; Schweiz. Bauzeitung 76 (1920) page 7.
[4] Schweizerische Bauzeitung 55 and 56 (1910) page 15 of the separate impression.
[5] Festschrift des osterr. Ing. u. Architekten-Vereines aus Anlasz der Feier seines 25 jahrigen Bestandes (1923) page 49.
[6] Schweizerische Bauzeitung 80 (1922) page 247.

(Bavaria)[1] and is also planned for the Achen lake works of the municipality of Innsbruck (Austria).[2] In the first case the point of water withdrawal lies 10 m., in the last one 14 m. below the lake surface.

Lastly, the water withdrawal can also be effected above the lake surface with the help of syphon pipes. Such solutions have been applied at the Kubelwerk (Switzerland), occasioning the laying of a second line of piping,[3] and at the Brusiowerk (Switzerland),[4] where, however, as I learned recently, the syphon design has been dropped and direct tapping has been chosen on account of the repeated service disturbances. For this reason, the same solution, which was also proposed at the Achen lake work, was abandoned.

The tapping of a natural lake basin by means of a gallery driven from the land side below the lake surface, serving either to lower the water level or else to draw out the water, is of especial interest, since it is a work of a great responsibility; for the complications caused by blasting (Klöntal lake), or suprises of a geological nature which may be responsible for the abandonment of the original project (Fully lake), are never absent.

Finally, the measures taken for the tapping of the Spuller lake may be described in brief.

At the Spuller lake work a special tap gallery was executed at a depth of 11 m. below the original lake surface, thus lowering the level of the lake by 11 m. for the purpose of driving the gallery for the upper water and of building the foundation of the larger of the two necessary dam-walls in a dried ditch. The tapping gallery traverses here the rocky bank which divides the basin of the Spuller lake on the south from the Sprenbach valley; this dam is to be erected on this bank so that the tapping gallery may be used in future as a bottom outlet.

The gallery has a length of 90 m. and rises towards the lake with a four per cent. gradient. At a distance of 12 m. from the gallery mouth a shaft has been constructed in which a regulating sluice has been set. The course, which runs through solid rock, at first unlined, has a cross section of about 4 m^2. In the neighbourhood of the tunnel, shafts were made during the winter through the ice covering the lake, to ascertain the configuration of the rocky ground; no definite results were, however, obtainable, the rock on the shore

[1] Zeitschrift des Vereines deutscher Ingenieure 67 (1923) page 36
[2] Elektro-Journal 1 (1921) November.
[3] A. Ludin, Die Wasserkräfte, Berlin, 1913, tome 1, page 660
[4] A. Ludin, Die Wasserkräfte, Berlin, 1913, tome 2, page 1,056.

dropping at a slope of 45 degrees for the whole depth of the water; it was later observed that it was covered at the point of construction with a layer of mud and clay 9 m. in thickness.

After the gallery had been driven forward for a length of 88 m., it was ascertained by test bore holes, made regularly in the last stages before each new attack, that the rock wall at the top was only 0·80 m. and at the bottom 2·40 m. thick; it was, therefore, possible to execute the last blasting earlier than was originally expected.

For this reason the working face of the gallery was made with 32 bore holes, loaded with 35 kg. of dynamite, and the loading was fired by electric ignition in May, 1920.

The rush of water, awaited with great interest, did, however, not occur when the smoke had subsided and the regulating sluice, previously lowered to about 0·40 m. above the gallery bottom, had been raised for thorough examination of the working face. It was seen that the dividing rock wall had disappeared, but the clay-layer now exposed was still damming the flow of water; an attempt to destroy this layer by blast shots carried out on the same day was made without result.

On the two following days nothing was done, as it was Whitsuntide. The sluice, of course, had been lowered again to 0·40 m. from the bottom and fixed in this position.

The work having been taken up again on the 25th of May the mass of clay was stated to have been moved by the water pressure to an extent of 5 m. into the gallery. Further blastings with gaspiping in 5 m. lengths and one inch diameter, loaded with 5 kg. dynamite and pushed into the clay, proved futile.

On the morning of May 26 the foreman found that the clay had advanced 15 m. along the gallery and heard a suspicious noise. He just had time to reach a safe place before the water broke through. The regulating sluice had been lowered on that day to 0·90 m. above the bottom.

The volume of water flowing through the gallery at first amounted to about 15 m^3/sec., but diminished in the course of the day to about 10 m^3/sec., the blocks being torn out and tending to obstruct the gallery. At first the water level sank at the rate of 0·10 m. per hour. After two days the lake surface was lowered by 4 m., after six days by 5 m., and after a fortnight by 8 m. The further lowering proceeded very slowly, repeated obstructions in the gallery having taken place, though they could always be easily removed.

After the lowering was completed, the gallery was completely

cleared and the flow of water regulated by a wooden gutter. Since that time the gallery has worked perfectly.

(3). SUBSIDENCE OF THE BANKS ON LOWERED NATURAL LAKE BASINS.

The lowering of natural lakes in connection with their utilisation for water power plants is usually accompanied by subsidence of the banks, which demands special attention.

Such was observed, for instance, at the lowering of the Ritom lake,[1] the Spuller Lake and recently on the Davos lake,[2] and formed repeatedly the object of theoretical studies in Switzerland.[3]

With lakes in high mountains or in lonely situations, far from habitations, such occurrences are of small importance; they may, however, have serious consequences with lakes in thickly populated districts. The use of such lakes will, however, become more and more frequent with the development and the enlargement of water power plants. It may, therefore, not be out of place to give some space to this question.

The effects of lowering a lake are seen principally in two forms; in subsidence of the banks and in the erosion of the banks of the lake by the streams which feed it.

(a). The subsidence of the banks appears everywhere; the banks consist of mud, sand containing much clay and loam, or of pure loam or clay, *i.e.*, where the ground possesses only a small permeability.

Banks built up of pure gravel or rough blocks, and therefore permeable, are not subject to such subsidence.

The important influence of the degree of permeability of the ground shows itself in different ways. If the ground be impermeable, the water contained in it is given up only very slowly. Consequently, the earth has a smaller natural angle of slope than in the dry conditions. It is, therefore, obvious that the combination of these two circumstances must lead to settling of the earth and to rupture of the banks.

In addition, as long as the lake is not lowered, the water permeates the banks evenly. If the level of the lake is quickly lowered to any great extent, the level of the water in the ground is not able to follow as quickly, if the earth is of a heavy quality. The result, therefore, is that such water is left in suspense in the banks. This

[1] Lago Ritom, Le lac Ritom, No. 13 of the Mitteilungen des Schweiz. hydrographischen Dienstes, Bern 1918, Schweiz. Bauzeitung 74 (1919) page 51.

[2] Schweiz. Bauzeitung 81 (1923) page 84, also 82 (1923) page 55.

[3] Schweiz. Bauzeitung 75 (1920) page 129,289, also 82 (1923) page 147.

gives rise to a tendency for the earth to slide down towards the lake.

A further consequence of this water in suspense may also result in such water producing a pressure which causes the banks to give way.

The masses thus put into motion as a result of the rupture are often very considerable ; it need only be mentioned that on February 7th, 1923, on the Davos lake, 900,000 m^3. began to subside, 450,000 m^3 of this disappearing completely in the waters of the lake.[1]

It should be mentioned that with rock banks, settling and subsidences of the banks do not occur.

In populated districts such movements of the banks present a considerable danger to buildings in the neighbourhood of the lake. Moreover, the lowering of the water in ground may have serious consequences for such buildings as have their foundations on wood piles which, when the moisture is removed, rot quickly.

(b). The erosion by the lake tributaries of the banks follows from the increased gradient that is given to these streams.

These have generally formed a delta at their entrance into the lake, consisting of mud, clay sand and clay gravel. If, now, the lake surface be lowered, the bed of the watercourse at the mouth of the lake does not take long to find the level of the surface of the lake.

The energy of the water in the tributary thus becomes much larger at the delta. The consequence of this is a deepening of the watercourse beginning from the lake and working backwards, producing a gradient the steepness of which is decided by the force of the water and the resistance of the subsoil.

Quite considerable ravines, the walls of which frequently give way, are thus formed. Here again the failure is due to the great weight of the moist earth, the gradient, the lag of the water in suspense in finding the new level, etc.

(4). CONCRETE DAMS.

The utilisation of natural lake basins may be effected not only by lowering the level, but also by damming and thus raising the natural lake surface. This means the construction of a storage installation.

This may consist of a dam either of earth or of masonry.

Large dams in Europe were, until recently, built of stone. All the older barrages on the continent are built in this manner, though American storage installations show the great advantages of

[1] Schweiz. Bauzeitung 82 (1923) p. 58.

concrete as building material. This method of construction is now being adopted in Europe. As examples, may be mentioned:— Monsalvens on the Jogne (Switzerland, maximum height 52 m., cubic content of dam 20,000 cubic metres, approximately),[1] Barberine (Switzerland, maximum height 77 m., cubic content of dam 200,000 cubic metres),[2] Wäggithal (Switzerland, maximum height 100 m., cubic content of dam 250,000 cubic metres),[3] Schwarzenbach (Bavarian Black Forest, maximum height 67 m., cubic content of dam 290,000 cubic metres),[4] Spullersee (Austria, two dams of maximum height 39 m. and 25 m., and cubic content 60,000 cubic metres and 20,000 cubic metres respectively).[5]

The reasons for giving up stone in favour of concrete vary in different places. Such reasons are : lack of suitable stone, lack of skilled masons and the necessity of rapid construction, especially on dams in the mountains where only few months of the year can be occupied in the work.

The concrete can be applied in two ways ; either as rammed or as cast concrete. Rammed concrete has been favoured for the barrage of Monsalvens and also for the two barrages on Lake Spuller and for that of the Strubklamm works ; the other concrete dams mentioned above are made of cast concrete.

Not so long ago, it was an accepted principle that concrete should be worked in a moist condition. Laboratory tests had shown it to be of greater strength and density than plastic concrete. Practice, however, showed that the superiority of moist concrete indicated by laboratory tests did not apply to actual building, since moist concrete leads to more defects in material than the plastic, a matter which more than counterbalances the advantages of the moist concrete. With this experience it was only a small step to go from plastic to liquid concrete.

It has been proved that a dam built of cast concrete is at least of equal strength to one built of rammed concrete. Now-a-days, in considering the question as to whether stamped or cast concrete is to be used, the strength or density is ignored and the question of economy is the deciding factor.

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[1] Mitt. über Zement, Beton und Eisenbetonbau (Deutsche Bauzeitung) 19 (1922) pages 86, 102, and 131.

[2] Schweiz. Bauzeitung 81 (1923) page 61.

[3] Schweiz Bauzeitung 77 (1921) page 85.

[4] Das Murg- und Schwarzenbach Kraftwerk in Forbach (Baden), herausgegeben von der Badischen Landeselektrizitätsversorgungs A.G. Badenwerk in Karlsruhe.

[5] Zeitschrift des Osterr. Ing. u. Arch. Vereins 75 (1923) page 61.

In the case of small dams and where local conditions are favourable, allowing of easy transport of the concrete to the building ground by light railway, the use of liquid concrete may be more convenient. For larger dams, however, where the configuration of the ground is unfavourable, preference is to be given to cast concrete. The liquid concrete is carried in a system of chutes, inclined at 30° to the work. The use of cast concrete necessitates no doubt more extensive works, and is profitable in general only on dams of large volume; but it makes for rapid work even under unfavourable local conditions.

The preparation of the foundation rock for concrete dams is, of course, the same as for masonry dams. Passing reference may be made to the method of forcing a filling of cement into the clefts in the rocky bed, thus obtaining absolute coherence of the dam with the bedrock and preventing the percolation of water to the dam foundations. This method is being adopted more and more in modern barrage building.

For draining the interior of the wall, the older barrages had an extensive network of drains as well as of inspection galleries and shafts; nowadays the tendency of the development is to cut down such drains to a minimum or even to dispense with them entirely; this is the case at the two barrages of Lake Spuller.

On the other hand, great importance is attached to the composition of concrete in order to get this as watertight as possible.

Besides the choice and the quantity of the binding materials (cement and chalk) and other additions, the grinding of the sand and gravel and getting the right granular proportion is of importance. The great influence of correct gauging on the quality of concrete has been emphasised in Switzerland by the "Kommission für Abdichtungen des Schweizerischen Wasserwirtschaftsverbandes" (Leakage Commission of the Swiss Union for Water Economy),[1] and in Austria by investigations of the "Materialprüfungsstelle der Bundesbahndirektion Innsbruck" (Department for Testing Materials of the Federal Railways, Innsbruck) under the director, M. Spindel, in connection with the questions of the construction of dams and pressure galleries. The most important part of modern building equipment for concrete walls is a well organised system for preparing the sand and gravel in such a way that the granular proportions can be safely guaranteed.

A question of great importance in the erection of concrete barrages is the shrinkage and volume changes caused by the heat of combination and subsequent cooling of the concrete. In masonry dams

[1] Schweiz. Bauzeitung 80 (1922), p. 153.

the proportion of mortar which may be subject to shrinkage to the total volume of the wall is small; therefore, the shrinkage is not of great importance. With concrete barrages it is a different matter; here the shrinkage is considerable, and the influence of the "setting heat" is also important. In this connection, mention may be made of the records of temperature, observed at the barrage of Monsalvens, mentioned before.[1] The temperature measurements were taken with 28 electric thermometers embedded at three points in the barrage wall at different heights and at different distances from the two surfaces of the wall. At the dams on Lake Spuller temperature measurements are also being taken.

The observations show that the temperature at which the concrete becomes solid lies between 28° and 40° C., depending on the temperature at the start. These high temperatures gradually decreased till they approximated more nearly to the average annual temperature in the inner portions, where the daily and the annual variations of the temperature of the outer air were hardly felt. The time taken by this cooling was suprisingly long and amounted to six months or more.

The shrinking of the concrete and the changes of volume in consequence of the variation of the temperature, mentioned before, make it desirable to build a concrete barrage not as a monolith but in separate blocks divided from one another by vertical joints. In this way the individual sections of the wall are able to comply more easily with the changes in size produced by the shrinking and cooling and prevents the occurrence of cracks.

The joints between sections may be made in a variety of ways, having regard to the conditions dictated by the foundation ground. The sections may be made to fit into one another or they may be slotted on the joint surfaces, these slots to be filled with concrete when the shrinkage is complete. Lastly, the joints may be stopped by means of elastic metal strips of say, copper. At the two dams on Lake Spuller, these three measures are used together in an ingenious combination. In this case, joints are to be filled in with cement mortar.

(5). PRESSURE GALLERIES AND SHAFTS.

As mentioned elsewhere, the head-race of a water power plant with a storage reservoir is usually developed as a pressure gallery; the reasons for this are partly technical, partly economic. A

[1] Mitteilungen uber Zement, Beton-und Eisenbetonbau (Deutsche Bauzeitung) 19 (1922) p. 131 etc.

similar solution can also be adopted for leading the water from the intake to the power station; constructions of this kind are called pressure shafts, and serve instead of the pressure pipelines commonly used.

Both pressure galleries and pressure shafts carry water under pressure. While the pressure galleries have only a low gradient of the order of 1 in 200, varying according to the frictional resistance to flow, the pressure shafts have a gradient varying between 1 in 2 to vertical according to the steepness of the hill sides and other local conditions. The pressure galleries have therefore an internal pressure at the lower end, which is only a little higher than that at the upper end, while pressure shafts have to withstand all the available fall of the installation.

The highest internal pressure in pressure galleries is therefore about 5 atm., while the highest pressure experienced in a pressure shaft amounts to 32 atm.,[1] and plants with pressures of 72 atm. are under construction.[2]

This difference of internal pressure was responsible for the fact that, while for the watertight lining of the pressure galleries concrete was, until recently, used almost exclusively, the pressure shaft had to be reinforced with an iron sheath.

Until a few years ago, the opinion prevailed that rock might be considered to be completely rigid for the construction of pressure galleries and shafts. If this opinion had been right, the lining of such constructions would have been subject to practically no stress, provided the lining touched the rock. In reality, however, even the most solid rock yields to a certain degree. The compression stresses are quite commensurable even at the small pressures met with in pressure galleries. In this connection, the measurements of the strains occurring in the pressure gallery of the Amsteg power station by the Swiss Federal Railways, resulted in valuable information.

If we now examine the straining of such a lining of a pressure gallery or pressure shaft, assuming the rock to be elastic and yielding, we find that there are very considerable tensile stresses tangential to the lining. These may be very serious if concrete has been used for the lining, since concrete alone possesses little tensile strength.

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[1] The pressure shaft of the Schnalsthal works of the municipalities of Bozen and Meran (Southern Tyrol) was planned in 1908-1911 by Messrs. Innerebner and Mayer, formerly J. Riehl, Innsbruck, Vienna.

[2] The last figure relates to the Installation of Pallanzeno, above Domodossola (Italy).

The conditions are here the same as in the theory of the permanent way of railways, where the older theory of Winckler, which assumes a rigid bed of the track, suggests far less rail stresses than would be obtained by the newer methods of calculation of Zimmermann, which assume the bed to be elastic.

This explains why numerous pressure galleries and shafts, lined only with rammed concrete, have developed leaks under the load where the rock has not itself been watertight.

Until recently such faults were supposed to be the consequence of careless construction. But since the discoveries at the Ritom works of the Swiss Federal Railways[1] and the consequent experiments carried out at the Amsteg power works, it has been recognised that the numerous failures on record (neglecting those due to careless construction) have their origin in the neglect of calculation for the yielding of the rock.

In this regard, the theoretical treatment of the problem offered valuable information,[2] adding to this the numerous practical tests of the different kinds of lining, made under the auspices of the Swiss Federal Railways at the Amsteg power station and the Austrian Railways at Lake Spuller.

Summarising all this, the present day knowledge of pressure galleries and pressure shafts consists of the following points :—

Before deciding upon the erection of a pressure gallery, it must be considered whether it is absolutely necessary, or whether the possibility of another solution exists which may appear more expensive but will be less costly in the long run. If, in spite of these considerations, the pressure gallery is chosen, the building of this gallery may be carried out on the following lines :—

If the rock be strong and watertight, special measures are not necessary, and provided working pressures are such as are usual in such cases the gallery need not be lined. Such favourable conditions have been found in the case of Barberine Power Works of the Swiss Federal Railways, but they are of course rare. The leakage of unlined mountain rock is exemplified by the tests in the granite stretch of the pressure gallery of the Amsteg Power Works

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[1] Gutachten der Experten Rothpletz, Rhon und Buchi über die Rissbildungen in Druckstollen des Ritomwerkes, Bern, und Zürich 1920; published in extract in the Schweizerische Bauzeitung 75 (1920) page 172 etc.

[2] See the treatise of J. Büchi in the Schweiz. Bauzeitung (1921) page 61, also the investigations of L. Mühlhofer, Zeitschrift des österr. Ing. u. Architekten-Ver. 73 (1921) page 101 a.s.f.; Schweiz. Bauzeitung 78 (1921) page 245; Der Bauingenieur 3 (1922) page 545 and 4 (1923) page 509; Die Wasserkraft 18 (1923) pages 91 and 185; Die Wasserwirtschaft 16 (1923) Nr. 17.

of the Swiss Federal Railways before it was lined. A section of the gallery of 150 m. length, corresponding to a wetted rock area of 1,500 m^2, showed at 4 atm. pressure a water loss of 4 lit/sec.

To show, however, how perfect the watertightness can be, I may refer to the percolation tests made in the fine broken dolomite stretch of the gallery of the Lake Spuller works of the Austrian Federal Railways. At a pressure of only 30 cm. water column, percolations of 0·03—0·05 lit/sec. per sq. metre rock area have been observed, corresponding to 30—50 drops from 1 $cm.^3$ volume per second for 1 m^2., rock wall,

If the rock be good in itself, but has fissures which give rise to anxiety, then the question of lining the walls with cement is to be considered.

If, here and there, local loosening of the rock is to be feared, even though the rock is in good condition elsewhere, with a working pressure of about 1 atm. then a lining of rammed concrete may be used. Nowadays the cross section is always circular, though formerly horseshoe or elliptical sections were in use. But these did not allow for the effects of side pressure.

With higher pressures or more unfavourable rock conditions these methods of lining do not offer sufficient security. In such cases the use of sheet iron must be considered. Further, an iron pipe conduit may be laid in the gallery, as has been done at the Lake Spuller works; or the sheet iron may be used merely as walls. In the latter case the sheet iron does not have the effect of withstanding stresses to a great degree, but ensures the watertightness of the channel.

With regard to pressure shafts, these can be used where the local conditions, such as gradient and danger of subsidence, make it too dangerous to build a pressure pipeline; or where the volume of working water is very large, necessitating very long or very numerous pressure pipes, the economic superiority of pressure shafts is evident.

With pressure shafts there is only one design worth considering, *i.e.*, a sheet iron lining.

In fixing the thickness of the sheet lining, it is to be remembered that the first task of the sheet is to effect tightness. Sheets of relatively small thickness are therefore sufficient.

Extra security of the sheet lining is, of course, gained by the support of the rock.

To obtain a good bedding, cement must be forced in the sheet iron pipe from the interior of the shaft.

It is, of course, of importance to choose a very soft elastic sort of

iron in order to reduce the straining. With this in view an interesting idea is to soften the sheet lining by rolling in longitudinal waves, an idea which was thoroughly examined for the construction of the lake Spuller works and is now to be realised in Italy.[1]

(6). SURGE TANKS.

Between the head-race and the turbine intake, a surge tank is nearly always inserted in order to serve as a buffer for load shocks. Such a surge tank must not overflow at a sudden drop of load; equally at a sudden rise of load the water surface should not sink so as to starve the water inlet or the outlet and let air enter the intake. Further, it should be of such dimensions that after any variation of load in the chamber the state of equilibrium will reassert itself; this does not always occur automatically. Under certain conditions it is quite possible for even a small variation of load to produce a sudden large variation of the water level in the tank; the disturbance of the equilibrium caused by a load shock may lead to even larger disturbances. Such a phenomen was observed at the power works on the Urf Valley barrage.[2]

The constructional engineer who is primarily concerned with static problems, is here at once forced to consider dynamic conditions appertaining to the interesting theory of the pulsation of water.

The first axiomatic studies on the surface movements in water chambers were made, as is known, by F. Prásil, when it was assumed, incorrectly it is believed, that losses of head are proportional to the first power of the velocity.[3] A calculation on the basis of a numerical integration where losses of head are considered correctly to be proportional to the square of the velocity, was published a little later by K. Pressel;[4] this method is very popular for the treatment of more complicated problems. A further important contribution to the design of water chambers is furnished by D. Thoma, showing reasons for the continual and the repeated appearance of pulsations of the water surface in the surge tank. He has explained the measures for preventing them and has examined in detail the connection between the tank and the regulation

[1] At the installation of Pallanzeno with a head of 720 m. Confront G. Fantilo, Sul problema delle gallerie e dei pozzi scavati in roccia per condotte forzate d'acqua, Annali del Consiglio Superiore delle Acque, Roma 1923.

[2] Zeitschrift des Vereines deutscher Ingenieure 52 (1908) No. 16119.

[3] Schweiz. Bauzeitung 52 (1908) page 271.

[4] Schweiz. Bauzeitung 53 (1909) page 57.

turbines[1]. Valuable statements are also to be found in the work of Ph. Forchheimer[2].

This scientific and valuable work was published in the middle of 1924 by Julius Springer, Berlin. It fills a big gap in existing literature on surge tanks and will be welcomed by engineers as a guide to the exact design of surge tanks.

With regard to design for plants with storage lakes of great height, the surge tank with upper and lower casing is gaining popularity.

In contrast to a tank of equal width at top and bottom, this arrangement offers the advantage that the storage of water takes place where its mass is most effectual, *i.e.*, increasing the load below and diminishing the load above. As the opening process takes place in the turbines, the water level sinks in the narrow rising shaft, falling slowly in the wide lower chamber; the large drop from the lake to the surge tank resulting from this produces a relatively quick acceleration of the water volume contained in the supply channel, which checks the sinking in the lower chamber. On the other hand when, the turbine admission is reduced, the water level in the narrow rising shaft rises quickly to the wide upper casing. This exercises a considerable counter pressure against the pressure of the water against the water chamber and checks the further rising of the water level in the upper casing. At the Lake Spuller works the lower casing is divided into two conduits each of a length of 14 m. and of circular cross section, narrowing at the back from 2·80 m. to 1·80 m. diameter, to enable the water to flow away and the air to escape.

The upper casing on the contrary is 30 m. in length 4 m. in height and 3 m. in width. The upper storage gallery is connected with both the under ones by a shaft of 50 m. in height and 4 m. width of circular cross section.

Surge tanks with casings make it possible to obtain with only half the total water volume the same effect as with a tank of uniform cross section; these are therefore more economical.

For installations with smaller variations between the highest and the lowest storage levels, however, the simple rising shaft without casings or with only the upper casing is preferable owing to the greater simplicity in construction.

The lining of a surge tank must of course conform to the same conditions as a pressure gallery or a pressure shaft. With larger

[1] Zur Theorie des Wasserschlosses bei selbsttätig geregelten Turbinenanlagen, München und Berlin 1910.

[2] Hydraulik, Leipzig und Berlin 1914, page 353/362.

heights, therefore, caution is also necessary as is shown by the cracks which appeared in the surge tanks of the Ritom work. These considerations made it necessary to armour, with iron sheets, the two lower galleries and the rising shaft of the storage on the Lake Spuller Works. The higest pressure amounts here to 50 m. water column. The upper storage gallery where the depth of water is never more than 3 m. is exclusively lined with rammed concrete.

(7). OVERFLOW CHANNELS FROM SURGE TANKS.

Sometimes the surge tanks of water power installations, even of those with storage facilities, have an overflow arrangement for safety. It must, of course, be made not lower than the highest storage lake surface at full capacity. On power installations without storage facilities, where the upper water channel is not subject to pressure, such an overflow forms an indispensible part of the installation.

If the surge tanks be located at a great height over the river into which it overflows, the overflow channel is the part of the whole water power installation requiring the most care in design. If the valley slopes consist throughout of solid rock, or if there be in the vicinity of the surge tank a natural water course of sufficient capacity, the construction is relatively simple and the possibility of an accident small; unfortunately such favourable conditions are the exception.

If it is necessary to make the whole channel artificial and if there is no rocky ground, the greatest care in necessary, because the water may in a few minutes cause the greatest ravages to the valley slope and possibly destroy the surge tank, the pressure piping, and even damage the power station itself.

At the Sill Works (Austria) it was necessary to lead a water volume of 8 m^3/sec. from the surge tank down to the Sill river, a distance of 190 m. The valley slope with the average gradient of 33 degrees consisted entirely of river gravel, no rocky ground was to be found. In the light of existing knowledge at that time the best solution appeared to be to construct cascades with interpolated basins in which the falling water would be checked. The building of this required, of course, a great volume of masonry, and both erection and maintenance have been costly.

At the Rutz works (Austria)[1], offering conditions similar to the

[1] For the electrification of the Mittenwald Railway, Zeitschrift für das gesamte Turbinenwesen 10 (1913) page 385, a.s.f.

Sill works, it was therefore decided to abandon the construction of a waste channel in cascades and to try to build an open waste channel. The maximum water volume to be carried was 6 m^3/sec., the fall height 175 m. In the upper part the channel has a gradient of about 38 degrees, the next stretch is 19 degrees, and this finishes at a steep rock wall 45 m. in height over which the water falls into the Rutz torrent. The channel has a trapeziform cross section, the bottom is 2·50 m. wide, the side walls have a slope of 45 degrees and a height of 1·60 m. The bottom and the sides are made of concrete with a lining of larch. This construction proved to be considerably cheaper and more effective than the cascade waste channel of the Sill works; it has proved during the past 11 years to be satisfactory in all respects. No repairs have been necessary.

The good results obtained with this overflow water channel were responsible for the use of the same design at the power works at Blühnbach (Austria). The water volume amounts to 2 m^3/sec., the fall, 150 m., the gradient at the upper part 28 degrees, at the lower part, 24 degrees. The ground is rocky for a short stretch, but consists for the rest of loamy gravel. The two overflow water channels constructed as tail-races, mentioned above, are of rectilinear plan. In cases where, in the current tract, changes of gradient are concave, it is necessary to take care that a rise of water at the bottom of the channel does not occur; this can be done by rounding off the gradient change more evenly than the trajectory corresponding to the upper part of the channel.

If the local conditions of the ground are such as to necessitate any deviation from the straight line in the ground plan, we have a very interesting problem. I recently had occasion to study such a case for the Opponitz power works (Austria[1]).

There are two possible courses open. One is to have angular changes of course and to put basins in the angles in order to break the fall of the falling water; the other is to choose a curved course. The latter solution appears perhaps to be the more hazardous. It is, however, if carefully constructed, the better one, since it has many advantages over a system of cascades.

In the arrangement of a curved course, it is recommended that the channel be planned like a railway line, *i.e.*, to use as large as possible a radius to interpolate between the arc and the straight line a transition curve (the best is a cubic parabola) and lastly, for economical reasons, to give to the bottom of the channel a banking

[1] For the power supply of Vienna: see Elektrotechnik und Maschinenbau 4 (1923) p. 149.

on the outside of the curve; the transition from the zero banking (in the straight) to the extreme banking (at the beginning and the end of the curve) should be planned as in railway construction according to the length of the transition curve. That is to say, that where it joins the straight, the radius of the curve should be infinite and where it joins a circle, the radius of this should be the same as the radius of the transition curve.

Regarding the banking, the following should be observed: the water flows through the channel at a great angle to the horizontal. Its oblique velocity may be resolved into two components, vertical and horizontal. The latter produces in the arc a centrifugal force directed outwards, the effect of which is that the water level from side to side of the channel no longer remains horizontal.

The force exerted by the water may be analysed on two assumptions. One is that the velocity at all points of the same cross section is equally great. The water surface then takes the form of a logarithmic curve with the convex side upwards. The other assumption is that the velocities at points in the same cross section are proportional to the distance of the centre of curvature, *i.e.*, only the angular velocity and not the real velocity is the same for all points in such a cross section. It is then seen that the water surface takes the form of a parabola, with the concave side upwards.

It is further seen that both these curves may practically be considered as straight, as long as the curve radius of the line be large enough in relation to the width of the channel, a proportion always to be aimed at. It is then clear that the banking of the outer edge of the channel above the inner one is to be calculated precisely on the same assumption as that made in railway construction regarding the banking of the track; the gauge of the railway track is here replaced by the width of the river bottom.

In such investigations relative to any lift of the water from the river bottom where convex changes of gradient occur and those relative to the banking necessary on curves, it is of importance to know the velocity with which the water flows through the channel. The knowledge of this velocity is also necessary in order to fix the dimensions of the overflow channel on the basis of the capacity required for this channel.

Since observations on the velocity of water in such steep channels have apparently not yet been published, there follow here the results of measurements taken in 1921 and 1923 by the civil

engineers Innerebner and Mayer, some of them in conjunction with the Wasserkraftwerke A.G., Vienna, in the overflow channel of the Rutz works.

The measurements were taken in the upper (about 38 degrees) gradient with the help of floats. The measured stretch had a length of 94 m. and was straight.

Date of measurement.	May 30, 1921	Sept. 30, 1921	Sept. 30, 1921	Aug. 9 1923	Aug.9, 1923	Aug. 9, 1923
Flow of water (without the air absorbed) m^3/sec.	1·02	1·47	1·58	2·77	3·75	4·50
Inclined velocity (in the direction of the channel bed) m/sec.	20·9	20·1	16·3	21·4	21·0	21·4

The velocity showed itself to be surprisingly independent of the volume of admission and amounted to about 20 m./sec. The velocities quoted represent a fair average value; whether the velocity at the end of this stretch was greater than at the beginning, or whether it was the same, cannot be inferred from this test.

If the motion followed the laws of fall on an inclined plane, it should, of course, have been accelerated.

Possibly, however, the water was limited by conditions which do not allow a further rise of velocity and therefore had a uniform motion. This limiting condition could be explained by the fact that the water masses, as they pour down, collect a considerable quantity of air. As the water tends to increase its velocity it also takes in more air ; this causes the water to become lighter and simultaneously rougher, which in turn checks the increase of velocity. It would be of value to collect material from observations respecting this matter from other places.

The value of the air absorbed occasioned a further surprise at these measurements ; details of this may be taken from the following summary :

Date of measurement.	May 30, 1921	Sept. 30, 1921	Sept. 30, 1921	Aug.9, 1923	Aug. 9, 1923	Aug. 9, 1923
Flow of water volumes (without the absorbed air) m^3/sec.	1·02	1·47	1·58	2·77	3·75	4·50
Flow of volume of the mixture of water and air m^3/sec.	4·97	5·81	5·92	7·04	14·70	16·50
Volume of the air absorbed in per cent. of the volume of the mixture of water and air	79·5	74·7	73·2	60·6	74·5	72·8

The real water volume was measured partly on the overflow of the water chamber by the height of the overflow, partly by the diagram of work of the turbine, the consumption curve of the admission gallery and of the efficiency of the installation, the volume of the water and air mixture followed as the product of the observed velocity and the cross section.

The water, as it fell, obtained therefore an increase by air absorption to about four times the real water volume, an important fact in view of the very considerable water masses. In this respect an improvement of testing material is greatly to be desired, economical planning being only possible if the bases for fixing the dimensions are reliable.

(8). DELIVERY PIPES.

If the water is led from the water chamber to the turbines in pressure pipes, there are two methods of construction, namely, the open and the covered method.

The open method allows for permanent accessibility for examination and is therefore very advantageous.

The covered method, on the other hand, secures the piping against the fall of stones, falling trees, wilful destruction of property and frost; in addition, a covered pipe is more or less immune from daily and yearly fluctuations of the outer temperature.

With regard to the plan of the line there are two principal building methods.

In one, the piping is divided into single straight sections. At the bend large anchor blocks of concrete are provided for securing the pipes. The single pipe sections are extensible in the longitudinal direction, by interpolating extension contrivances in the form of stuffing boxes and packing rings in order to compensate for the variations of the length caused by temperature.

In the other method the pipes are laid partly in straight lines, partly in curves.

Anchors are always used at both ends, and in cases of necessity at intermediate points. Extension contrivances are not necessary, because the compensation of the variation of the length is effected by sides of the piping and especially in the curves. The anchors in this case are never placed at bends in the piping.

Correct dimensioning of these anchor blocks is important, not only from the technical but also from the economic point of view, since considerable masses of concrete are concerned. The seven fixed points of the delivery pipes for the Lake Spuller works have a total volume of 3,600 m^3, with a weight of 7,900 tons.

(9). CONCLUSION.

The relatively rapid developments and extension of water power works, and especially of those with storage facilities, has been the cause of several errors, the price of experience. It is very important to observe the facts that become apparent on the completion of a work and to add them to experiences at other places; this report may serve to help in this direction.

RÉSUMÉ.

L'auteur passe en revue les expériences faites avec les dérivations de bassins de lacs naturels existants, en ce qui concerne les éboulements de rives de lacs dont on a réduit le niveau, les barrages en béton, les galeries et puits à pression, les bâtiments de turbines, les canaux d'amenée pour turbines et enfin, les calculs de construction des divers systèmes de tuyaux sous pression; il cite une série de publications dans des journaux techniques paraissant en Autriche, en Suisse et en Allemagne.

PROGRESS IN MECHANICAL ENGINEERING WITH REFERENCE TO POWER PRODUCTION

VERBAND DER DEUTCHOESTERREICHEN MACHINEN INDUSTRIE.

PROGRESS OF WATER TURBINE CONSTRUCTION IN AUSTRIA.

Within the last few years Water Turbine Construction in Austria has made considerable progress; in addition to many improvements in constructive details achieved by constant efforts in that direction, success has been attained in three vital aspects, materially extending the limits of possibility as to size of the units, *head* and *speed.*

The direction in which development is possible is determined by the special geographical conditions of Austria. We do not possess any water power of such gigantic size that we could build works of the same capacity as the most important foreign plants. Nevertheless, we have already, partly under construction and partly designed, several power stations with a total capacity of 40-80,000 H.P.

The amount of water available, and other considerations of water economy, make it desirable to divide the plant into three to five units.

The capacity of the units has thus been increased to about 15,000 H.P., and the amount of head (mostly under 250 m.), and the desire to obtain the greatest possible number of revolutions of the generator have produced a standard type, the Francis Spiral Turbine, for Austrian high fall power installations.

The only exceptions are the works used for the railways, where, on account of the low frequency ($16\frac{2}{3}$ per sec.) and the great fluctuations of load, the impulse turbine was considered preferable. In the Francis Turbine, the desire to lead the water into the turbine in the most advantageous way, and to reduce as much as possible the space required for the machine, has led to a somewhat special arrangement; it is a two-bearing set with horizontal shaft, and the runner of the turbine is mounted on the extended shaft of the generator, the bearing nearest to the turbine serving as a thrust bearing of double pressure in segments for withstanding the axial forces (Teigitsch Power Co., lower stage). This

is an essentially new kind of construction for Austria, and the same remark holds for the spiral turbine with the vertical shaft, screen generator mounted direct on the shaft and a counter running brake turbine (Partenstein); the very large axial forces and the high speed of revolution (750 and 600 per minute respectively) make an enormous demand on the bearings, which, however is fully met by the oiling arrangement and re-cooling of the segment foot-step bearing.

In respect of the "head," great progress has also been made lately. Heads that would lead to considerable difficulty with free jet or impulse turbines do not exist in sufficient numbers in Austria to justify the construction of such sets, but the reasons given above make it desirable to use heads as high as possible with the Francis spiral turbine. The Teigitsch works make use of the greatest head of pressure, *viz.*, 250 metres so far employed. Such a very high pressure not only makes extreme demands on the quality of the material and the constructive reliability of all the power transmitting parts, but in view of the great speed of the water, makes it essential that all spaces that carry water are of such a shape that all eddying, whirling or chemical effects (corrosion) are eliminated with absolute certainty, and mechanical friction can be reduced as much as possible.

The construction of turbines of such a nature necessitates a most exact theoretical understanding of the process of flow; for, when we deal with such high values of pressure and speed, excellence of material used must be combined with perfectly correct design in hydro-dynamic details in order to obviate entirely the difficulties referred to above.

The greatest and most obvious progress achieved in the construction of water turbines in Austria is in respect of *speed*. The application of the propeller turbine has in this case widened the limits of possibility to an extent that only a little while ago was thought out of the question. This increase of the specific number of revolutions to double and treble the amount that was obtainable in the Francis turbines is of special importance for Austria, since the small and medium Alpine rivers in their lower courses have quantities of water from 20 to 80 m^3. per sec., and heads of 4-10 m., and present the best field of application for the high speed vertical turbines with the screen generator direct coupled.

The first large plant (The Central Siebenbrunn on the Traun) that was built on these principles has been in operation since the

summer of 1923, and, at the tests when taken over, has shown efficiencies between " full " and " ¼ " load which greatly exceeded all expectations.

For the present this plant includes two four-vaned propeller turbines with adjustable guide vanes. These have been designed with a thorough understanding of the theory of hydraulics, and as a result of innumerable experiments, they may now be considered as standards for the construction of runners.

These experiments have shown that, in the case of runners of very high speeds at comparatively high heads and suction levels, great difficulties may arise from the separation of the water from the lower parts of the blades (cavitation). Careful study, however, of the whole question and suitable design of the form of the blade have made it possible to overcome this difficulty; the complete success of the Siebenbrunn plant may be considered as proof that the designers of these machines need not apprehend any disappointment in future.

The regulation of the Siebenbrunn turbines also represents an innovation; the simultaneous adjustment of the stationary blades and the moving blades is such that at any given time the highest possible efficiency is ensured, the adjustment being effected by means of two servo-motors which, although separate, work together by the operation of a cam, the control being hydraulic.

The propeller turbine, of which both the theory and the practice have now been placed on a secure foundation, is likely to find a wide field of application in the Austrian Lower Alps.

But as, on the one hand, making the propeller vanes adjustable entails a fairly large increase in the cost of the turbine, and as, on the other hand, plants having several sets do not require each single unit to be able to satisfy such high demands as to adjustability up to ¼ and ⅕ of the full load, we may expect that a combination of vane wheels with fixed and movable blades, whether for " full admission turbines " or " adjustable turbines," will be the most economical solution of the problem of the large power-station with low pressure head.

MOTORS FOR RIVER NAVIGATION AND WATER POWER PLANT.

The development of water power in Austria aims at saving the country, which is poor in coal, from the irksome necessity of importing coal from the neighbouring states. This question has encouraged interest in obtaining energy from the water power of Austria. There is, however, a sphere of commercial activity,

which at present does not admit of the use of electrical energy in the way of current distribution from central stations. This is *river navigation.* The energy required must still be produced in the ship itself. Accordingly, such vessels are still nearly always worked with steam plant, though there is no stock of coal immediately available on the Danube, the coal having to be taken to the Danube from comparatively large distances to be stored as bunker coal in the larger ports.

The coal in question, apart from that coming from the Moravian Silesian coal district, has little heating power. As river navigation necessitates the use of boats of small draught, only limited quantities of coal can be carried. Consequently the radius of action of the normal steam tug is limited and more frequent supplies of coal are required. There is a wide scope for greater economy by using the crude oil engine for river navigation.

The Roumanian oil fields are situated in a locality so favourable to Danube shipping that the crude oils in question (gas oil) can be carried to the oil bunkers of the boats at very little expense. Besides, the high heating power of the crude oil per unit of space renders the quantity taken on board in Roumania sufficient for a complete passage up and down stream. Such boats, therefore, do not require an intermediate stock of fuel on the Danube.

However, the greater part of the traffic on the Danube is towage, *i.e.*, a number of barges are towed by steam tugs.

The hydrographic conditions on the Danube, which we are not going to discuss here in detail, require for the purpose of most economical towing power, the division of the Danube into zones, in each of which, suitable steam tugs are used. This circumstance renders possible a smaller stock of fuel as only smaller spheres of action are, in this way, required for the individual steam tug. Generally speaking, with regard to the supply of crude oil, the whole length of the Danube may be divided into two zones, the first of which, that of the lower and middle Danube, reaches from the mouth of the Danube to Budapest, and is provided for by Roumanian crude oil. The second zone reaches from Budapest to Ratisbon along the entire navigable upper Danube and will have to be provided for with crude oil, according to the condition of the market, either from the stocks of Galician crude oil in Vienna or at Pressburg, or will have to use the Roumanian crude oil taken to these towns in tank boats and stored in tank installations.

There is a wide scope for the use of the crude oil engine, a

use which has only been begun to a very slight degree. Apart from the great Danube shipping companies, who have been working almost entirely with steam power in recent years, a few small enterprises have been started for the piece goods traffic both as express and as ordinary cargo traffic by means of mechanically propelled cargo boats. The Schiffswerft Linz A.G., Linz on the Danube have built and supplied the greater part of these motor cargo boats and have, in this way, been pioneers in this important field.

The net working expenses (consumption of fuel and lubricating oil) amount to about $\frac{1}{3}$ of those working with steam. In addition, there are a number of other advantages such as smaller staff, no waste of time in getting up steam, smaller capital outlay, much smaller weight, etc. In this way, the newly established companies were able to attract sufficient trade. Generally speaking, they did not get higher freight rates, but they offered their customers the advantage of quicker transit, and could obtain favourable results even at times of small Danube traffic, owing to the economy of their motor craft compared with those of the large companies.

Working by means of mechanically propelled motor cargo boats is, of course, restricted to piece goods and similar traffic; bulky goods, which really constitute the principal part of the Danube traffic, must be excluded. In order to exploit the above advantages of motor working for this type of traffic, motor working should also be introduced on the tug boats. The above firm have tackled this problem also, and have solved it by means of a twin screw motor tug boat.

The peculiar features of the current of the Danube offer many difficulties to the screw steamer owing to the frequently low water levels. This makes it desirable to keep to the present paddle boat working, at least for certain difficult parts of the Danube. The small number of revolutions of the paddle wheels offers certain difficulties to the introduction of the crude oil motor. However, this problem has also been already tackled and will be solved within a short time. There will then no longer be an obstacle in the way of the transformation of the Danube river fleet to crude oil motor working. When this is done, not only will shipping traffic become much cheaper but also a considerably greater efficiency of the present tug boat fleet will be obtained, for the smaller weights of the

internal combustion engines render possible an increase of the tugging efficiency by 20-40 per cent. with the same hull.

Besides this we may find in Austria another sphere in which the energy stored in the crude oil can be made use of.

In addition to the large water power stations, there are a great number of water power works owned by small communities, individual industries and even private individuals.

However, all these water power works have a common trouble. They have to contend with scarcity of water in abnormal years, a scarcity which, though perhaps it seldom endangers the normal current, frequently prevents the daily demand peak from being met.

Such cases have occurred repeatedly within the last few years and have, though not in Austria, had economically catastrophic effects. We refer to the great lack of water in Upper Italy shortly after the war. Upper Italy, as is well known, already has a very extensive water power network, and at the same time is the centre of the greater part of Italian industry. At that time it became necessary to stop industrial works entirely for certain days of the week, and, in addition, to arrange the times of working of the individual factories so that at least limited working was rendered possible for all the consumers of current. At the same time a number of measures to economise public lighting had to be carried through.

Consequently in addition to the water power plant, reserve plant has to be provided, either as reserve power for times of water scarcity, or, and this may well be the most favourable economic solution for medium and small water power plants, for the purpose of meeting the day to day peak loads.

The second case renders possible a considerable increase of existing water power plants owned by communities or private persons.

Among the existing crude oil engine systems for this purpose, the low pressure crude oil engine should be compared with the expensive Diesel engines on account of its low price, which hardly amounts to half that of a 4-stroke Diesel engine. If used for this purpose its consumption of crude oil, which is only slightly greater, is more than made up for by its far smaller price and cost of maintenance.

STOP VALVES FOR SUPERHEATED STEAM.

When, about 25 years ago, superheated steam began to be used

more generally for driving steam engines, steam valves of the type used up to then had to be adapted to the new working requirements. Materials were, therefore, used for their construction which were more suitable for high temperatures and of greater heat resisting qualities. Cast iron was replaced by cast steel, bronze by nickel. Even so, these valves were apt to cause interruptions in working owing to changes in shape caused by the high temperatures to which they were often subjected, or by lack of sufficient play. An endeavour was made, however, to obviate the evils resulting from such causes by more careful attention; this succeeded more or less. Little by little, however, it became clear that the old steam valve, which repeatedly forces the steam to change its direction suddenly, forms a source of loss of energy.

This period saw a great activity of constructions designed to prevent this evil; in some cases attempts were made to transform the well-known water valves so as to render them useful for superheated steam; in others, attention was directed towards improving the conduction resistance of the ordinary steam valve. That these endeavours have not yet ceased, and that technical literature again and again contains new variations on this theme, would in itself be a sufficient proof that the final solution of the question has not yet been found, a fact which would probably be confirmed by every works manager of large steam central stations.

The stop valve is the first mechanical arrangement encountered by the steam passing from the boiler to the engine. It is permanently exposed to the full pressure and the full temperature of the steam. It must be perfectly steam-tight and easily movable at the highest and lowest temperatures. It is exposed to enormous stresses, due both to the operator and to the pipe line which puts it sometimes into tension, sometimes into compression. In many cases it is more important that it should always be ready for use than the engine itself. Moreover, the economy of the whole plant depends on it in a way that cannot be overrated.

In our opinion, a stop valve can only comply with all these difficult requirements if it answers the following conditions:—

(1) *Free and Straight Passage.* The closing device should offer the full free cross section of the pipe but should not require any changes of direction. Only then will the conduction

resistance correspond to that of a straight piece of tube of the same length, and only then does the problem appear to be solved in this respect.

(2) *Permanent Steam-Tightness.* This can only be attained if the seating surfaces are separated and closed in an axial direction so that there is no sliding of surfaces.

(3) *Symmetrical Formation.* The valves should be built so that they are unaffected in action by the direction of the current of steam. This is especially important with ring mains where the direction of the current may change.

(4) *Independence of the Position.* The valve must act in exactly the same way whether it is inserted hanging, standing, or in any other position. If this requirement is complied with, the arrangement will be made much easier for the constructor and the operator.

(5) *Independence of the Temperature.* Many valves either develop leaks or have not sufficient play according to whether they are closed in a cold or hot condition. In the former case, they have to be closed down tighter; in the latter, the strain on the material may cause faults, or forcible opening may cause fractures. An absolutely reliable provision should, therefore, be made so that changes in form caused by the fluctuations in the temperature neither increase nor diminish the closing pressure to any extent, and so that the device, once closed, should always remain tight and easily movable.

(6) *Simple Operation.* It should be possible to close and open the valve in the same way as the valves used up to now merely by working a hand wheel; this is of the utmost importance, especially in cases of danger.

(7) *Equalisation of Pressure.* All the valves of large section require before opening a certain equalisation of pressure. It should, however, not be forgotten that, in many cases, this equalisation is only possible to a certain extent. Therefore, devices which can only work faultlessly with a perfect equalisation of pressure should be rejected.

(8) Durability. Within the space exposed to the superheated steam there should be no sliding surfaces or mechanical parts requiring lubrication; certainly no springs, as they become inefficient at high temperatures.

(9) *Facility of Grinding In.* It is desirable that the packing rings of the device should admit of grinding in at any time at a

high temperature without the valve being dismantled; or, better still, without its being opened at all.

Important as the requirements mentioned here may be, no literature known to us indicates any stop valve having been produced which entirely complies with them.

STOP VALVES FOR WATER POWER PIPE-LINES.

The devices for closing pressure pipe-lines may be viewed from three angles :—

(1) with regard to their purposes, (2) with regard to the design, (3) with regard to operation.

(1) *The purpose* mostly effects the place of insertion in the pipe-line. With most modern water conduits in the form of closed water pipe for high pressure it is a question of the following devices: (a) One or more valves at the inlet to the reservoir from the pipe-line, (b) One or more valves at the beginning of the real high pressure pipe-line. These are usually such that they can be opened and shut at will for working purposes and automatically closed when the safe water velocity is exceeded, (c) the valves at the end of the high pressure pipe-line, suitable for starting and stopping individual turbines, (d) the valves for draining the reservoir where closed conduits are used for this purpose.

(2) With regard to the design, the following sub-division may be made: (a) *Water valves* characterised by the wedge shaped or disc like closing plate being introduced into the conduit perpendicularly to the direction of flow, (b) *Water valves* where the closing element moves in the direction of the flow. The seating may either be perpendicular to the axis of the main pipe or parallel to it; (c) *Valves* the closing plate of which can be rotated around an axis perpendicular to the axis of the pipe. The two axes may in this case intersect one another or cross one another perpendicularly on a different place, (d) *Cocks* in which the rotating body can be twisted within a suitably formed chamber so that their bores either coincide or a part of the surrounding surface of the former closes the bore of the latter. This closing part of the surrounding surface may also have its own special motion. These may be called globe cocks and offer a number of advantages in comparison with other constructions.

(3) With regard to *working,* the following types may be mentioned: (a) *Hand operated,* with which the desired motion is

effected by means of hand cranks, hand wheels, spoke wheels, ratchet, screws, racks, etc., (b) *hydraulic operation* in which the motion is effected by hydraulic cylinders with pistons or plungers. The compressed water required for this can either be taken from the pipe conduit or be produced by pumps which can either be worked by hand or by mechanical means. In this case various combinations are possible in order to increase temporarily the available pressure of the operating water. In this group also those gears may be included with which a hydraulically retarded falling weight does the desired work and can be returned to its original position by means of a pump, (c) *electric operation*, this is usually arranged like an ordinary hand operated valve and provided with an electric motor. Attractive as this arrangement may have been in various respects, especially for remote control, it is rarely used nowadays. Electric motors do not respond to the considerable variation in load between the large force necessary at the start of the operation and the relatively slight force required when the valve is nearly closed, (d) *Combined driving.* This is mainly used for purposes of remote control. Usually an electro-magnet is made to release a hydraulic force or a weight, (e) *automatic* arrangements mostly used as safety devices. Their object is to close the valve automatically and within a specified time, when a certain speed of the water has been exceeded. For this purpose use is made of hydro-dynamic pressure. It may either act immediately on a balanced valve device or else on a suitable relay releasing an electromechanical or hydraulic arrangement.

In addition, various combinations of the above kinds of apparatus are possible, and accordingly have been used when required.

The numerous new constructions coming from armature and turbine manufacturers, among which many good devices are to be found, have to overcome great opposition from conservative and cautious users. However, we must admit that the requirements usually advanced as to the reliability and working safety of such valves cannot be put too high, as their failure to act may cause more serious results than the failure of the turbine plant itself.

A second requirement of no less importance is that these devices should be so constructed that their resistances to the flow of water is as small as possible.

In conclusion, the following principles appear to be gaining favour:—

A. *Stop valves to be operated at will.* (1) Replacement of mechanical hand operation by hydraulic apparatus and the adoption of anti-frost precautions, (2) possibility of operation without pressure compensation, (3) possibility of remote control, especially for closing; this, particularly in the high mountains, is of special importance, (4) remote control by an electro-magnet releasing a hydraulically retarded falling weight, *i.e.*, electro-mechanical relay, but not electro-motive power.

B. *For Automatic Stop Valves for Safety.* (1) Duplicated mechanism so that when the one fails to act the other one acts. (2) possibility of closing at will by remote control.

These principles are the result of long experience, but only the most careful attention to details and most accurate workmanship coupled with considerations for any conditions that may arise in operation can ensure that unfailing safety in working which is demanded by stop valves for water power pipe-lines. The large water power works, some of which have been completed within the last few years, and some of which are still in course of construction, provide objects for the study of the characteristic conditions and ought to produce designs based on the above principles. The *Wiener-Armaturen und Maschinenbau, A.-G.*, formerly *Teudloff and Dittrich*, have been especially active in this work, and with numerous new patented designs have solved these problems, and their devices are now fitted in nearly all new large water power works of Austria.

The fact that these power stations together have a peak output of about 130,000 H.P., and that such devices have to be specially designed in each case, indicates clearly the amount of work involved.

THE OIL ENGINE AND ITS VARIOUS APPLICATIONS.

One of the most urgent problems of the engine constructor is the adaption of the oil engine to all kinds of use by building special machines and also by lowering prices by means of standardisation, and the application of the principle of "mass" production in its widest sense. Both tasks are closely connected, for the separate parts must be strictly standardised, not only within one series of types, but for all.

For small and medium requirements from 25-1000 B.H.P. four series of 5 types each are built. They are :—

1. Stationary oil engines with standard number of revolutions.
2. High speed oil engines for stationary installations, marine use and locomotives.
3. Direct reversible marine oil engines with standard number of revolutions.
4. High speed direct reversible marine oil engines for ships.

For medium and large requirements (600 to 2,000 B.H.P.) there are three series of types, of 5 types each, and all of the cross-head type. They are as follows :—

5. Large stationary Diesel engines for standard number of revolutions.
6. Large stationary low speed Diesel engines.
7. Direct reversible marine oil engines.

The types are vertical single-acting, four-stroke engines.

The latest problems of the oil engine maker are those of solid injection of the fuel and the increase of power by pre-condensation, and are closely followed by the modern engineer, but the work has not yet progressed sufficiently to enable us to report on it here. During the last few years the problem of using low grade fuel has lost some of its importance.

The greatest attention is devoted to reducing the cost of stationary standard Diesel engines. Care is taken that this reduction does not cause an increase in the working cost or impair the working safety; rather have efforts been made to ensure a reduction of the cost per B.H.P. hour. The number of revolutions of the latest types, therefore, are only slightly greater than those of the older types, and due regard has always been paid to obtaining the extra speed by reducing the weight of moving parts and by suitable design of such parts of the engine as are exposed to thermal stresses. From the point of view of design, therefore, it was simply a question of reducing the cost per litre of volume of the cylinder, and, from the point of view of the builder, of standardisation, mass production and the use of special machines and appliances, and also of reducing the amount of material used.

These endeavours have led to certain new methods, and have made possible a saving of material up to 50 per cent. for the heavier parts, such as bed-plates, frames and crank shaft. This has been done without sacrificing in any way the reliability of

the material, introducing any technical difficulties or increasing the cost of production, but solely by a more economical treatment of the theory of engine stresses. If the relation of the cost of material to that of wages, which, in the years immediately following the war rose to about 12 to 1, is borne in mind, the effect of the saving of material on the cost of production will be apparent.

We will briefly indicate here how these important savings of material have been effected, whilst preserving the well established fundamental shape of the "A" frames, and freely accessible big end bearings. First of all, the distance between the cylinders was reduced as much as possible, and a new system of lubrication has been introduced for the crank shaft and other parts. Standard motors of small and medium power have been hitherto built with ring lubrication, and were not capable of economy in space, as the poor circulation of oil necessitated bearings of considerable length. The method of forced lubrication which is now applied to high speed oil engines, in which the oil is kept steadily circulating through the bearings, allows the smallest possible length of bearings, but this system now in general use for high speed engines is not suitable for standard stationary types as the consumption of oil is 10 to 20 times that of the ring lubrication, and would, therefore, entail a considerable increase of working costs.

The new system of lubrication combines the advantages of both methods without their disadvantages. It is merely centrifugal lubrication. The oil is not allowed to drop from the bearings into the crank case, but is led by special oil return rings into the bearing casings which are inter-connected; one pump draws it from all the bearings and circulates it back to the bearings. These oil return rings are fixed to the crank in such a way that they require no extra space, and, therefore, no increase is necessary in the length of the machine. Every bearing has two such rings, of which one also serves as centrifugal oil ring for the crank pin.

This also leads to a number of minor advantages, which, however, we cannot discuss here.

The new method of lubrication, therefore, makes not only for a minimum of oil consumption, but also for a reduction in the length of the bearings, and enables machines to be made just as compact with forced lubrication. The "A" frame construction is adhered to as it gives convenient access to the bearings, notwithstanding the small distance between the feet of the frames

and consequent loss of lateral rigidity can be compensated by lateral tie-rods. The machines thereby attain extraordinary rigidity, and the bed-plate is entirely free from all bending stresses exerted by the forces in motion.

For the present, the new engines are being run solely with the fuel injected by air pressure. The injectors have compressors of a special design.

To eliminate the disadvantages of air injection it is not necessary to do away with the compressor altogether; accuracy of design and construction of compressor will do as well. Great interest

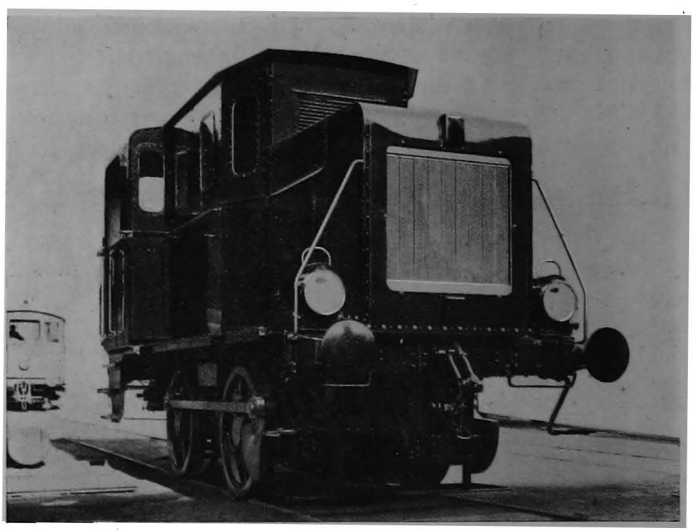

Fig. 1.

has been devoted to the study of this question for many years now.

By special calculation of cylinder volumes, without any special device or without increasing the cost of our present compressors, an automatic distribution of the pressure of the single steps or stages is obtained in such a way that for all loads the temperature at the end of compression and the expense of power remain constant. The small super-charging that occurs frequently at the last stage of compression, especially with small loads, has been entirely eliminated, and the temperature of the heated air is as much as 100 per cent. lower than with compressors of the

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ordinary kind. In conclusion, we may mention the latest production, the Gratz Diesel Lentz locomotive. Fig. 1 shows the first O-B-O shunting locomotive with 60 H.P. engines which has been working since the summer of 1923. The motor locomotives with hydraulic transmission are at least equal to all other types with regard to control and safe operation, while they offer considerable advantages in respect of initial cost and economic working.

RÉSUMÉ.

Le rapport de l'Association porte seulement sur quelques parties d'intérêt spécial montrant dans quelle direction tendent les efforts de l'Industrie des machines en Autriche.

Ces chapitres spéciaux sont :

1). Les progrès de la construction des turbines hydrauliques en Autriche.

2). L'utilisation des moteurs à huile lourde dans la navigation fluviale et dans l'exploitation des forces hydrauliques.

3). Vannes de fermeture pour vapeur surchauffée.

4). Vannes de fermeture conduites forcées de turbines pour hydrauliques.

5). Adaptation des Machines à Huile lourde aux diverses applications.

1). *Les progrès de la construction des turbines hydrauliques en Autriche*

La construction des turbines hydrauliques a fait des progrès remarquables dans les dernières années, spécialement en ce qui concerne la dimension des unités individuelles, la hauteur de chute et la vitesse de rotation.

Considérant toutes les conditions de la chute disponible et si l'on veut atteindre une vitesse de rotation assez grande générateur pour la turbine Francis à spirale se présente comme type modèle pour l'installation des usines à grande puissance pour grande chute.

Exception est faite seulement en ce qui concerne les usines de force motrice pour traction électrique, où, en raison de la frequence peu élevée (16 2/3 par sec) et des fluctuations de charge, une turbine à libre jet d'eau est plus avantageuse.

Concernant la chute le progrès est très remarquable ; l'usine de "Teigitsch" avec une chute de 250 m en est un exemple.

Les progrès les plus hauteur importants et les plus évidents dans la construction des turbines hydrauliques en Autriche concernent toutefois la vitesse de rotation par l'application du propulseur de turbine, laquelle, dépasse toutes les espérances du passé.

La première usine de ce système fonctionne depuis 1923 dans la Centrale de Siebenbrunn avec 2 turbines à propulseur système Kaplan.

2). *L'utilisation des moteurs à huile lourde dans la navigation fluviale et dans l'exploitation des forces hydrauliques.*

Pour la navigation fluviale il n'est pas possible de se servir de l'énergie électrique des grandes Centrales par transmission à longue distance. La navigation fluviale en Autriche est donc forcée de produire l'énergie

nécessaire dans les bateaux malgré les frais élevés du combustible, importé de l'étranger.

Une grande économie est toute fois possible par l'utilisation des moteurs à pétrole brut (huile à gaz), importé de Roumanie par la voie du Danube et transporté directement dans les bateaux à un coût très modéré.

Le chantier des bateaux fluviaux de la Société Anonyme de Linz sur le Danube a en effet construit la majeure partie des bateaux pour la navigation du Danube avec moteur à pétrole.

Les frais d'exploitation par comparaison avec le charbon sont seulement de 1/3, sans faire mention des autres avantages.

Un moteur à pétrole à basse pression est tout à fait utilisable pour le Danube.

3). *Vannes de fermeture pour vapeur surchauffée.*

Peu à peu on a reconnu, que l'ancienne soupape d'admission, forçant la vapeur à changer souvent et soudainement de direction est une source de pertes considérables d'énergie.

Les plus grands efforts tendent à la suppression de cet inconvénient, comme le prouve le nombre considérable de brevets d'invention.

Les conditions nécessaires pour les organes de fermeture sont décrites dans le rapport. On doit convenir cependant qu'il n'existe pas encore de vannes de fermeture satisfaisantes.

4). *Vannes de fermeture pour conduites forcées de turbines hydrauliques.*

Le rapport traite des conditions nécessaires pour la construction de ces organes.

Les grandes installations de forces hydrauliques en Autriche avec des hauteurs de chutes considérables ont obligé l'industrie à produire des organes de fermeture de la meillure qualité possible. Ces organes sont fabriqués en Autriche et font honneur aux usines de ce pays.

5). *Adaptation des Machines à Huile lourde aux diverses applications.*

1. Programme de production du constructeur.
2. Description générale des types déjà construits.
3. Essais faits pour diminuer le prix du moteur par la construction de types spéciaux.
4. Installation d'un nouveau système de lubrification.
5. Locomotives, système Diesel-Lentz avec transmission hydraulique.

HISTORICAL NOTE ON THE KAPLAN TURBINE

DR. ING. F. KNEIDL

The following paper refers to a new type of water turbine suitable for medium and low heads. The Kaplan, or rather the Storek-Kaplan[1] turbine, which was originated and constructed in the territory of Czechoslovakia, has moveable runner blades and the advantages gained by its use are that, compared with the Francis turbine usually employed under similar conditions, a much higher relative speed can be attained and an efficiency achieved which remains practically constant under varying discharges and heads of water.

Much work had to be done before these advantages were obtained. During 1908-1911 Professors Kaplan, Mieses and Hamel, all of the German Technical University of Brno, elaborated the theories of multi-dimensional flow. Later, Professor Kaplan, anxious to put those theories to practical test, asked Mr. Storek to supply him with a testing station at the Technical University. In the same way as a chemist after experimenting on a small scale desires to test his ideas on a large installation, so Kaplan intended to elaborate his trials on water turbine construction.

Mr. Storek gave the necessary facilities and supplied a small turbine having a runner of 100 mm. diameter with which Kaplan made his experiments by the aid of glass suction pipes, etc.

The result of those investigations was the Kaplan turbine which has been patented in all the principal countries.

In 1918, Mr. Storek, having acquired the rights of manufacture, constructed the first turbine having moveable runner blades, for Hofbauer Witeve, Velm, Austria, the tests on which were carried out by Professor Budau, of Vienna, in 1919. The dimensions of this machine were as follows :—

Diameter of runner	600 mm.
Power	35 B.H.P.
Head	3 metres.
Discharge	1100 litres per second.
Speed	480 r.p.m.
Specific speed	700-800.

[1] The results of the braking tests of this turbine are published in *Die Wasserkraft*, 1919, Nr. 17.

More machines followed and in the construction of these with higher specific speed many difficulties had to be overcome.

The Czechoslovakian Government, taking an interest in the new type of turbine, had a machine made for trial, and the Ministry of Public Works selected a site, originally built for the reception of a Francis turbine, at Podebrady, on the Elbe.

The dimensions were as follows :—

Diameter of runner	1800	mm.
Power	275	max. B.H.P.
Head maximum	2.5	metres, min. 1.5 m.
Discharge maximum ..	10	cu. metres per second.

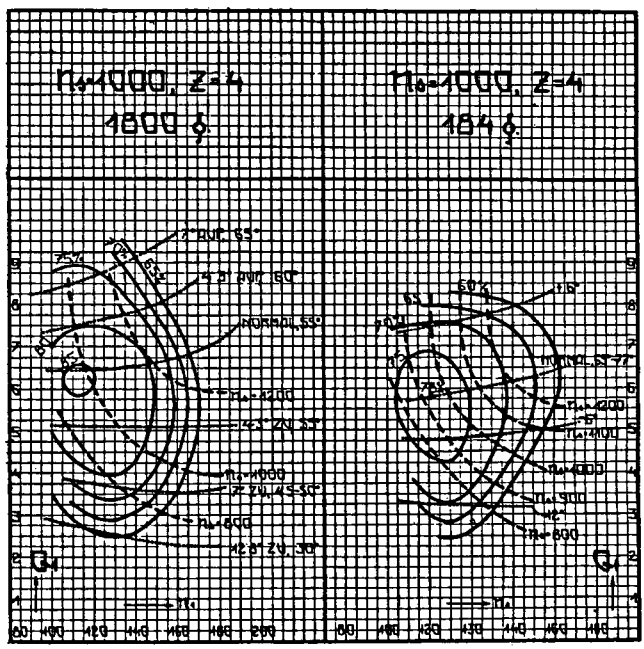


Fig. 1.

Curve of braking test at Podebrady. Comparison with the Kromeríz runner of 184 mm. diameter, NS. = 1,000-1,100.

In Fig. 1 are shown the results of the tests at Podebrady.[1]

[1] See Professor Dr. Hybl in *Zpravy verejne sluzby technicke*, vol. 4, No. 4, and a German translation of this treatise in *Die Wasserkraft*, 1922, Nos. 12 and 13. See *Strojnicky Obzor*, 1923, Nos. 2, 4, 5. Ing. Losef Linsbauer: zkusebni turbina Storek-Kaplanova v Podebradech.

In 1921, the representatives of a German firm made certain tests in Storek's testing station on experimental turbines having a diameter of 300 mm. By comparing the test curves of Velm, Podebrady, and laboratory tests of turbines equipped with similar runners, it can be seen that the Kaplan turbine conforms with the law of development of Professor Camerer.[1]

In order to investigate the cavitation produced by high speed runners a Kaplan turbine was mounted for trial at the power plant of Mr. F. Schmitt, of Iserthal, in a setting having window panes in the suction pipe.

The wonderful results obtained at Podebrady and at Iderthal led to the installation of other plants. At Gorizia two Kaplan turbines were erected for the Colonoficio Irieslina Brunn, S.A., each having the following dimensions :—

Diameter of runner	..	1800 mm.
Power	..	1000 B.H.P.
Head	..	5 metres.
Discharge	..	20.5 cu. metres per second.
Speed	..	315 r.p.m.

In the power house at Kromeríz on the March, turbines of the following sizes were erected :—

Diameter of runners	..	2200 mm.
Power	..	1000 B.H.P.
Head	..	4.4 metres.
Discharge	..	23 cu. metres per second.
Speed	..	214 r.p.m.
Specific speed	..	1100

Official tests have not yet been made and private tests cannot be published. The efficiency curve, however, will resemble that of Podebrady.

The above information will, it is hoped, be sufficient to show that in Czechoslovakia a pioneer movement of great importance to water power development has been initiated.

[1] See Dr. Camerer, Vorlesung uber Wasserkraftmaschinen, p. 415-41.6

RÉSUMÉ.

La valeur de la "Turbine Storek-Kaplan" d'invention Tchéco-slovaque, réside dans sa vitesse de rotation relativement élevée et dans la régularité de son rendement à divers régimes.

De 1908 à 1911 les Prof. Kaplan, Mieses et Hamel élaborerent les théories des courants à dimensions multiples. Plus tard le Prof. Kaplan, en collaboration avec Mr. Storek, enterprit des recherches pratiques qui aboutirent à la Turbine Kaplan. Les résultats des essais effectués sur cette turbine à Podebrady sont représentés par un graphique.

On estime que cette turbine marque un pas important dans le développement de l'énergie hydraulique.

SPECIAL CONDITIONS OF CIVIL ENGINEERING FEATURES OF WATER POWER DEVELOPMENT IN THE DUTCH EAST INDIES

W. BLASER, M.N.R.I.E.,
Chief Hydraulic Engineer of the Government Service for Water Power and Electricity in the Dutch East Indies.

1. Since special interest has been paid by the Government to the water power problem in the Dutch East Indies (1912), several modern power stations have already been built; others are still in course of construction and numerous big schemes have been worked out in preliminary and detailed projects. As almost the whole of this work has been done by engineers who have made their technical studies in Europe, where most of them have already had some practical training in this special kind of engineering work, these schemes, generally speaking, do not differ in any way from similar developments in European or American countries. On the other hand, it is true that no two power schemes are alike and that a good solution of a problem of power development always forms a compromise between several conflicting factors. It will, therefore, be clear, that this paper will not give a description of any standard construction, but only a summary of the special hydrological, topographical and other conditions of the archipelago, which demand special requirements in the planning and execution of power schemes in these colonies. But, in consequence of the fact that the islands of Borneo and New Guinea are still practically unexplored, the following remarks only apply to the other islands of the archipelago, chiefly Java, Sumatra and Celebes.

2. When, about ten years ago, systematic research on the existing possibilities for the development of water power was started, no other hydrometric data were available than those collected by the different sections of the Irrigation Service. But these observations were to a large extent incomplete and inaccurate, because they were based exclusively on floating measurements, worked out with coefficients which had not been determined experimentally. Besides, these data were only available for those parts of the country

3,000 m. above sea-level, are situated in ranges or groups and do not form table lands of great extension. Therefore the upper part of the rivers generally have a very steep fall, the drainage areas are relatively small and possibilities for water storage are very scarce. On the islands of Sumatra and Celebes, several big depressions have caused the formation of lakes of considerable surface area.

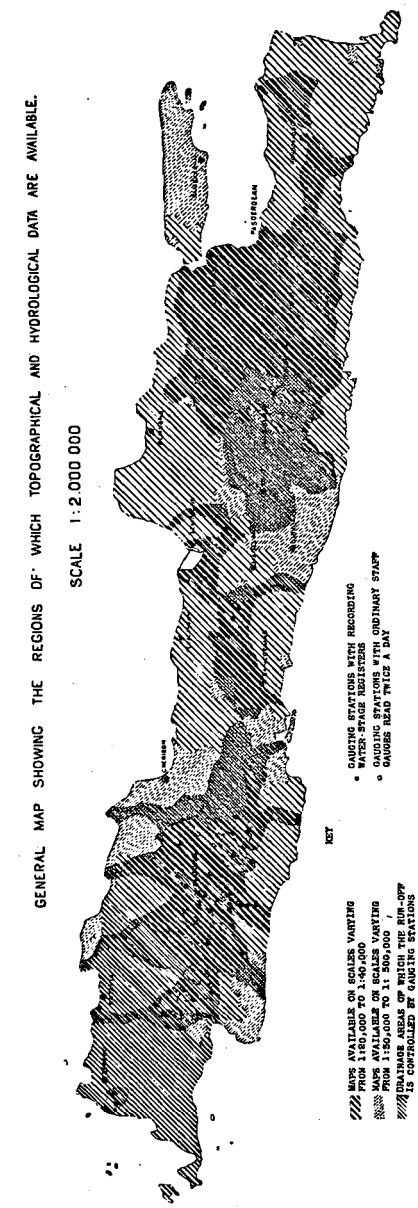
Sound rock (andesiet) generally lies deep under different strata of firm sorts of soil, which often contains a great percentage of clay. Limestone is very scarce.

Earthquakes are comparatively numerous, and although they are generally not very heavy, constructions must be selected which have a certain flexibility and will not be entirely destroyed by the least deformation or settlement of the foundations.

The climate is characteristically tropical; snow and ice are, up to the heights where power developments are possible, unknown. The evaporation is nearly constant throughout the whole year (about 6 mm. per day from water surface at sea-level to about 2 mm. on heights of about 1,000 m.). The fall of the leaves goes on during the whole year.

The yearly precipitation is very heavy, increasing from an average of about 2½ to 3 m. on average heights up to 8 m. on the tops of several mountains. South of the Equator (Java and the greater part of Sumatra) there is a dry and a wet season (monsoon), each lasting nearly six months. In many parts of Java, the total precipitation during four months of the wet season is as much as twenty times greater than that during the same period of the dry season. The heavy pelting rains, amounting to 10 inches and more in twenty-four hours, cause very sudden and serious floods in most of the rivers, with risings of the water levels from 2 to 5 m. in less than an hour. By these floods, extraordinary quantities of floating trash and sediment of all sorts, from big stones to silt, are washed down.

4. The considerations which have to be taken on account of other water users are practically limited to the irrigation. But this is such a usual kind of water right, that water power development in the lower parts of the rivers, and everywhere else where the banks consist of flat land suitable for the cultivation of rice, is practically impossible. This is the reason why, especially in Java, we have to deal with comparatively small quantities of water and high heads (about 50 to 350 m.). Other circumstances such as fishing and floating timber or bamboo, generally do not cause any difficulty to power developments.


GENERAL MAP SHOWING THE REGIONS OF WHICH TOPOGRAPHICAL AND HYDROLOGICAL DATA ARE AVAILABLE.
SCALE 1:2.000 000
KEY
MAPS AVAILABLE ON SCALES VARYING FROM 1:40,000 TO 1:40,000
MAPS AVAILABLE ON SCALES VARYING FROM 1:50,000 TO 1:500,000
DRAINAGE AREAS OF WHICH THE RUN-OFF IS CONTROLLED BY GAUGING STATIONS
GAUGING STATIONS WITH RECORDING WATER-STAGE REGISTERS
GAUGING STATIONS WITH ORDINARY STAFF GAUGES READ TWICE A DAY

5. In most of the rivers, a sufficient quantity of stones (andesiet) suitable for good masonry can be found; stone quarrying practically does not exist, owing to the scarceness of compact bodies of sound rock. In Java, the river sand is generally mixed up with such quantities of silt and clay, that it has to be washed thoroughly before it is used for mortar. In Sumatra, many river channels contain great quantities of very pure quartz sand.

Portland cement is comparatively expensive and, therefore, the use of concrete for ordinary construction work is extremely limited. Generally, only those parts of constructions are built of cement mortar, which will come in direct contact with the water and must be water-tight and have great strength at the same time. All other parts are built of lime mortar with red bastard cement, the latter being manufactured at the different places of use by burning and grinding a sort of volcanic soil containing much clay.

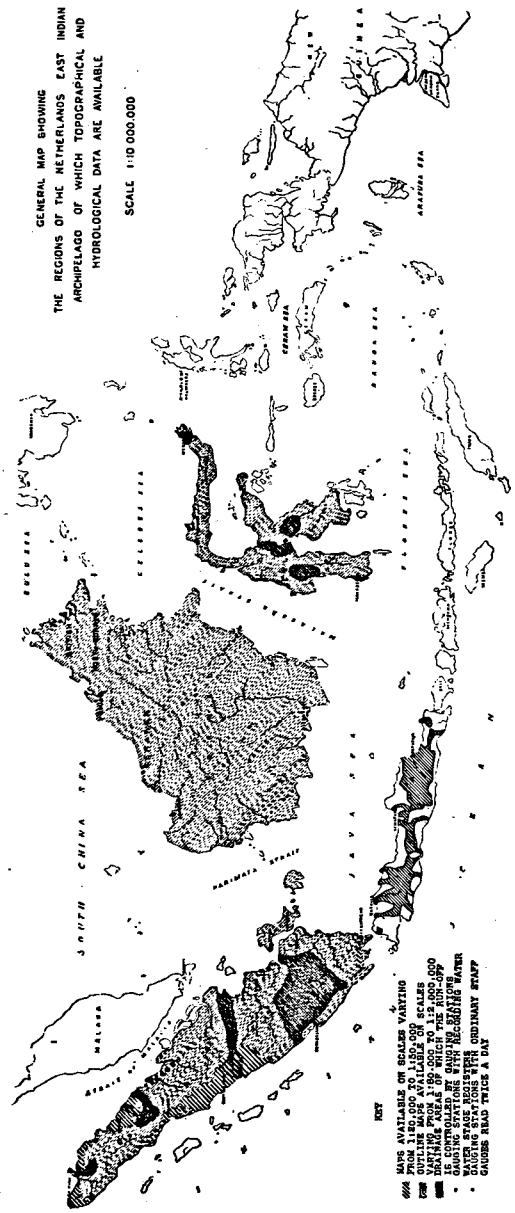
Until now, all kinds of iron have had to be imported from abroad. Because of the high temperature and the great percentage of atmospheric moisture, all steel constructions have to be carefully painted. On account of the white ants, which exist almost everywhere in the soft soil, only certain special kinds of timber, the very best being teakwood, can be used for permanent construction work.

Most of the railways have a gauge of 1 m. Owing to this fact, the dimensions of the largest pieces which can be transported in normal wagons are limited to about 11 m. in length by 2·7 m. in width and height, the maximum weight being about 15 long tons. With special cars, pieces of $11 \times 3{\cdot}6 \times 2{\cdot}7$ m. dimensions and a weight of about 20 long tons, can be transported.

The existing roads are very good, but naturally they do not approach very close to most of the principal power sites. New roads, 3 to 4 m. wide, which have to be specially constructed for building operations on these sites, cost from 10,000 to 25,000 guilders per km., including expropriation, bridges, etc.

On account of the fact that, especially in Java, native labour is very cheap ($\frac{1}{2}$ to 1 guilder a day) and generally obtainable in sufficient quantities, most of the ordinary construction work is still done by hand and only in exceptional cases by means of m chanical appliances. Owing to the lack of a sufficiently numerous population, conditions will be entirely changed when at some future date the big possible power schemes in Sumatra and Celebes are developed.

Generally speaking, the natives are very willing to do regular work and very tractable. For skilled work, they can be trained and made competent in a relatively short time; but until now, skilled


GENERAL MAP SHOWING
THE REGIONS OF THE NETHERLANDS EAST INDIAN
ARCHIPELAGO OF WHICH TOPOGRAPHICAL AND
HYDROLOGICAL DATA ARE AVAILABLE
SCALE 1:10 000.000
SOUTH CHINA SEA
JAVA SEA
MALAKKA
KEY
MAPS AVAILABLE ON SCALES VARYING
FROM 1:100 000 TO 1:1 000 000
OUTLINE MAPS AVAILABLE ON SCALES
VARYING FROM 1:100 000 TO 1:1 000 000
IG. CONTROLLED BY GAUGING STATIONS
GAUGING STATIONS WITH RECORDING WATER
LEVEL INDICATIONS
GAUGING STATIONS WITH ORDINARY STAFF
GAUGES READ TWICE A DAY

labourers have been scarce. Moreover, as the natives do not have the Western sense of duty, they are generally rather unreliable.

6. The above-mentioned special conditions have to be considered in the design and construction of power schemes and they demand in more than one respect special requirements, which can briefly be indicated as follows :

For diversion dams and intakes it is generally impossible to find sites where the foundations will reach sound, compact bedrock. The dams, therefore, consist generally of a structure of masonry, not higher than is absolutely necessary to deepen the water of the stream as far as to allow of a satisfactory intake. The underlying strata, generally, not being very firm or impervious, the foundations must be relatively deep, even for small dams. As sheet pilings are generally impossible, owing to the big stones in the river bed, the flow under the construction is cut by deep trenches filled with masonry and big aprons have to be built on the down-stream side of the dams to prevent undermining by the falling water. The only movable construction consists of a sluice gate (usually sliding and made of wood) near the intake for the removal of gravel deposits.

Intake trash-racks must have a considerable allowance for accumulation of trash on account of the big quantities of this floating material, transported during high floods, and because of the doubtful reliability of the native attendants.

Settling basins are not made greater than necessary for retaining small gravel and coarse sand. The water contains such considerable quantities of very fine silt, which cannot be removed until the water has been practically stagnant for several hours, that this sediment in suspension settles only in the forebay reservoirs. These reservoirs, therefore, have to be provided with vigorous sluicing devices.

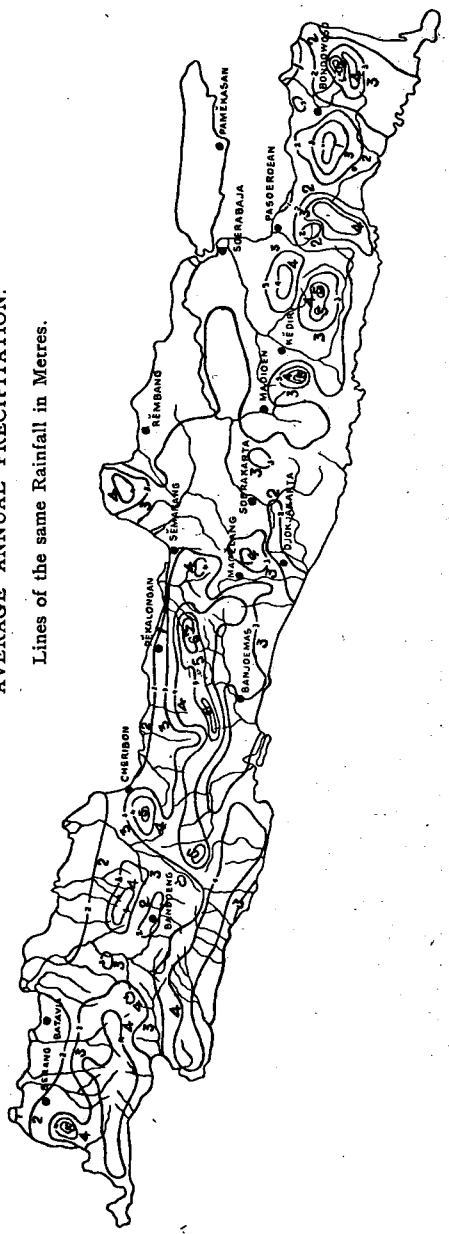
The head-race canals have to be lined along almost the whole length, not so much to prevent excessive leakage losses, which generally would not occur owing to the great percentage of clay, but to keep the hill-sides entirely dry in order to prevent landslides. Much of the hill-sides have such a steep gradient and are so frequently and deeply eroded by small torrents, that tunneling is often cheaper than open canals. They too have to be lined over almost the whole of their length. The cost of tunneling is about three times that of an open canal of the same length.

The pipe lines are generally long, because very steep runs with a sufficient stability are scarce, due to the lack of solid rock banks. For the same reason, the anchoring requires special attention and considerable masonry.

GENERAL MAPS OF JAVA 1: 5000 000, SHOWING:

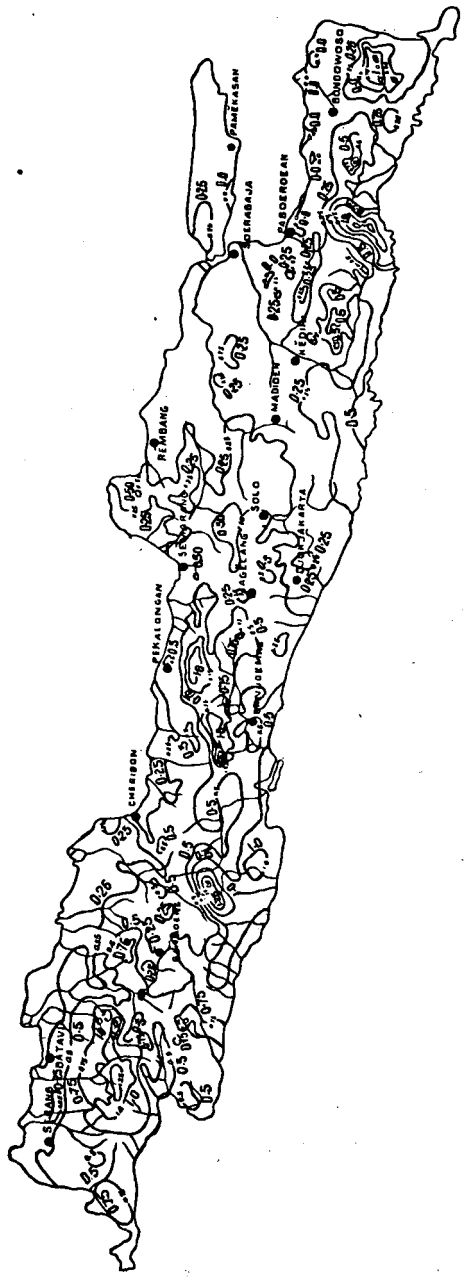
AVERAGE ANNUAL PRECIPITATION.

Lines of the same Rainfall in Metres.



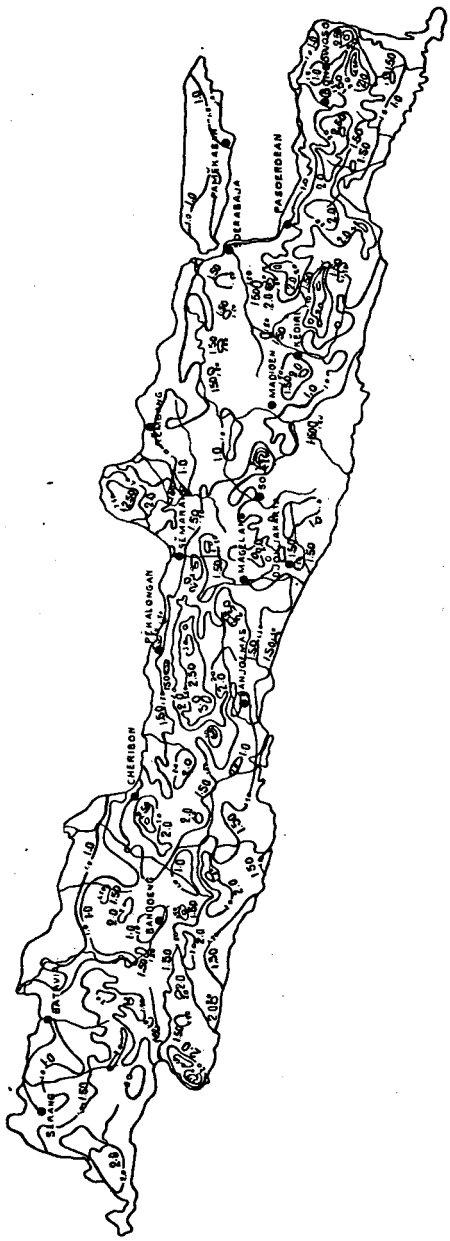
AVERAGE PRECIPITATION DURING FOUR MONTHS OF THE DRY SEASON.

Lines of the same Rainfall in Metres.



AVERAGE PRECIPITATION DURING FOUR MONTHS OF THE WET SEASON.

Lines of the same Rainfall in Metres.



AREAS, WHICH ARE REGULARLY IRRIGATED
CHERIBON
PEKALONGAN
SEMARANG
DJAPARA
REMBANG
GOENOENGKIDOEL
SOERABAJA
PASOEROEAN
BONDOWOSO
Permanent irrigation works built by the Government.
Semi-permanent irrigation works.

Storage reservoirs cannot be formed by damming the natural river channels. The enormous quantities of transported deposits would fill up the total space of accumulation in a very short time. Forebay and peak load reservoirs have generally to be excavated and lined. Except the few cases, where natural lakes can be used for storage, the available run-off during nine months is about twice the minimum flow in dry weather.

RÉSUMÉ.

Ce rapport donne une description très brève des conditions spéciales à considérer dans l'établissement et la construction de stations centrales hydro-électriques dans l'archipel des Indes Orientales Néerlandaises.

Le sujet est exposé de la manière suivante :

1°. Introduction.

2°. Importance et exactitude des données hydrologiques et topographiques dont on dispose et méthodes utilisées pour en recueillir de nouvelles.

3°. Caractéristiques physiques de la topographie, du sol et du climat.

4°. Considérations dont il faudra tenir compte du fait d'autres exploitations de forces hydrauliques.

5°. Transport du matérial et question de la main-d'oeuvre.

LARGE LOW HEAD WATER POWER DEVELOPMENTS

DR. ING. FRANZ LAWACZECK

It is possible to develop water power where the cost of hydro-electric energy is not higher than that of energy generated from fuel. One kilowatt hour is equal to about 360,000 metre kilogrammes or 850 metric calories. At a head of one metre, the potential energy of 360 cubic metres of water is able to develop one kWh. This is a considerable volume, while on the other hand the quantity of coal which contains the same amount of energy is a mere handful, one-tenth of a kilogramme. It follows that the transformation of one kWh. in a thermal power plant requires much smaller and therefore cheaper equipment than in a hydro-electric plant if the head is low. For thermal energy, the initial cost per kW. is much smaller, although the generation of energy from coal involves low efficiency, whereas the efficiency of hydro-electric transformation is high. This somewhat detracts from the superiority of coal, but all the same successful competition of " white coal " will be the exception and not the rule.

The chances of hydro-electric energy are further reduced to a considerable extent by the fact that the transportation of energy stored in coal is much cheaper than the transmission of electrical energy by wire.

Coal to generate one brake kWh. may be carried by rail for a distance of 800 to 1,000 kilometres at a cost of one pfennig, and for a much greater distance by boat, while the cost of transmitting one kWh. by a high tension transmission line is one pfennig for 150 kilometres.

Therefore, even if the cost of generating one kWh. were reduced to an amount equal to that of coal by super-power development, the radius of such a super-power hydro-electric plant is reduced very much owing to the cheaper transport of coal, and there is the possibility that the plant will not be able to sell all the generated energy within the commercial radius. The greater the distance from plant to consumer, the higher the costs—a fact that is generally ignored. The system of a hydro-electric plant should not be extended beyond the limit where it can sell its energy at this price.

In a system whose radius corresponds to this condition and whose power plant is in proportion to the selling possibilities of the district, the economy of the plant will be at its maximum.

Nor is the superiority of coal reduced by the cost of coal consumption, as coal will only be consumed when energy is required, while hydro-electric energy is charged with interest for every second, no matter whether energy is sold or not. As, at full load, the total amount of energy required will be generated during an average period of three to four months, the rate of interest, which is the principal charge against hydro-electric energy, is increased three to four times. In view of this, it is immaterial that the water costs nothing at all.

It follows that energy generated from coal is superior to hydro-electric energy on account of its low initial cost. The coal consumption is quite a secondary consideration, notwithstanding the poor efficiency of transformation. The consequence is that only about 2 per cent. of the World's water power has been developed. In 1913, that is before the war, fifty times the energy generated by water power might have been generated from the coal mined in Germany.

In hydro-electric plants, particular stress is laid on high efficiency of turbines, although the cost of motive power is nil, less attention being paid to cheapness of plant, although the initial cost per kW. determines the selling price of the kWh. Would it not be better to aim at a condition equal to that which is responsible for the superiority of coal, that is, cheaper plant, and efficiency not quite so high?

In low head plants the principal items of initial cost are those for supplying and storing the water. Here, economy is of prime importance and that is why side channels have been given up and the power plant placed in the river bed. Nevertheless, the cost of machinery is only 20 to 30 per cent. of the total cost.

Notwithstanding this, a saving in cost of machinery may be of some importance, even if the efficiency is reduced thereby. It will be necessary to consider very carefully what every single per cent. of higher efficiency is worth. At present, the importance of efficiency is generally overrated. The water quantity of a river is subject to fluctuations within wide limits, see Fig. 1. If the total water supply of a river is utilised, the number of kWh. will obviously be a maximum. But the turbines would rarely run at full load and the average load would be a minimum. The shorter the periods of

operation, the greater will be the influence of the initial cost on economy, and the less the influence of efficiency.

Therefore, a plant should be equipped with two sets of turbines, the first set to be operated continuously at practically full load, that is, in Fig. 1, it would be designed for 500 cubic metres per second.

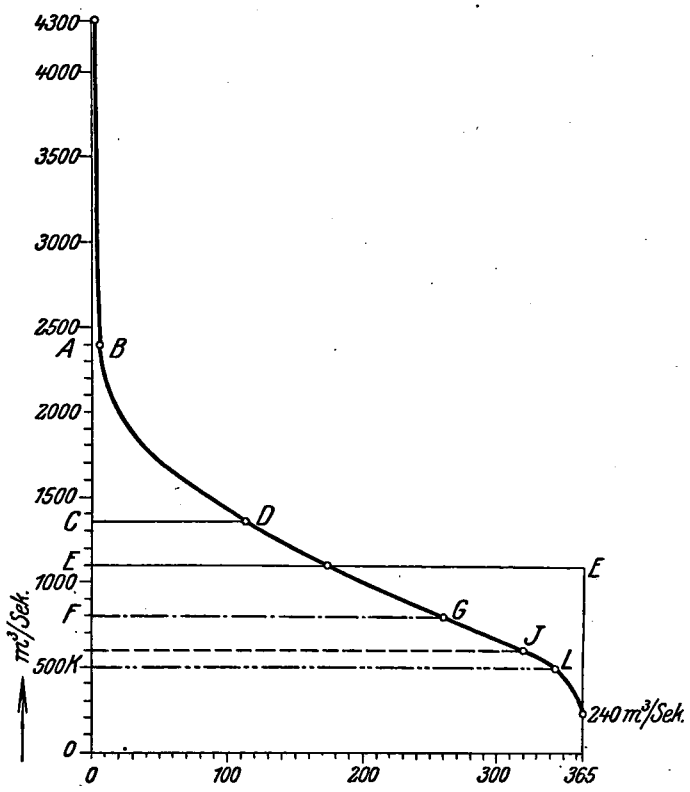


Fig. 1.

Water budget of the Upper Rhine at water mark "Basel Schifflaende" year 1917.

AB Maximum capacity to be gained by the Ruemelin plan.
CD Maximum capacity to be absorbed by main transformer.
EE Average quantity 1,100 m³/sec.
FG Plan providing for the development of 800 m³/sec.
HJ Hallinger plan providing for the development of 600 m³/sec.
KL Power aggregate I.

The efficiency of this group should be as high as practicable, as each per cent. of efficiency is valuable because it increases the output of kWh. to a comparatively great extent, owing to the continuous

operation of this first set. The second set of turbines would utilise the excess water. If the excess water were 1,500 cubic metres per second, the turbines would have to be designed for 1,000 cubic metres per second, that is, twice the capacity of the first set. This set would be under full load for only 100 days per year, and under half load for 200 days, while it would be idle for, say, 80 days. Obviously, the efficiency is of minor importance in the second set owing to the limited period of operation, while the initial cost will be the determining factor.

This second set should be as cheap as possible and its efficiency may be less than that of the first set, which may be more expensive on account of its higher efficiency.

As the second set can be installed quicker than the first one, it should be installed first, as this provides for early utilisation of power. The first set of high class machinery should be installed only after it has become necessary, owing to increased power demand.

The designing engineer is faced by two opposed problems:

1. To develop a type of machinery whose efficiency is a maximum, low initial cost being of course desirable.
2. To develop a type whose efficiency should not be too poor, while low initial cost is the primary consideration.

The development of the first type is connected with the names of Francis and Voith.

Francis found that the work in the rotating runner could have nothing to do with centrifugal action and was the first to propose inward runners. Mankind is generally slow in adopting a new development, as is clearly shown in the present case by the long period which elapsed until the new type became general. The same phenomenon may be observed at the present time in connection with the centrifugal pump, where the inward flow runner has not yet been adopted and even experts consider it as impossible. Francis' idea was applied to practical construction by Voith, at Heidenheim, Germany, and it is a memorial to his energy that the first large sized turbines at Niagara Falls are Francis turbines built by Voith.

Francis turbines are those having inward flow runners and axial discharge. All modern turbines are of this type.

The flow of the water in a Francis turbine appears to be very intricate. Since Francis turbines were first developed, investigators and designers were at great pains to throw light on this subject, but without success. For the last twenty-five years no progress has been made with the theory of flow in the turbine. Mathematical investigation, as attempted by Prasil, Lorenz and Bauersfeld, has

failed. Mathematical formulæ are an excellent means for interpreting knowledge after it has been ascertained, but it will never be possible to obtain new knowledge by developing formulæ.

The consequence was that the vanes of the Francis turbine were of arbitrary and sometimes curious form, as dictated by the instinct of the designer. It is impossible to ascertain to what extent—if at

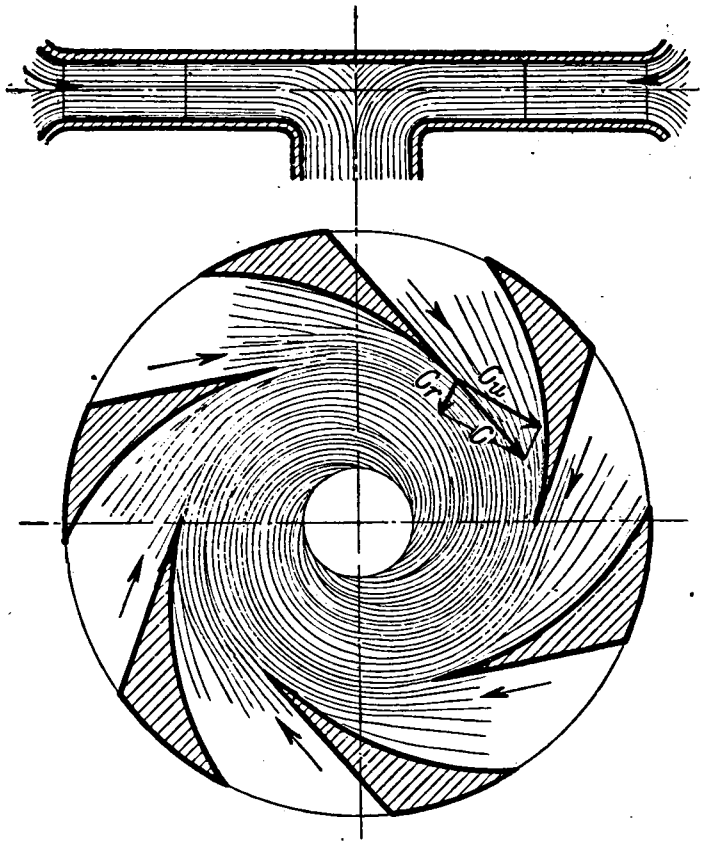


Fig. 2.
Water Eddy.

all to any—the fundamental law of work transmission, which was so clearly and simply expressed by Zeuner, based on Euler's investigations, is correct. It is also impossible to ascertain whether the ideas of the designer regarding the flow conform to what really takes place and, if not, what are the consequences, because a large number

of entirely arbitrary factors influence the form of the vanes. To make as many runners as would be required if only one of these factors were variable, is impracticable, as the designing of a wheel takes several weeks of drawing and pattern making.

To obtain fundamental knowledge about the operation of a runner, the author thought it necessary to fall back on the very simplest ideas.

By the action of the guide vanes, the water flowing into the central opening, Fig. 2, becomes a whirl. A runner is immersed in this whirl, the vanes of the said runner being of such a form that they will not influence the whirl in the entrance space, but, beyond this space, they will so alter it that the whirl is broken up at the discharge and and no more rotation components will exist in the draught tube.

If the runner is rotating while being so immersed, the pressure of deflection will do work. Theoretically, a runner may rotate in a given whirl of any peripheral speed u for the same output. The only factor influencing the specific speed is the inflow angle selected for the runner. With this angle less than, equal to or more than 90 degrees, u will be less than, equal to or more than cu, the speed of the whirl, that is, in the first case the runner will rotate more slowly than the whirl, in the second case the velocities will be equal and in the third will rotate faster than the whirl.

With the simplest idea, the work is merely influenced by the outflow, the inflow determines the specific speed, and the space intermediate between the inflow and outflow has no influence at all. The outflow space must be a helical surface whose pitch is in proportion to the axial water velocity. Similarly, the inflow space is a helical surface whose pitch, however, varies at all points in accordance with the whirl. Both helical surfaces and their intermediate surface are given by a single cylindrical section and the generating line. It follows that it must be possible to make a vane fulfilling all hydraulic requirements by means of a template.

If such a vane gives high efficiency this will be an indication that the simple idea of the operation as outlined above is sufficiently exact, the usual troublesome method of making vanes may be abandoned and a series of vanes designed in which only one of the several influencing factors, say the inclination of the generating line, or the inflow or outflow angles, is variable. Then the influence of such variables on the capacity, the speed and the efficiency may be ascertained experimentally.

The first impeller of this type, which was for a pump, made in the summer of 1914, gave excellent efficiency at a high specific speed,

so that all low pressure pumps were provided with this type of impeller. With an efficiency of 74 per cent., the specific speed attained was ns=1,500 (metric system, the English ns is got by dividing by 4·47), and this high speed was sustained at heads up to 40 metres, without cavitation troubles.

The first turbine runner of the author's type, 900 millimetres in diameter, was tested in 1921 at the Charlottenburg Technical University, by Geh. Rat Professor Reichel. Its efficiency was 87 per cent. at ns=500.

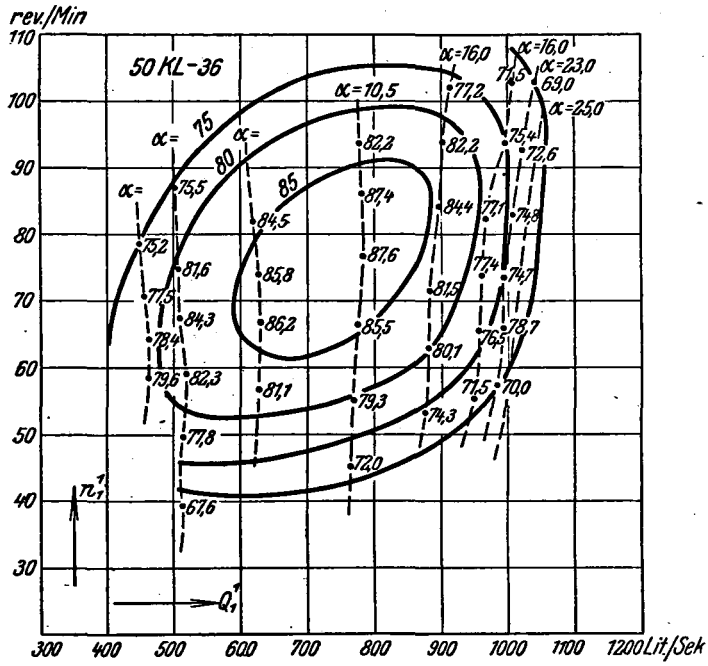


Fig. 3.

Q—n = Equi-efficiency curves for Lawaczeck Runner 50 KL—36.
D = 460 mm. (1 ft. 6 in.) conical suction pipe.
n_s = 210 (47) at $\eta_{max.}$ = 87·6 per cent.

The new type was thus shown to be much superior to the complicated turbine runners previously in use, and it was decided to test it on a large scale. Within one year, the author's company have tested forty-five runners of 200 and 460 mm. diameter, respectively, and twelve runners of 1,000 mm. diameter, the number of series of tests being about 400. In these investigations, the

influence of angles, position of vane edges, form of section of generating line, of boss, number of vanes, outflow velocities, area of blades, guide vanes and draught tube, on the capacity, speed and efficiency, was ascertained. The object of investigating three sizes of otherwise exactly similar runners was to find out the extent to which the rule of similarity could be applied.

Figs. 3, 4 and 5 show results of tests made with three runners at specific speeds of 200 to 650.

The variation of efficiency within this wide range of specific speed is only 3 per cent., although all runners were tested with the same guide vanes. The efficiency curve for constant number of revolutions at variable load becomes the flatter, the lower the specific

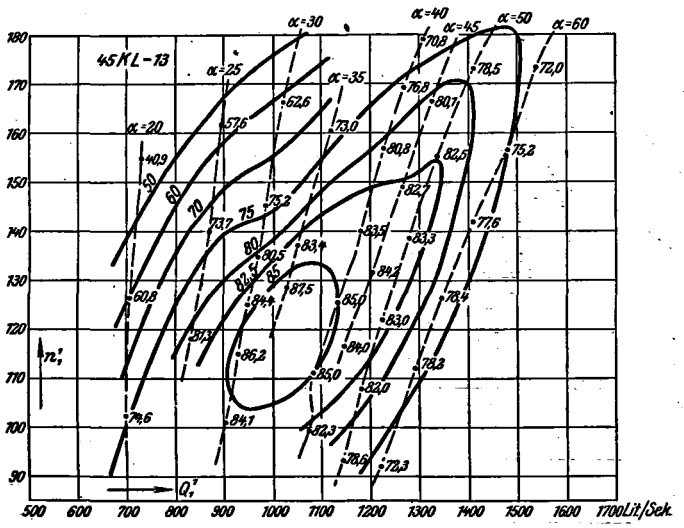


Fig. 4.
Q—n = Equi-efficiency curves for Lawaczeck Runner 45 KL—13
D = 450 mm. (1 ft. 9·6 in.); 4 Blades; Curved suction Branch.
n_s = 410 (92) at η_{max} to 640 (143) at η = 75 per cent.

speed, and is equal to, if not better than Francis runners of the old type, in this range. With the old type of Francis runner, the specific speed does not exceed 400 to 450. The new type of Francis runner gives good efficiency even at 700, and it is likely that the efficiency will be further increased as the new type is but at the beginning of its development.

The simple idea of the operation of a turbine runner as outlined

above is therefore sufficiently correct, even though the specific speed is not regulated by means of the inflow angle.

The new type is much more exact and cheaper than the old one, the time for manufacturing it being reduced by 60 to 75 per cent. Generators are cheapened considerably by the higher speeds obtained.

As explained above, high efficiency, not initial cost, is the deciding factor for the first set of turbines in the power plant considered.

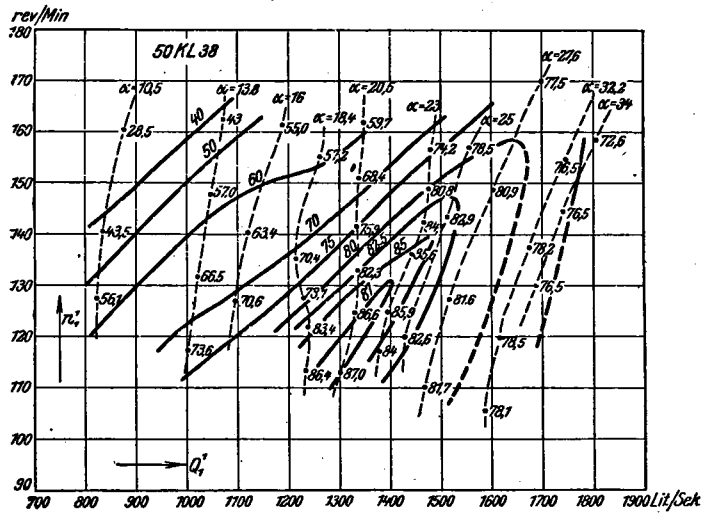


Fig. 5.
Q—n = Equi-efficiency curves for Lawaczeck Runner 50 KL—38
D = 460 mm (1 ft. 6 in.) 6 Blades ; conical suction pipe.
n_s = 527 (118) at η = 87 per cent., 600 (134) at η = 84 per cent.
630 (141) at η = 80 per cent.

For this set, the specific speed selected should be that corresponding to highest efficiency. It will probably not be economical to go beyond ns=650.

Fig. 6 shows that in the vicinity of this specific speed, the new type attains an efficiency of almost 90 per cent. These curves were taken on turbines for the Government power plant at Lilla Edet, ordered from A.B. Finshyttan, at Finshyttan, which turbines are the largest in the world, having runners of 6 metres diameter. A third turbine, also ordered for the Lilla Edet power plant, is of the Kaplan type. As this Kaplan turbine is to effect the regulation, the runner is provided with adjustable vanes in order to obtain a good efficiency at part load, the result being excellent. Therefore, the two

Lawaczeck turbines may always be run at the most favourable load, and it is no drawback that their efficiency is reduced at part load. The important point is that their top efficiencies are higher. With all this, they are much cheaper than Kaplan turbines.

The second set of the plant considered may be operated at a higher *ns*. However, the limit will soon be attained here also because by increasing the speed the cost of the generators is not reduced

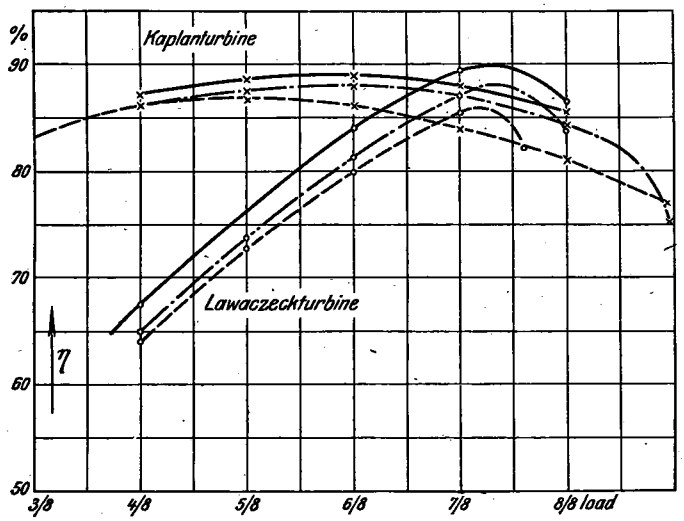


Fig. 6.

Comparison between Kaplan and Lawaczeck Turbine at " Lilla Edet "[1] power station.

———— Calculated efficiencies when enlarging diameters of runners to 19 ft. and 19 ft. 8 in. respectively.

— · — · — Guaranteed efficiencies.

— — — Efficiencies of the wheel models braked at Lilla Edet.

sufficiently. To reduce the cost a considerable extent, altogether new means must be adopted.

Since the cost of generators is the principal item of the power plant, their number should be a minimum. The problem may be solved thus: instead of generators, centrifugal pumps placed below water level, are connected to turbines. These pumps are coupled in series, the water delivered by the first pump being conducted to the suction of the second, so that the pressure is doubled, the water under this pressure being delivered to the third pump, and so on, and

[1] Rreproduced from " Tekniska Meddelanden från Kungl. Vattenfallsstyrelsen Ser.B., No. 2; Statens Kraftverk vid Lilla Edet."

the water delivered by the last pump being utilised for actuating an impulse turbine, Fig. 7. The turbine runs at high speed on account of the high pressure so that it will be comparatively cheap and, what is most important, only one generator will be required. The low pressure energy of the river is transformed into high pressure energy by the pumps in series. In one tranformer, the pressure may be increased to ten times the head, so that with six transformers the

Fig. 7.
Transformer chamber of the Muffat weir plant in the Isar river at Munich.

head of the impulse turbine would be sixty times that of a low head turbine. The total efficiency of transformers may attain to 70 to 72 per cent., being 64 to 66 per cent. at the generator shaft. This is not high, but the cost of the plant is but one-third. Besides, very considerable savings in buildings are feasible so that the cost of the power obtained is reduced by 50 to 75 per cent.

An experimental transformer plant of this type was built in the Isar River, at Munich, about a year ago, and is in successful operation during high water periods, Figs. 8 and 9.

Owing to the intimate co-operation of turbines and centrifugal pumps, no torque is transmitted to the foundation by the transformer. The foundation, therefore, may be much weaker than a foundation for generator turbines in which the foundation is stressed

not only by the weight but also by the total torque from the turbine to the generator casings. Any unsteadiness of the foundation is prohibitive for the operation of the generator, while the transformer is not influenced thereby, and its weight is but a fraction of the generator weight. The dam containing the transformers may therefore be constructed with consideration to the water pressure

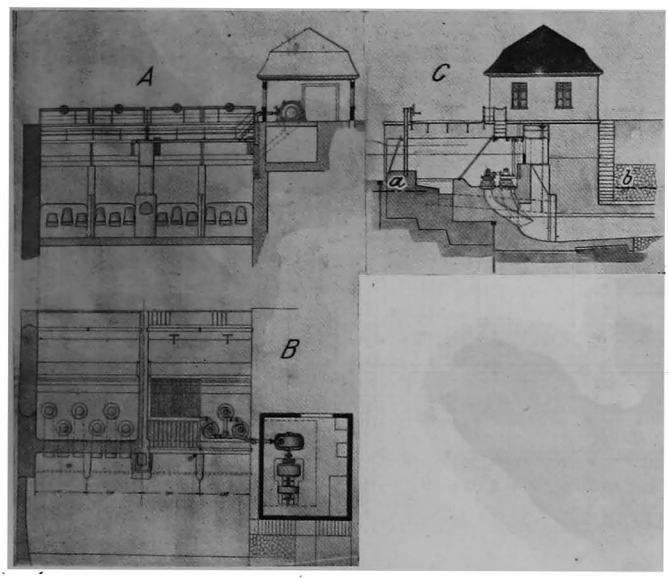


Fig. 8.

Trial station of a transformer plant, as mounted in the Muffat weir, Munich.
A. View from low water side
B. Section a—b and ground elevation
C. Cross section.
Erected and in operation six transformers, coupled in series, consuming 100 to 140 cu. ft. of water at H = 10 ft. Pressure at Pelton wheel abs, 500 ft. Mean efficiency of plant 55 per cent.

only, saving considerably. Every power plant requires an expensive dam construction to get rid of the excess water. If a transformer is placed in such a dam, the dam will become cheaper and the excess water will be utilised. The cost of the dam must not be charged against the tranformers, but only the very low costs of the transformers to determine the cost of the kWh. developed by this set. Therefore, transformers will pay even if they are only used with excess water on 100 days per year, but they should be considered when designing the plant so as to profit by all possible savings in the

cost of the dam and be able to design the expensive main set of turbines as favourably as possible. Frequently it is necessary to conduct away high water peaks, which may last for a few days only, through energy destroyers. Here, transformers will be useful which will utilise the energy of such water.

The less the building costs, the less important will be the efficiency of the turbines. There is a limit, however, where the cost of the

Fig. 9.
Transformer plant at Muffat weir, Munich. View from low water side.

machinery becomes important even for set No. 1. This applies to large rivers in a flat country. The fall of such rivers is about 0·6 metres per kilometre. Side channels would have to be rather long, besides consuming a considerable head. Channels with earth slopes require a gradient of 0·4 m. per km., leaving only 0·2 m. per km. for utilisation, an obvious impossibility. In concrete channels, the loss is reduced to 0·05 to 0·08 m. per km. In any case, side channels will have a loss of 8·5 to 13 per cent. of the river head.

It is impossible to supply to the side channel the entire water quantity of the river, for the obvious reason that a certain amount of water must remain. The influence of the low water period is of longer duration in side channels and reduces the average water content of the channel by 10 to 15 per cent. Transformers in the

river bed, on the other hand, will utilise every drop of water apart from the excess quantities which a side channel is never able to utilise.

Side channels lose 18·5 to 28 per cent. of the energy they take from the river, a loss that cannot be made up even with the best turbines, considering the cost of the channel.

The loss of the transformer is 25 to 30 per cent. so that it should be

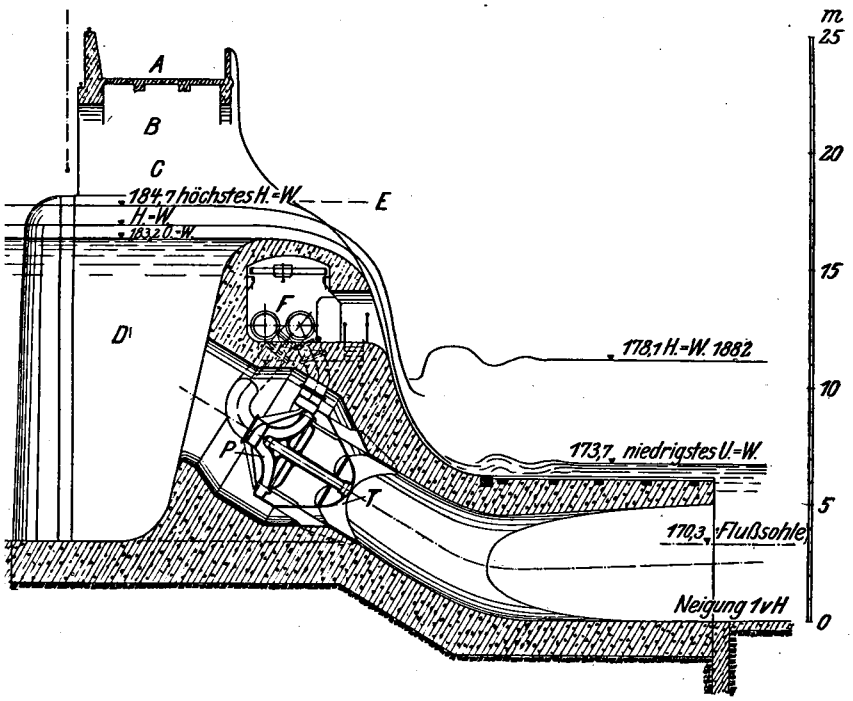


Fig. 10.

Transformer weir (reproduced from: Ruemelin, Der Staffelflussausbau, München Dreilaenderverlag 1923).

A. Operations bridge
B. If necessary: room for traveller
C. Pillar (30 m. span)
D. Side walls between each two Transformers
E. Transformers working even at maximum high water
F. High pressure pipes
P. Pump Impeller
T. Turbine Runner

höchstes H=W: maximum high water.
niedrigstes U=W: minimum low water.
Flussohle: Lowest point of river bed.
Neigung 1 v.H.: Gradient 1 per cent.

preferred on account of its cheapness. Besides, the transformer is able to utilise the entire water quantity of the river, so that a transformer plant is able to get much more energy out of a river than a side channel. Transformers are able to utilise the smallest heads. If a river is to be made navigable by weirs, such weirs may be as low as required and permissible with consideration to agricultural requirements. The head is always sufficient for operating a transformer if only there is enough water.

From Bâle to Strassburg the average fall of the Rhine is ·8 m. per km. This fall causes currents which greatly obstruct navigation. By transformer weirs, as shown in Fig. 10, it is possible to obtain unobstructed navigation and to utilise the power of the river at the same time. The well known engineer, Rümelin, who is responsible for the development of the Isar River, has worked out a scheme for transformer plants of the type described. Nine transformer weirs will be constructed on the line, which is 120 kilometres, and power plants of 115,000 kW. each will be served by the said transformer plants.

A comparison of Rümelin's scheme with the well known schemes providing side channels, is given in the following table.

	Scheme.		
	Hallinger's	French	Rümelin's
Available volume in cubic metres per second	600	800	1,100 not including high water.
1. Electrical energy, milliards of kWh. per year	3·3	3·78	5·04
2. Initial cost, milliard marks, index August, 1920	1·95	2·24	1·80
3. Cost per kWh. pfennigs index August, 1920	4·7	4·7	2·95
4. Annual earning, milliards marks	24	28	188
5. General	Obstruction of navigation, unfavourable to agriculture.		No obstruction, development of agriculture.

It is not necessary to make any comments on this. The transformer is obviously a commercial means for increasing the small energy density of rivers and so enabling them to be utilised. Consequently, it will be useful where great amounts of energy but of small density, are found, particularly for utilising tidal power. Its development will be favoured by the fact that it does not obstruct but facilitates navigation.

RÉSUMÉ.

En raison de l'installation coûteuse (et des intérêts élevés) des stations centrales de force motrice hydraulique, spécialement celles pour l'utilisation des faibles chutes, il est recommandé de n' installer des machines chères avec un rendement maximum que lorsque la charge permanente de la centrale le demande. Pour les turbines de ce genre un mode de construction et de fabrication très simple de la roue turbine est indiqué, où le moule pour les aubes de forme hélicoïdale est fait au moyen d'un gabarit. Toute la quantité restante d'eau disponible est utilisée par des turbines simples, légères et moins coûteuses, sur l'arbre desquelles est montée directement une pompe centrifuge. Toutes ces pompes d'une installation sont mises en série, de sorte que l'eau à haute pression débitée par la dernière pompe de cette série est admise à une petite turbine à haute pression et à grande vitesse accouplée à un petit générateur peu coûteux. Des " Transformateurs de chute," semblables à ceux décrits sont applicables pour l'utilisation et la régularisation des grands fleuves en les installant dans le barrage de chaque gradin à côté des écluses et sans gêne pour la navigation.

EXPERIMENTAL RESEARCH IN THE FIELD OF WATER POWER

D. THOMA,
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EVOLUTION OF RESEARCH WORK IN GERMANY.

The theory of water turbines has represented since the time of Euler a favourite field for theoretical research. The first turbine designs were almost exclusively based upon theoretical speculation. With the development of turbine construction during the second half of last century, sensible engineers soon recognised that theory, even if logically deduced, is unable to explain the complex facts of reality on account of the simplifying and not always exact assumptions underlying all theories, and that these must be supplemented by experimental research. This opinion led, more than forty years ago, to the foundation, by W. Hansen, of the first German laboratory, near Gotha, in Central Germany. Many laboratories have since been founded in Germany; the more important firms have long made it a principle that no turbine must be delivered unless a geometrically similar trial turbine on a smaller scale had been previously tested. The computing of figures obtained in laboratories for the larger dimensions and heads of actual plant has proved itself very reliable. In the few cases in which divergence was noted it has been proved that lack of geometrical similarity between model and full-size machine was the cause. The increase of efficiency through enlargement of dimensions can be introduced as correction; the formulæ indicated by Camerer have been found to be fairly correct. For this reason it is permissible to experiment with relatively small runners which are more economical, so that one can obtain and test a large number of runners at reasonable cost.

The fact that the whole German turbine design has been based for a long time upon experimental research is, curiously enough, not sufficiently emphasised in the press. Though many laboratories have been described in technical periodicals and reports on research work, text books say little about the fact and some text books are misleading enough to suggest that it is possible,

by the aid of theory alone, reliably to design turbines, even those with high specific speed. This circumstance may have led sometimes to an incorrect judgment on German water turbine practice.

Table (1a and 1b) contains details of German water turbine laboratories, so far as I could obtain particulars. It may be mentioned here, that firms who do not own laboratories often make use of the laboratories of the Technical Universities.

TABLE No. 1a.

LABORATORIES OF HYDRAULIC ENGINEERING FIRMS.

Firm.	Name or Place of Laboratory.	Built	Experimental head. m.	Maxim. quantity of water li/sec.	No. of Test beds.	
Fritz Neumeyer A.G., Munich	Mechterstädt	1880	2·5	600	1	*
	Sundhausen	1884	2·25	600	1	**
with Briegleb, Hansen & Co., Gotha	Gotha	1913-14	4·5	1,200	2	
	Small laboratory Gotha	1913	30·0	120	1	
F. Schichau, Elbing	——	1920-21	11·1	2,400	2	
J. M. Voith, Heidenheim	Bettenbach a/Nagold	1895	6·0	5,000	1	***
	Itzelberg a/Brenz	1896	2·6 280	2,500 20	1 1	†
	Bleiche, Heidenheim	1900	1·6-1·9	4,500	1	††
	Hermaringen	1907-8	2·0-5·8	10,000	2	
	Brunnen-Mühle	1908-9	6-100	450	5	
	Small laboratory, Brunnen-Mühle	1918-19	2·0-3·0	280	1	†††

* closed down, 1884.
** „ „ 1914.
*** „ „ 1904.
† „ „ 1899.
†† „ „ 1908.
††† Being rebuilt for head of 10 m. and 540 li/sec. water.

TABLE No. 1b.

LABORATORIES OF TECHNICAL UNIVERSITIES.

Technical University.	Principal of Laboratory.	Built.	Experimental Head. m.	Max. water quantity litres/sec.	Number of Test Beds.
Charlottenburg.	Prof. E. Reichel	1904-6	1·56	2,500	1
			6	300	2
			400	50	2
Danzig.	„ Schulze-Pillot	1910	4·3	130	2
			28		
Darmstadt.	„ Wagenbach	1903-4	5·5	1,000	5
			70	20	
			300	7·5	
Dresden.	„ Lewicki	1900-2	4	1,200	5
			100	26	1
Hanover.	„ Oesterlen	1913-14	5	900	6
		1919-21	30	100	
Karlsruhe.	„ Spannhake	1923-24	4·5	125	1
Munich.	„ D. Thoma	1911-14	5·5	2,200	4
			18	1,100	1

TEST BENCHES FOR THRUST BEARINGS.

Firm.	Shaft.	Load up to	Speed up to
Fritz Neumeyer, A.G., Munich.	vertical	250 to	350 r.p.m.
J. M. Voith, Heidenheim	vertical	45 to	600 r.p.m.
	horizontal	15 to	1,000 r.p.m.

METHODS OF RESEARCH.

To improve an existing turbine design, one builds a somewhat similar trial turbine and finds experimentally the alterations of its qualities. Alteration without fixed aim leads forward very unsteadily. A useful method has been one which I have termed " the principle of superposition of small variations." From an existing shape of vane new forms are deduced by the addition of some small " variations." The changes, partly favourable, partly unfavourable, of the hydraulic qualities are found through the trial. The favourable variations are selected and superposed on the original form and it may rightly be expected, that the *effect* of the separate variations is also superposed, and that, therefore, a better runner has come into existence, which can serve as basis for a repetition of the process.

This method meets with various difficulties; first, the superposition rule comes true for small variations only; therefore, the alterations of the hydraulic qualities are also only small, so that very accurate checking is required. This difficulty has been overcome by the improvement of the method of measuring. Secondly, it is also difficult to draw the superposition of the variations, if the vane surface is represented by a series of curves.

Dr. Lawaczeck has made some progress here, however. Following his theory, he represented the vane shape for propeller turbines by an equation containing several (2-3) parameters. A variation of the vane surface can now be fixed by the variation of a parameter; the superposition of different variations is effected by the simultaneous variation of the parameters and thus made possible in a simple and straightforward manner. The judging of the various test results is very much facilitated, for the shape of the vane surface is given by a few figures—the only thing that makes systematic filing of the results at all possible. A great advantage in research work has been secured in this way, which has no doubt contributed to the success of Lawaczeck's work considerably.

I am of the opinion that this method will prove fruitful without restriction to any special theory and for other forms than that particular one of Dr. Lawaczeck, for the improvement of turbines.

RECORDING THE RESULTS.

The comparison of the results obtained in various countries is impeded by the diversity of the measuring systems. Moreover, many coefficients are chosen arbitrarily; as an instance, for the specific speed the power is measured by 75 mkg. *per second* (in the metric system), whilst the revolutions are counted by the *minute.* For this reason I suggest the adoption of absolute coefficients.

The specific angular velocity ω_s can be termed the angular velocity of a turbine, which under a head 1, at gravity 1, driven by a fluid of a specific weight 1, gives an output of one weight unit × linear unit in the time unit.

If A is the power of a turbine $\frac{(\text{weight unit} \times \text{linear unit})}{\text{time unit}}$

ω the angular velocity, H the head, g the gravity and γ the specific weight of water, then with

$$\omega_s = \frac{\omega\sqrt{A}}{H^{5/4}\, g^{3/4}\, \gamma^{1/2}}$$

ω_s becomes absolute, its value independent of the measuring system.

By calculating with $g = 9{\cdot}81 \frac{m}{set^2}$ and $\gamma = 1000 \frac{Kg}{m^3}$ one finds the following relations to the usual coefficients,

$$n_s \text{ (metric)} = 193{\cdot}3 \ \omega_s$$
$$n_s \text{ (ft.-lb. system)} = 43{\cdot}47 \ \omega_s$$

A turbine of normal specific speed has approximately the specific angular velocity 1.

The power, discharge and angular velocity can be expressed in a similar way by absolute coefficients, taking into consideration the diameter D of the runner.

$$K_N = \frac{A}{D^2 H \sqrt{g H} \cdot \gamma}$$

$$K_Q = \frac{Q}{D^2 \sqrt{g H}}$$

$$K_\omega = \frac{\omega \cdot D}{\sqrt{g H}}$$

$$\frac{K_N}{K_Q} = e$$

$$K_\omega \cdot \sqrt{K_N} = \omega_s$$

With the usual coefficients N_1', Q_1' and n_1', which express power (H.P.), discharge and number of revolutions for a runner of diameter 1 and under a head 1, the following relations exist :—

$$K_N = 0{\cdot}02395 \ N_1' \text{ (metric)} = 1{\cdot}553 \ N_1' \text{ (ft.-lb.-system)}$$
$$K_Q = 0{\cdot}3193 \ Q_1' \text{ (metric)} = 0{\cdot}1763 \ Q_1' \text{ (ft.-lb.-system).}$$
$$K_\omega = 0{\cdot}03343 \ N_1' \text{ (metric)} = 0{\cdot}01846 \ N_1' \text{ (ft.-lb.-system).}$$

It is to be hoped that by the adoption of these absolute coefficients the international exchange of experiences may be advanced.

SOME TEST RESULTS.

The Fritz Neumeyer A.G., Munich, has applied itself since 1920 (at the start jointly with Dr. Lawcazeck) to the development of the propeller turbine. A test carried out at their Gotha laboratory (Fig. 1) with a propeller turbine with relatively low specific angular velocity has produced efficiencies shown by Fig. 2.

The efficiency of a propeller turbine for higher specific angular velocities, built by J. M. Voith, Heidenheim, is shown on Fig. 3. The test was made in the Hermaringen Laboratory

The firm of Voith has occupied itself also with the development of the Kaplan turbine and has achieved the improvement shown on Fig. 4 against the original form.

If one considers the improvement of efficiency, due to the increase of the runner diameters, one can justly draw the conclusions from these test results that to-day an efficiency of 90 per cent. can be obtained with certainty from large turbines with $\omega_s = 2{\cdot}5$ approximately, and can be easily surpassed with lower ω_s, assuming naturally that the total arrangement of the plant is hydraulically favourable. This agrees with the results obtained in America.

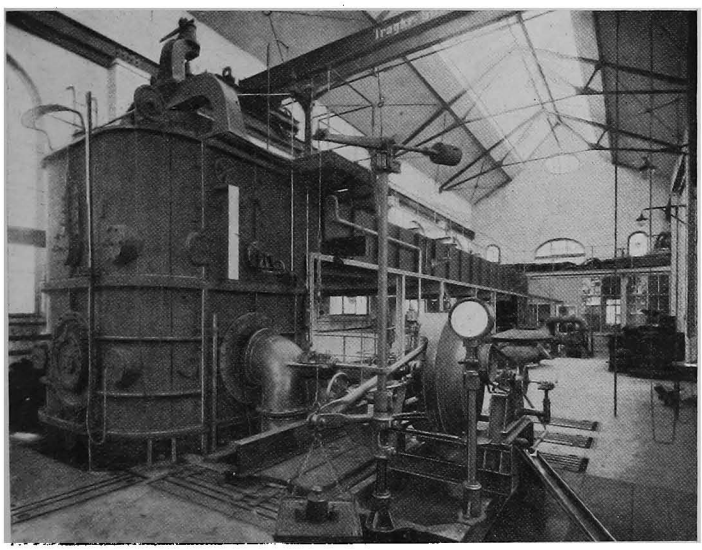


Fig. 1.
The Gotha laboratory of the Fritz Neumeyer A. G., Munich.

Cavitation, however, forms a serious obstacle against high efficiency and high specific angular velocities.

THE PROBLEM OF CAVITATION.

Attention has been given in all countries for several years to the trouble arising from a high suction head. A high suction head is desirable in almost all plants in respect of the construction of the power house and sometimes is a deciding factor in the whole layout

of the plant. Unfortunately turbine manufacturers concede to their customers, who sometimes know little of this matter, excessively high suction heads to the detriment of themselves and their clients.

Void spaces are formed with excessive suction heads at first probably behind the exit tips of the runner vanes, perhaps also close behind the entrance tips in runners with high peripheral velocity,

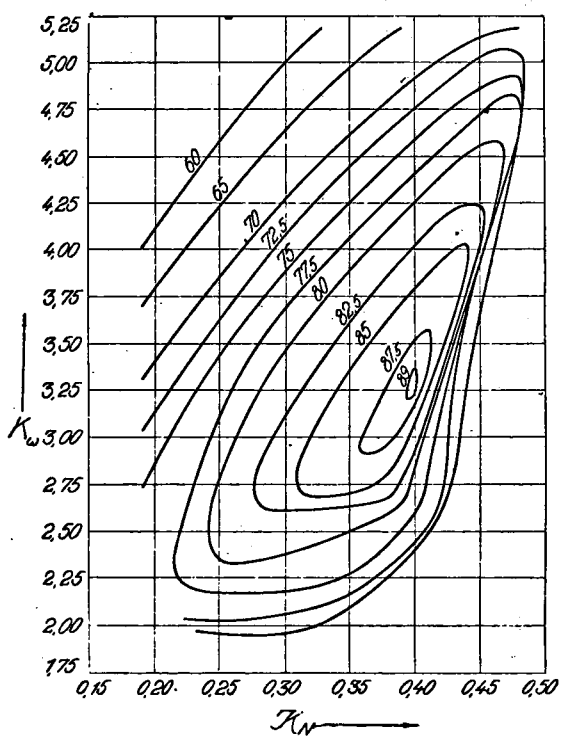


Fig. 2.

Efficiencies in per cent. of a Propeller Turbine of the Neumeyer Works, obtained with a runner of 460 mm. = 18 in. diameter.

especially if the speed or the gate opening are abnormal or if the vanes are thick and not flattened enough in front. Further increase of the suction head leads probably to a cavity extending all over the back of the vane. The detrimental effect of cavitation is felt in three directions. First, it alters the water flow so that power and efficiency may be reduced; a relatively small cavity on the rear

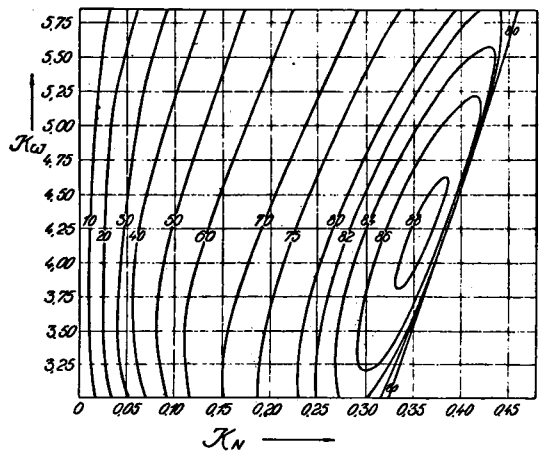


Fig. 3.

Efficiencies in per cent, of a Propeller Turbine of J. M. Voith, obtained with a runner of 700 mm. = 27½ in. diameter.

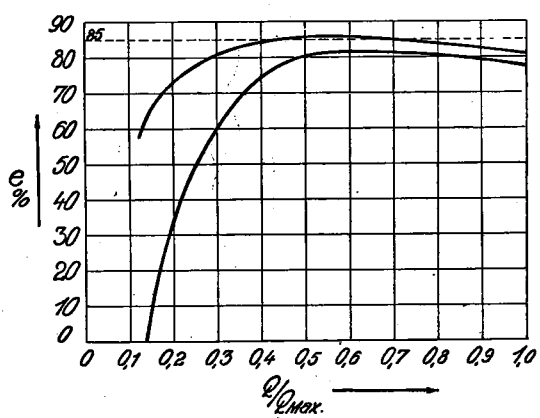


Fig. 4.

Efficiency curves of two Kaplan Turbines, designed by J. M. Voith. Lower curve = original form; upper curve = improved form. $\omega_s = 3{\cdot}8$.

edge may suffice for this. Secondly, the formation of a void results in the freeing of gases contained in the water (chiefly oxygen), which attack the material of the vanes, as the protective oxide layer is always knocked off by the fast running water in turbines with high head. A condition for this seems to be that the cavity is not stationary. Thirdly, noise may arise, from a faint creaking to heavy concussions, which damages machinery and buildings.

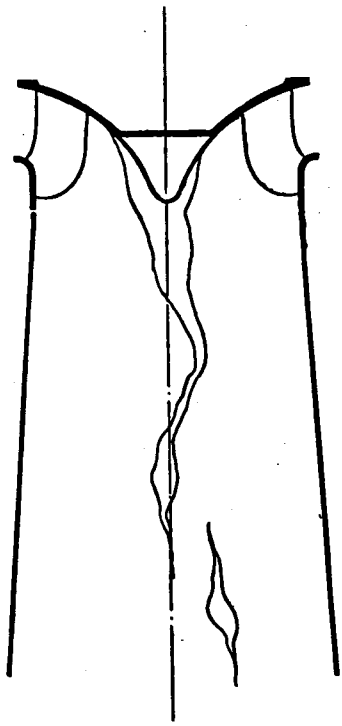


Fig. 5.
Cavitation at great values of c_{u2}

The noise originates from particles of cavities being torn away by the water flow and filling in regions of higher pressure.

Of a special kind is the cavity not arising directly at the runner, if, with abnormal speed or gate opening, c_{u2} is larger. As, after leaving the runner c_u increases in inverse ratio to the radius, very high velocities and a corresponding drop of pressure originate near the centre line, and may lead to the formation of a central cavity and heavy concussions (Fig. 5). As a counter measure against

this trouble may be considered the central core, which rises from the suction chamber to the hub of the runner. It has been introduced by American engineers and may prove advantageous in other directions too.

Much can be found theoretically regarding cavitation, especially on propeller turbines; for these, the measurements of the pressure distribution on aeroplane wings can be taken into consideration. But only experiment will give reliable results. As such tests—like the usual brake tests—can be carried out with small turbines and low heads only, a computing scheme must be worked out.

THE LAW OF SIMILARITY FOR CAVITATION.

Let us consider a turbine (Fig. 6) with the headrace (level 0) at

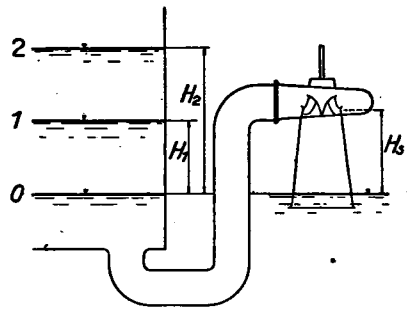


Fig. 6.

first at the same level as the tailrace, the total head being $H=0$, and all parts filled with water completely. If the suction head (elevation of runner above tailrace) is termed H_s and the barometric suction head (corresponding to atmospheric pressure minus vapour pressure of the water) H_a, a reserve exists in the runner against cavity formation equal to a pressure H_a-H_s. If the headrace level is raised, the arising waterflow causes a dynamic pressure reduction in the runner. If the beginning of cavitation is noticed after a raising of the headrace to level 1, corresponding with a total head H_1, it means that the dynamic pressure reduction just balances the previous reserve H_a-H_s. Without making assumptions on the flow in the runner, one can state that the dynamic pressure reduction is proportional to the total head H, if the angular velocity of the turbine is altered proportionally to $\sqrt{H}$. If, for instance, the headrace is raised to double the height, to level 2, corresponding to a total head $H_2=2H_1$, then the dynamic pressure reduction is doubled also. If the original pressure reserve would

have been double the former value, the turbine would then again touch the limit of cavitation. This proves that the same conditions exist for cavitation, as long as $\frac{H_a - H_s}{H}$ remains constant. The same result can be obtained from H. B. Taylor's and L. F. Moody's theoretical deductions, which were put before the Hydro-Electrical Conference, at Philadelphia, 1922, and which rest upon special assumptions regarding the flow.

If one accepts the absolute coefficient

$$\sigma = \frac{H_a - H_s}{H}$$

as measure for the conditions inducing cavitation, it must be added that an exact mechanical similarity between model and actual turbine is conditional upon $\frac{\text{runner dia.}}{\text{head}}$ being the same for both. In case of non-fulfilment of this condition the static pressure on the vane surface will not vary in relatively the same manner as in the actual machine; but this should remain negligible, at least for vertical shaft single runner type turbines. To be on the safe side, H_s must be measured to the top of the runner vane, if $\frac{D}{H}$ is larger in the actual machine than in the model. In the test results given below, the suction head is calculated from the centre of gravity of the exit tips of the runner vanes.

CAVITATION EXPERIMENTS.

The firm of Voith has tested two Kaplan turbines under nearly constant headrace level and adjustable tailrace level with the results as shown in Fig. 7. The efficiency of the runner with the larger vane area increases with rising suction head from 81·3 to 82·0 per cent. The firm attributes this increase to the relative reduction of friction losses with the higher total head; but the experiment referred to below lets one think of other possible causes.

I have installed in my laboratory a testing arrangement according to Fig. 8. Gate valves are inserted into the pressure pipe immediately after the tank and in the suction pipe at the lower end of the vertical section. Before the start of a test the air is removed by closing the lower and opening the top valve. During tests the throttling is done on both valves so that the absolute pressure at the draft tube end assumes different values the total head remaining the same. After tightening all joints and water-sealing the

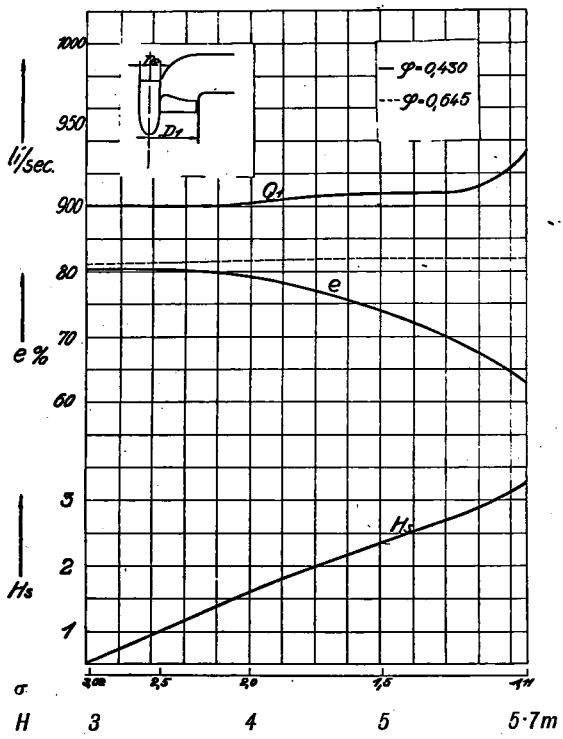


Fig. 7.

Results of cavitation tests with two Kaplan Turbines; built and tested by J. M. Voith. $\omega_s = 4{\cdot}15$. Barometer 718 mm. Hg. Water temperature 14°.

$$\varphi = \frac{\text{projected area of blades}}{\frac{D_1^2\,\pi}{4} - \frac{D_2^2\,\pi}{4}}$$

dangerous spots, all parts remained completely filled with water during the tests. The total head is measured by means of a differential mercury gauge connected between *a* and *b* the suction head by means of a common mercury gauge at *b*. The arrangement provides geometrically correct conditions and at the same time the possibility of lowering the absolute pressure at the end of the draft tube. Several months were required to remove all small faults. The measurements were then very exact; as the total head (within 0·3 per cent. and in later tests within even narrower limits) and the gate opening are kept constant all sources of faults remain unaltered during a change of suction head so that *alterations*

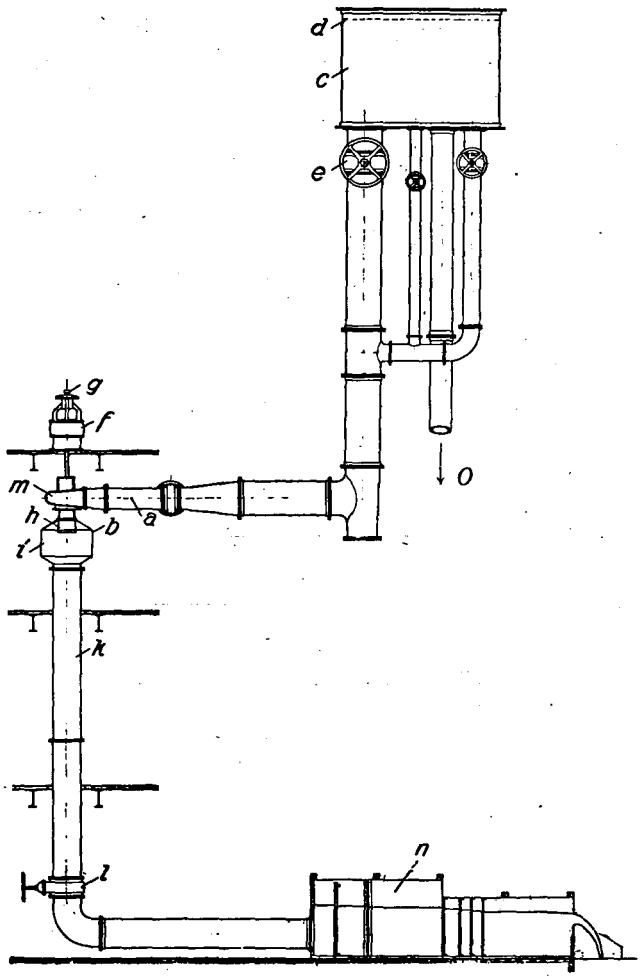


Fig. 8.

Arrangement of cavitation tests in the Munich laboratory with a spiral casing turbine with runners of 180 mm. = 7 in. diameter.

Differential mercury gauge connected between a and b, simple mercury gauge at b.

c tank
d crest of spillway
e gate valve
f D.C. generator
g pulley for recording tachometer
n weir box
h draft tube of the turbine
i suction tank
k suction tube
l gate valve
m turbine casing
o drain of surplus water

of power discharge and speed can be observed very closely (error less than 0·1 per cent.). For every suction head three measurements were taken at slightly altered speed to interpolate for a constant K_ω. To exclude any errors due to the bearings or the windings of the generator not having reached stationary temperatures, measurements were operated several times without stopping.

First a Francis turbine with $\omega_s = 1{\cdot}55$ was tested with gate opening for max. power and with gate opening for max. efficiency. The results are given in table 2. The zone of strong cavitation has not been reached, yet an influence can be noticed plainly though in an unexpected direction.

TABLE No. 2.

a	H_s	3·28 m. = 10 ft. 9 in.	7·71 m. = 25 ft. 3½ in.
	σ	0·656	0·192
	K_N	0·350₀	0·352
	K_Q	0·444₆	0·441₀
	e	0·794₀	0·800₂
b	H_s	3·14 m. = 10 ft. 3½ in.	7·61 m. = 25 ft.
	σ	0·671	0·202
	K_N	0·292₈	0·295₂
	K_Q	0·347₄	0·346₅
	e	0·842₂	0·851₂

Total head constant = 12·3 m. = 40½ ft. Barometer 710 mm.Hg. Temp. of water 10° Cent. Gate opening constant: *a* for max. power, *b* for max. efficiency. The last figures in small print are unreliable.

A propeller runner with $\omega_s = 2{\cdot}58$ was then tested for all suction heads from −0·15 m. (−½ ft.) to 7 m. (23 ft.) in a total head of 9 m. (29 ½ft.). The results can be seen from Fig. 9. Noise was heard at $\sigma \leq 0{\cdot}37$.

OTHER METHODS FOR THE IMPROVEMENT OF RUNNERS.

By observing the details of the flow in front, inside and behind the runner one can recognise disturbances and find remedies for them. Tests in which the flow has been measured with Pitot tubes have frequently been made and published. They have given insight into the very complex actual happenings. Measurements with Pitot tubes have the disadvantage that only some average value of velocities is obtained if the flow is non-stationary and that one cannot differentiate between a non-stationary flow of high frequency and a stationary one. For this reason I am of opinion that the optical observation of coloured current veins is very important, though qualitative results only are obtained.

I have reported previously on investigations during which the image of the exit side of a Francis turbine was brought to rest by an optical device, so that direct observation was possible. Francis turbines permit of only partial observation of the flow on account of the overlapping of the vanes and the presence of the outer rim. Better conditions prevail on the propeller turbines. With them the stroboscopic observation from the radial edge of the vanes through a glass window may be considered. Investigations are being made at present in Germany in this direction, but no results have been published so far.

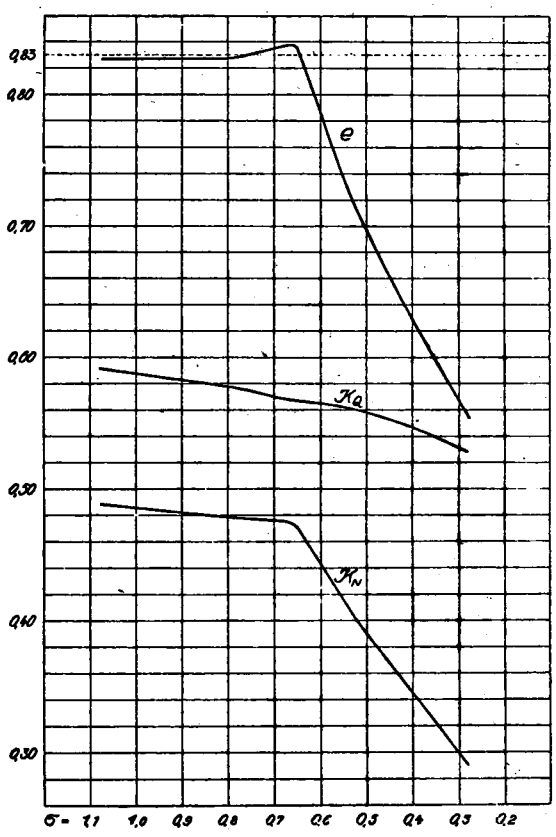


Fig. 9.

Test results with a propeller runner at various suction heads, total head 9·0 m. = 29½ ft., and gate opening remaining unchanged. Barometer 708 mm. Hg., water temperature 10° c.

FURTHER PROBLEMS FOR EXPERIMENTAL RESEARCH.

Since the great influence of the bent draft tube has been discovered by the laboratory at Sundhausen in 1905, the experimenting with draft tubes has gone on to the present day. As it was soon proved that various runners show different degrees of sensitiveness towards the noxious influence of the bend, it became clear that draft tubes must not be treated by themselves but that the whole unit consisting of turbine and draft tube must be investigated. The position is similar for the spiral casing, with which many trials have been made in the laboratories. These investigations form therefore, part of the runner investigations.

Farther reaching hydraulic problems have also been handled by the laboratories, for instance concerning the influence of specially shaped penstock intakes, the loss of head at canal intakes, the correct arrangement of buildings in the river bed, etc. Theory cannot do much in this direction and experiments must be made which, if the laws of similarity applying to free surfaces are observed, give very reliable information and permit the evolution of better outlines. Unfortunately little has been published on such trials. I may mention however the recently published instructive report of the Hydraulic Power Co. "Mittlere Isar A.G." Munich, on "Model experiments on the shape of various hydraulic buildings."

EVOLUTION OF THE RELATION OF THEORY TO EXPERIMENT.

Since the start of German systematic experimental work in 1880, theory has been perfected enormously; but the demands have grown at the same rate. For the solution of the difficult and complex problems by experiment, much improved and more sensitive instruments have been evolved. The ratio of efficiency of theory and practice remained practically the same. All serious engineers of to-day, as in the past, agree that experiment based on command of the latest theoretical knowledge is indispensable for the advancement of the art.

RÉSUMÉ.

Développement des recherches expérimentales en Allemagne. Premières recherches systématiques 1880. A présent il existe 13 laboratoires. Méthodes de recherche. Principe de la superposition des petites variations. Surfaces des aubes représentées mathématiquement par des équations à paramètres. Coëfficients absolus pour représenter les résultats d'essais. Quelques résultats avec des turbines à hélices. Les grandes turbines atteindront facilement un rendement supérieur à 90 pour cent. à de hautes vitesses angulaires. Problème de la cavitation. Loi de similarité pour la cavitation. Autres méthodes et problèmes. Essais de modèles hydro-techniques avec bâtiments. Progrès de la théorie et des méthodes expérimentales.

RECENT DEVELOPMENT IN DAM CONSTRUCTION IN ITALY

ING. L. MANGIAGALLI

The continual development of the applications of electricity, the economical necessity for every nation to extend its system of irrigation, to provide for great land drainage systems, regulation of its rivers, distribution of water in general, and the continued impoverishment of coal basins, have required and still require more rational and intensive utilisation of the hydraulic forces existing. In consequence, a great development in the construction of artificial accumulating and regulating reservoirs has been universally decided upon within the last few years.

The possibilities and the development of these artificial lakes are closely connected with the possibilities and convenience of the dams by means of which they are constructed. The art of building these dams has been continually developing to the same extent, and in this way retaining dams of all kinds and of all shapes have been increasingly used in every country during the last twenty years. Progressive evolution of technical construction and calculation has led from the irrational and primitive types of the ancient Spanish and Algerian dams to the light triangular shape of solid gravity dams, to the extremely light arch dams of New South Wales and to the convenient and light reinforced concrete multiple arch structures.

* * *

The serious development of reservoirs in Italy began little more than ten years ago.

At first obstacles were found in the public diffidence, if not fear of the high retaining walls, and in the facility with which, according to the demand of the moment, the first sources of hydroelectric power could be developed. Later on their increasing use was determined by the progressive agricultural, industrial and general development of the nation, by a better understanding by the technical authorities of their economic importance, by the difficult situation in which Italy found herself during the war for want of coal, and by legislative provisions granted for their utilisation.

From the first small construction of Corrongius and Gorzente Lakes for the provision of drinking water to the towns of Cagliari and Genoa, development has led to the present-day number of some hundred or more dams in existence or in course of construction.

Sardinia, where, in 1866, the first Corrongius reservoir (one million M.^{3} capacity, with a dam 21·50 M. high) was constructed, has to-day the highest and largest dam in the world of the " multiple-arch " type, on the Tirso, 69 M. high, with the largest reservoir in existence (460 million M.^{3} capacity and 26 km. long), which has already been working for more than a year. In this island there is also in construction the dam on the Coghinas, 52 M. high, which will form a reservoir of 260 million M.^{3} of water. In the same way, important dams have been constructed in the Alps at a great altitude as, for example, that of Lake Gabiet, which is situated at an altitude of 2,369 M. near the Monte Rosa glaciers; their application has already been extended to the colonies with the construction of the first two dams of Belesa and Ad Nefas in Eritrea.

Unfortunately, foreign countries know very little of Italian activity in this kind of work, for want of published statistics. Italy, without doubt, may be considered to be the most advanced of European countries both with regard to the size of the reservoirs and to the type of dams.

Nearly all the reservoirs have been constructed for the most complete and rational utilisation of hydro-electric plant; but there are characteristic examples in which their construction has been decided by a triple economic interest, *i.e.*, motive force, irrigation, and regulation of flow. Amongst these we include the Tirso reservoir in Sardinia, which effects a production of 90 million kw., the irrigation of 20,000 ettari, and the elimination of the costly dykes along the lower course of the river. Such also is the Hone reservoir in Sicily, which produces 20 million kwh. and irrigates the " conca d'oro " of Palermo (2,000 ettari). In the last-named reservoir, the waters of the river Hone, whose natural outlet is on the south coast of Sicily, have been diverted to the Tirreno side in order to make this irrigation possible.

* * *

No special design is followed in Italy for the construction of dams.

Just as modern design has transformed the primitive shapes of the old-fashioned gravity dams and has partly evolved, partly

created, other types, thus the topographical, geological and economical conditions and the varying necessities, which are particularly noticeable in our country where the construction of a dam is concerned, have led to the application of every known type.

On the other hand, one can point to the tendency or general preference for constructing dams of solid construction on more harmonic lines of resistance, which are demanded by the conditions generally found in the places where dams are to be constructed.

The Italian dams, for many reasons, are chiefly to be employed in mountainous districts where the sites are narrow, irregular and even contorted, and where, very often, the use of wide dams would lead to useless expense.

These natural conditions have specially influenced the use of rock-filled dams, rendering the American type little adaptable or convenient, and in many cases have prejudiced the adaptability and constructive convenience even of multiple arch dams.

All the above-mentioned types have been widely used in Italy, with the exception of earth dams and, if the tendency prevails in existing or proposed designs towards the old type of solid gravity dam, which without a doubt is more easily adaptable, we now have, after many American applications and the construction of the important dam at Tirso, a remarkable technical orientation in favour of the light types of multiple arch dams.

The fact that only within these last few years have the reservoirs and dams been greatly developed, justifies the planning and construction of Italian dams of modern design according to the more recent calculations and data, and as the result of wide American experience. Also, in Italy there is not that variety of type which characterises the period of uncertainty as to design and continual evolution, which preceded the building of the first modern French dams.

* * *

With reference to dams of the old solid gravity masonry type, it is remarkable how universal is the adoption for Italian dams of a simple triangular shape with a minimum section and a planimetrical disposition, with arch accentuated as much as possible without taking into account the conditions of resistance of the section.

The curved planimetrical disposition, also, of gravity dams (which is required by the characteristic topography of our narrow ravines), is considered by our engineers to be the most rational and efficacious way of obtaining that further margin of safety which is

where water was already used for irrigation purposes and where power developments of any importance were, therefore, no longer possible.

Since 1913, gauging stations have been established on the most important rivers, and continuous gauge readings and periodical current meter readings and chemical measurements of the run-off are taken. At present, there are sixty-five gauging stations in Java, thirty-three of which are equipped with continuous recording water-stage registers and the others with ordinary staff gauges, which are read twice every day. In Sumatra, the corresponding numbers of stations are three and seven, and for Celebes, five and six. During the year 1923 a total of 340 current meter readings and chemical measurements and eighty-five floating measurements were taken. The average daily run-off of the stations is published annually by the Government Service of Water Power and Electricity.

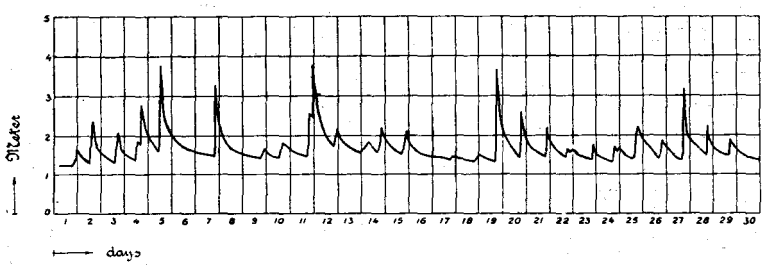
Because of this relatively small number of gauging stations for such a big area (Java 50,800, Sumatra 163,000, and Celebes 72,800 square miles), and on account of the short period of recording, it is frequently necessary to calculate the data required for selecting a good plan of development from the drainage areas and the rainfall. Rainfall measuring stations, with records covering a period of more than fifteen years, exist in a sufficient number.

As to the topographical data, conditions are much more favourable. The maps, which have been prepared by the Government Military Topographic Service, of almost the whole island of Java and large areas of Sumatra, on scales varying from 1 : 20,000 to 1 : 50,000, may be said to be very accurate. Of the remaining parts of Sumatra and several parts of Celebes, outline maps on smaller scales are available. The detailed maps (scales 1 : 1 000 to 1 : 2 000), of fixed power sites, necessary for the design of the developments, are made in a comparatively short time by means of the transit method. Experiments have been made with the stereo-photographic method of mapping, but the results have not been satisfactory, chiefly because of the thick covering of the land with brush and other vegetation.

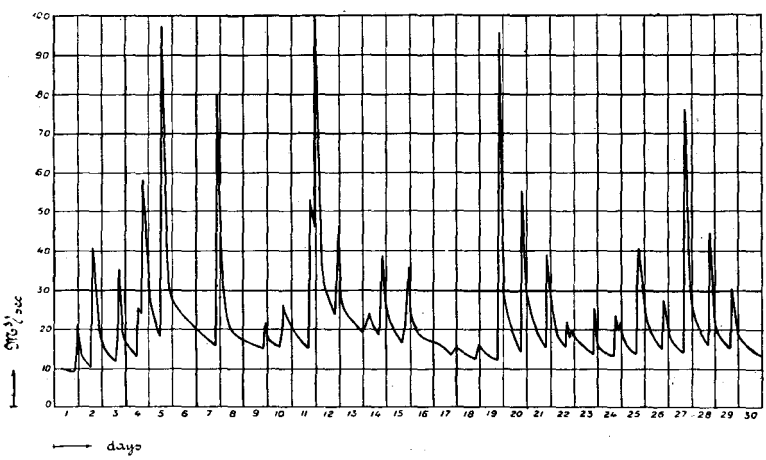
3. Geologically speaking, the East Indian Archipelago is comparatively young. Therefore, a great deal of the mountain slopes are still steeper than the natural slope of the stable material of which they consist, and landslides are numerous. Most of the hill sides are in state of rapid disintegration and erosion. In Java, almost all the mountains are volcanoes, some of which are still active. These cone-shaped mountains reaching to heights of more than

Hydrological characteristics of the river Tjianten near Buitenzorg. (September 1917)

Fluctuations of the waterlevel, recorded by a waterstage register.



Fluctuations of the run-off.



necessary to allow for temperature changes, for the eventual upward pressure, and for the ice thrust at the top.

The calculation of the dimensions is based upon the theory of solid homogeneous elastic material, taking the portion of the wall from which the equilibrium is studied as a solid monolith of various sections, and calculating for the upstream and downstream sides the main normal and tangential tensile stresses as first indicated by Levy.

According to the consideration of the upward pressure, the calculation, based on the hypothesis of the triangular distributed pressure on the base of the dam, and hypothetically variable from zero on the downstream side to the total height of water or to a fraction of it on the upstream side, does not convince our engineers in general, who do not consider it other than a mere theory. There is therefore not yet an example in Italy of a dam designed and constructed according to the Levy method, where the pressure in every part of the upstream side is greater than or equal to the pressure of the corresponding water.

The hypothesis, which is very vague, does not explain the lineal and triangular distribution of the upward pressure, and of its maximum unit value, and the consideration of a quantity of water in the base of the dam is purely a system of calculation to obtain a higher margin of safety by the use of larger dimensions.

But the increasing of the size, if this larger coefficient allows, always leaves indefinite the genuine character and amount of the upward pressure and, if it were not absurd to assume the constant upward pressure corresponding to the maximum static head, there would always remain, owing to the vagueness of the hypothesis, the uncertainty and in some cases the deficiency of the coefficient of safety.

Nevertheless, the recent technical regulations of the Italian Government prescribe that for a dam higher than 25 M. there must be taken into consideration an upward pressure or " uplift," which will occur on the base of the dam. This is in order to assure a wider margin of safety to the section of the dam.

In cases where an uplift might occur, especially in connection with rectilinear or insufficiently curved dams, it is certainly more preferable to construct it in such a way as to avoid the upward pressure; that is to say, with a drainage system along the upstream wall and even along the base if necessary.

This system has been and still is widely used in the construction of American dams. In Italy there are three notable examples of

dams with drainage systems; the dam of Lake Moncenisio, 21 M. high, situated at an altitude of 2,000 M., rectilinear and provided with expansion joints at a distance of 15 M. apart; the dam of Lake Gabiet, 50 M. high, at an altitude of 2,400 M., under the glaciers of Monte Rosa, with a curve of 210 M. radius and without expansion joints; the dam for the Scandarella reservoir in Marche, 50 M. high, at an altitude of 700 M., with a curve of 150 M. radius and without expansion joints.

In these dams the vertical drains are placed between horizontal accessible tunnels, the ends of which form the head of sloping galleries which lead from the bottom up to the top of the side. The drainage wells are about 30 to 40 cm. in diameter at a distance of 2 to 3 M. apart, and they are formed by square porous cement bricks which are placed on top of each other at irregular angles for the better cementing of the body of the dam. If the draining wall is of proved efficiency for any percolation from the upstream wall, it is always possible with heavily-fissured rocks for the water to drain off round the bottom. It is therefore necessary to construct the drains horizontally along the whole base of the dam, but in every case the drainage system must be completed by making a deep channel in the rocky strata along the bottom of the upstream wall, and in many cases also with deep troughs along all the external line of the wall.

In gravity dams also there is a noteworthy tendency to reduce the normal dimensions by the use of hollow types. A large gravity dam (for the State Railway), 51 M. high, is actually in course of construction on T. Rochemolle, near Bardonecchia, at an altitude of about 2,000 M., and it is the first application of the type studied many years ago by the Italian engineer Figari, well known to technical authorities.

* * *

With regard to the arched masonry dams, for which all the load is taken by arch formation, we have fewer examples in Italy, owing to the great difficulty in finding favourable conditions for their application. The existing dams or those in course of construction are, however, typical. Very characteristic is the dam of Corfino in Tuscany, of an extremely light design, 40 M. in height and with a thickness at the top of 1·5 M., and at the bottom 7 M., with an upstream radius of 23·5 M. This dam was built of concrete in 72 days; it was left intact by the violent earthquake of Garfagnana which destroyed all the surrounding buildings.

Both the Turrite dam, which has been in use for some years

(40 M. high, with an upstream radius of 34 M.), and the Valla dam in course of construction (43 M. high, with an upstream radius of 52 M.) are both equally characteristic because they are arched spillway dams. The Cismon dam is also of interest, as it was the first one of importance constructed in Italy as a spillway dam with maximum head on the crest of 2 M. (1)

In the calculation of arched dams constructed, in course of construction, or only designed, it was and is still assumed for determining the general dimensions, that the structure is to be divided into horizontal sections in several strata of which the static equilibrium is studied. The calculation on the theory of elastic arches is only applied to higher strata to a depth at which the application of elasticity formulæ can be still assumed to be possible.

The methods of calculation tending to divide the arched dam into a series of vertical cantilevers and horizontal strata which should have the same elastic deflection at the corresponding points, although they have been considered, discussed and in some cases applied, have not convinced our engineers of their soundness; and the recent Government technical regulations for dams, established by a commission of specialists, advise the use of the original system of calculating which, owing to the great element of uncertainty in the structure, approaches more nearly to the theoretical and practical point of view. That is to say that Italian engineers confirm the opinion of Wade, the designer and constructor of the dams in New South Wales who, even at that time held this same opinion about the new methods of calculation, which greatly complicate the various calculations and do not reduce the uncertainty of the results.

In effect, as Guidi has authoritatively observed, the real resistance of the single arch dam is that of curved slabs of variable thickness with the upper edge free, and the remaining perimeter fixed so that it takes the weight of water pressure. This structure has in consequence a distribution (not quite uniform) of the water pressure against the outer surfaces of strata of arched dams.

Calculation based on the determination of the elastic deflection, while it would logically demand the symmetry of the whole dam, a condition which cannot be carried out in practice, does not take into any account the effect of structural slabs, which render illu-

(1) Among those in course of construction must be mentioned the Chiusella dam, 20 m. high. It is the first of the " constant angle " type of dam with variable radius, studied by Jorgensen.

sionary the results of calculations which are based on this deflection on the hypothesis of uniform water pressure.

* * *

Referring to hollow gravity masonry dams of light design with flat or arched decks spanning between the buttresses, there are three examples already constructed in Italy. The first one was that of Comba Mala, on a tributary of the T. Maira, 39 M. high and of American type (Ambursen), with flat decks over the buttresses; later, the first multiple arch dam at Scoltenna was constructed, and a little later the largest dam of this type existing in the world, that of Tirso, which is 69 M. high. The dams with flat reinforced concrete decks, in spite of the interesting example of Comba Mala, have not been adopted again because to-day they represent a type which is surpassed by the multiple arch dam.

The type with flat decks, though more easy, practical and speedy to construct, has its weakness in the limited span between the buttresses and in the cost of reinforcement of the decks. This limitation of distance on account of our narrow valleys with steep and irregular sides, bringing the foundations of the buttresses too close together, often annuls every advantage of this type of dam.

The fundamental characteristics of the Italian multiple arch dams, in absolute contrast with American types, lies in the constructive system, that is to say, in the concrete arches resisting only by compression, and reinforced only to withstand the effects of temperature, and in the thick buttresses of masonry or concrete with stone walls. These characteristics are due to special economic conditions such as labour, material and transport which are peculiar to our country.

Even the dam at Comba Mala has its buttresses constructed in this way, in contrast with the Ambursen type.

Technically, this design follows more naturally in the evolution from the solid structures to the hollow one with buttresses which have concentrated loads. The American completely reinforced type, on the other hand, is the result of a modern improvement in which maximum economy of the structure is combined with maximum safety.

The calculation of these dams is made separately for the arches and for the buttresses which support them.

The arches are usually made of circular section and constant thickness from the crown to the abutments, in the normal plane to the slope of the upstream wall, and are calculated as elastic arches, taking into account the water pressure, the normal com-

ponent of its weight and the changes of temperature, and excluding all tensile stresses.

The slope of the arches varies approximately from 35 to 45 degrees; preferably, arches of a minimum amplitude of 160 degrees are used.

The same method of calculation is used for the buttresses as for the solid gravity dams, excluding, however, every hypothesis of upward pressure.

* * *

With regard to rock-filled dams, we must remark that they had a period of great favour in Italy a few years ago. The examples of American types of dams in Lower Otay, Morena and Strawberry, to mention the most important, the desire to realise the economic advantages of the Colonial and Alpine dams, and not to take into consideration any eventual uplift and not to be afraid of earthquakes, have led many of our engineers to believe in a standardisation of these structures, and even to think that with this type of dam the construction of the reservoirs would be greatly increased.

The direct experience gained from the construction of the first dams could only confirm the opposition of some engineers and constructors. From the very beginning they had been opposed to this dangerous tendency and demonstrated that even this type of dam, which is neither ideal nor economical, could be used with success, only in specially-determined cases and when the use of other types resulted in failure.

The chief characteristic of the Italian rock-filled dams is their narrowness, which is accounted for by the special system of construction.

These are not like American types of rock-filled dams consisting of a fill of loose rock in large blocks irregularly placed, leaving many hollow spaces in the structure and requiring only small slopes of the walls to assure the natural adjustment of the equilibrium of the blocks, but are structures of stones regularly placed, with few cavities and therefore very compact and stable. They are adaptable for narrow and irregular localities where it is possible to reduce the dimensions of the structure.

The topographical and constructive conditions of places where it is possible to build dams have led almost exclusively to the adoption of narrow designs.

Among the Italian examples of this type of dam, the Hone dam is the most typical and characteristic, as well as one of the largest

in existence (33 M. head of water, 37 M. high, with a volume of 150,000 M.^{3} and a reservoir of 33 million M.^{3}).

* * *

The chief characteristics of this dam are found in the cross-section and in the design of the drainage system of the upstream wall, which is the first and only example.

The shape is symmetrical with the slope of the walls, and calculated so that the total water pressure passes through the middle of the base, where it meets the vertical resultant of its weight.

This condition assures a more uniform distribution of the pressure on the base of the foundation and the whole dam, whether the reservoir be full or empty, for any height of dam, and reduces the probability of unequal stressing of the material.

The structure of the drainage system comprises a first wall of rubble laid in cement mortar with special internal supports, placed about 12 M. apart in the broken stone.

On this protective wall is placed (with the same internal supports 12 M. apart) a coating of reinforced concrete, pierced with conduits 20 cm. in diameter and 40 cm. apart which form drains. These are divided according to the amount of water, into three groups, lower, medium and high, and each group connects with two longitudinal galleries accessible for inspection, one below and the other above.

With this arrangement, every point of the upstream wall is both accessible and visible and any possible percolation is controllable.

A last peculiarity of this dam is in the protection of the whole of the foundations by a light layer of concrete and by the use of mortar in the construction of the first layer of broken stone at the bottom.

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With regard to preliminary study and design, it can be affirmed that for some years now the most modern systems have been employed in Italy.

Much time has been given to the preliminary study of the plans which are carried out with great care. The stereographic system, which is the most modern and exact, and particularly necessary for the good design of arch dams, has been widely adopted for the topographical survey. For the geological examination of the site of the dam, investigations are usually carried out with test pits and borings.

Mechanical methods have been very largely used in the construction of the dams, especially since the war, owing to the very

great increase in the cost of manual labour, the greater size and importance of the work, and of the necessity for more rapid execution.

This would have found an even wider application, if it had not been naturally limited by economic convenience in the special condition of the dam sites and by the size of these works.

The special American machines for plastering, for covering the walls of rock in the foundations, for grouting and for the transport of concrete either by elevators and subsequent gravity descent, or for projecting it with compressed air (cement-gun) are particularly popular.

In all the workshops for dam construction, laboratories for photographic work and for tests of the material have been greatly developed.

The great importance and responsibility of these structures is today well realised by State technical authorities, and the regulations which in Italy govern the study of the projects and the construction of the works are doubtless amongst the most complete and modern in existence.

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This brief review of the recent development in dam construction in Italy for artificial reservoirs, will, I hope, bring to the notice of foreign countries the successes in this field that have been attained by Italy. And I dare to hope, also, that a glance at the designs depicted at the end, of dams constructed and in course of construction, will make the technical specialists on the other side of the Alps wish to know more of our designs, and will persuade them that in such work Italy has had magnificent technical experience.

SVILUPPO RECENTE NELLA COSTRUZIONE DELLE DIGHE ITALIANE.

ING. L. MANGIAGALLI

Il continuo sviluppo delle applicazioni dell'elettricità, la necessità economica per ogni nazione di estendere le reti d'irrigazione, di provvedere allè grandi bonifiche, alle sistemazioni montane e alle distribuzioni d'acqua in genere; l'impoverimento progressivo dei bacini carboniferi, hanno richiesto e richiedono una utilizzazione sempre più razionale e intensiva delle energie idrauliche disponibili, e di conseguenza hanno determinato ovunque, in questi ultimi anni, un intenso sviluppo nella costruzione dei serbatoi artificiali di accumulazione e regolazione.

La possibilità e lo sviluppo di questi laghi artificiali, sono strettamente connessi alla possibilità e convenienza delle dighe con cui essi vengono creati. L'arte di costruire queste dighe ha dovuto quindi continuamente svilupparsi

con cammino parallelo, e così gli sbarramenti di ogni genere e di tutte le forme si sono moltiplicati in ogni paese durante questi ultimi venti anni. Dalle irrazionali e grossolane forme delle antiche traverse di Spagna e di Algeria, l'evoluzione continua della tecnica costruttiva e di calcolo, ha condotto agli esili ed armonici profili triangolari per le dighe piene a gravità, alle sottilissime dighe ad arco della Nuova Galles, alle razionali e leggiere strutture in cemento armato a volte multiple su contrafforti.

Lo sviluppo intenso dei serbatoi in Italia data da poco più di un decennio.

Prima esso trovò ostacolo nella generale diffidenza, se non nel timore, verso le alte strutture di sbarramento, e nella facilità stessa con cui, in rapporto alle necessità del momento, poterono svilupparsi le prime derivazioni idroelettriche; in seguito fu favorito dalla maturata comprensione, negli organi tecnici dirigenti, della loro importanza tecnica ed economica, dal continuo sviluppo industriale e agricolo della nazione, dai provvedimenti legislativi di favore, dalla situazione in cui l'Italia venne a trovarsi nel periodo di guerra per la mancanza di carbone.

Dalle prime e modeste costruzioni di Corrongius e dei laghi Gorzente per provvedere di acqua potabile le città di Cagliari e di Genova, si può oggi calcolare di oltre cento il numero degli sbarramenti esistenti e in costruzione, con un complesso di un miliardo di acqua accumulata.

E' la Sardegna, dove fu costruito nel 1866 il primo serbatoio di Corrongius di 1 milione di mc., con una diga di mt. 21.50 di altezza, che ha oggi (ultimata e in esercizio da più di un anno) la più alta e importante diga del mondo ad archi multipli sul Tirso di mt. 69 di altezza, col più grande serbatoio artificiale che esista di 460 milioni di mc. e di Km. 26 di lunghezza; mentre nella stessa isola è attualmente in costruzione lo sbarramento sul Coghinas di mt. 52 di altezza che formerà un serbatoio di 260 milioni di mc. d'acqua. E così dighe importanti sono state costruite sulle Alpi ad altissima quota, come quella del lago Gabiet a mt. 2,360 di altezza presso ai ghiacciai del Monte Rosa, mentre la loro applicazione si è già estessa alle colonie con le prime due dighe di Belesa e Ad Nefas costruite in Eritrea.

L'attività italiana in questo campo costruttivo è purtroppo ben poco nota negli altri paesi per deficienza di pubblicazioni e di statistiche; ma indubbiamente l'Italia può oggi considerarsi, e per importanza di serbatoi e per tipi di sbarramenti, fra i paesi più progrediti del gruppo europeo.

Quasi tutti i serbatoi sono stati costruiti per la più completa e razionale utilizzazione degli impianti idroelettrici; ma si hanno già esempi caratteristici in cui la loro costruzione è stata determinata da un triplice interesse economico, di forza motrice, di irrigazione, di regolazione delle piene. Fra questi citiamo il serbatoio del Tirso in Sardegna col quale si provvede ad una produzione di 90 milioni di kwo., alla irrigazione di 20,000 ettari, alla eliminazione delle costose arginature lungo il corso inferiore del fiume; e il serbatoio dell'Hone in Sicilia col quale si provvede ad una produzione di 20 milioni di kwo. e alla irrigazione della conca d'oro di Palermo (2,000 ettari). Con quest'ultimo serbatoio anzi le acque del fiume Hone, che hanno sbocco naturale sul versante meridionale africano della Sicilia, sono state deviate al versante Tirreno per rendere possibile quest'irrigazione.

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In Italia non si ha una tecnica particolare degli sbarramenti.

Coma la tecnica moderna ha trasformato il primitivo profilo della classica diga a gravità, e ha dovuto in parte evolvre e in parte creare altri tipi di

diga, così le condizioni di sensibile differenziazione topografica, geologica, economica, e costruttiva che particolarmente si verificano nel nostro paese dove uno sbarramento è possibile, hanno portato all'applicazione di tutti i tipi conosciuti.

Si può invece parlare di tendenza, cioè di preferenza generale verso strutture di dighe a masse ridotte, a più armonica linea resistente, e ciò richiedono del resto le stesse condizioni di impostazione che generalmente si riscontrano nelle nostre possibili strette di sbarramento.

Le dighe italiane per un complesso di ragioni possono infatti svilupparsi con prevalenza in regioni montuose dove le località di sbarramento si presentano strette, irregolari e spesso contorte, e dove il più delle volte l'ampiezza dei profili conduce ad un inutile dispendio economico.

Condizione di fatto questa che ha avuto riflesso principalmente nelle applicazioni dei tipi in pietrame a secco, rendendo poco adattabile e conveniente il tipo americano di diga a scogliera; e che in molti casi pregiudica l'adattabilità e la convenienza costruttiva anche delle dighe a volte multiple.

Tutti i tipi come dicevamo hanno avuto larga applicazione in Italia, fatta eccezione per le dighe in terra, e se la prevalenza delle costruzioni compiute o in esecuzione è per le classiche dighe a gravità, che indubbiamente trovano più facile adattamento, sta di fatto che, in questi ultimi tempi dopo le numerose applicazioni americane, e dopo la costruzione della grandiosa diga del Tirso, si è determinato un notevole orientamento tecnico per l'applicazione dei leggieri tipi a volte multiple.

Il fatto che solo in questi ultimi anni i serbatoi e gli sbarramenti hanno preso notevole sviluppo, giustifica come le dighe italiane sieno state in maggioranza progettate e costruite di profilo moderno, e secondo le più recenti norme in materia, frutto della preziosa e larga esperienza americana; e come non si riscontri da noi quel campionario di profili che è stato caratteristico per le costruzioni sviluppatesi nel lungo periodo di incertezza e di continua evoluzione della tecnica che ha preceduto la costruzione delle prime moderne dighe francesi.

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Nel campo degli sbarramenti del classico tipo di muratura piena a gravità, è subito da rilevarsi l'adozione quasi generale nelle dighe italiane del profilo semplice triangolare a sezione minima, e della disposizione planimetrica ad arco accentuato quanto più è possibile, senza che di ciò si tenga conto nelle condizioni di resistenza del profilo.

La disposizione planimetrica arcuata anche per le dighe a gravità (e che pure è tema quasi obbligato d'impostazione con le caratteristiche topografiche delle nostre strette), è nella nostra tecnica considerato come il più razionale ed efficace accorgimento per quegli ulteriori margini di sicurezza di stabilità che si vogliono raggiungere nei riguardi delle dilatazioni, per le eventuali sottopressioni, per le spinte dei ghiacci in sommità ecc.

La calcolazione dei profili è fatta in base alla teoria dei solidi elastici omogenei, considerando il tronco di muro di cui si studia l'equilibrio come un solido monolitico a sezione variabile incastrato al piede, e verificando ai paramenti le tensioni principali normali e tangenziali, come per primo ebbe a indicare il Lévy.

In rapporto alla considerazione delle sottopressioni, la calcolazione in base all'ipotesi di un carico triangolare sottostante alla diga, e ipoteticamente variabile da zero nell'estremo lembo a valle, al valore di ritenuta, o a frazione

di esso, nell'estremo lembo a monte, non persuade in genere i nostri tecnici che la considerano più che altro un artificio di calcolo, e guindi non si hanno ancora in Italia esempi di dighe progettate e costruite secondo la prescrizione Lévy di pressione in ogni punto del paramento a monte superiore o almeno eguale alla pressione d'acqua corrispondente.

A parte l'ipotesi non persuasiva, perchè molto vaga, della distribuzione lineare e triangolare della sottopressione, e del suo massimo valore unitario, la considerazione di una lama d'acqua sottostante la base della diga è un puro artificio di calcolo per arrivare con un più ampio profilo, ad un più elevato coefficente di stabilità.

Ma l'aumento del profilo, se consente questo maggiore coefficiente, lascia pur sempre indefiniti il carattere e l'entità reali della sottopressione che può verificarsi, e, se non si vuol giungere all'assurdo di supporre una sottopressione costante e corrispondente alla massima unitaria, resta pur sempre, per l'indeterminatezza dell'ipotesi, l'incertezza e in dati casi la deficienza del coefficiente di stabilità.

Ciò nonostante le recenti norme tecniche governative italiane, prescrivono che per le dighe di altezza superiore ai 25 metri si tenga conto convenzionalmente della possibilità di una sottopressione variabile a seconda dei casi, ma solo allo scopo di assicurare alla sezione della diga un più largo margine di stabilità.

All'eventualità della sottopressione che pure occorre considerare in particolari casi, e sopratutto con dighe rettilinee o non sufficientemente arcuate, è indubbiamente preferibile di provvedere con disposizioni tecniche che tendano ad evitare il prodursi delle sottopressioni, e cioè coi sistemi di drenaggio poco a tergo del paramento a monte, e anche in fondazione quando occorra.

Sistema questo che ha avuto e ha larga applicazione nelle dighe americane. In Italia abbiamo tre esempi importanti di dighe con dispositivo drenante, la diga del Lago del Moncenisio di mt. 21 di altezza a 2,000 mt. di altidutine, rettilinea e provveduta di giunti di dilatazione a distanza di mt. 15; la diga del Lago Gabiet di mt. 50 di altezza, a 2,400 mt. di altitudine sotto il ghiacciaio del Monte Rosa, in curva ma di mt. 210 di raggio e senza giunti di dilatazione; la diga del serbatoio di Scandarella nelle Marche di mt. 50 di altezza a 700 mt. di altitudine, disposta in curva ma di mt. 150 di raggio e senza giunti di dilatazione.

In queste dighe la serie verticale dei drenaggi è compresa fra gallerie orizzontali accessibili che ai loro estremi fanno capo a gallerie inclinate che seguono dal fondo fino al ciglio tutta l'imposta della diga. I tubi di drenaggio sono di circa cm. 30 ÷ 40 di diametro con interasse da 2 a 3 mt. e sono stati ottenuti con blocchetti quadrati di calcestruzzo poroso preparati in cantiere, e montati a sovrapposizione e a spigoli sfalsati per l'efficace ammorzamento nella massa della diga. Se la parete drenante è di dimostrata efficacia per eventuali filtrazioni dal paramento a monte, è pur sempre possibile che con rocce molto fessurate, le filtrazioni possano aggirare il drenaggio di fondo. Si rende allora necessario di costruire i drenaggi orizzontali lungo tutta la base della diga, ma in ogni caso il sistema drenante va integrato coll'esecuzione di un profondo taglione di guardia incassato nella roccia sana lungo tutto il piede del paramento a monte, e in determinati casi anche con iniezioni profonde lungo tutta la linea esterna di paramento.

Anche per la dighe a gravità va rilevata la tendenza di ridurne il volume del profilo normale con tipi derivati a vani interni. E' attualmente in costruzione

per conto delle Ferrovie di Stato un'importante diga a gravità sul T. Rochemolle presso Bardoneechia a circa 2,000 mt. di altitudine, e che è la prima applicazione del profilo di diga studiato molti anni fa dal nostro Ing. Figari e ben noto ai tecnici.

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Nel campo degli sbarramenti di muratura piena o calcestruzzo, ma resistenti solo come volta per la loro forte disposizione arcuata, abbiamo applicazioni meno numerose per la minor facilità di trovare le adatte impostazioni. Le dighe esistenti o in costruzione sono tuttavia tipiche; caratteristica fra le prime è quella del Corfino, in Toscana a profilo esilissimo, di mt. 40 di altezza con spessore in sommità di mt. 1.5, alla base di mt. 7, con raggio di estradosso di mt. 23.5 che fu eseguita in gettata continua di calcestruzzo in 72 giorni, e che fu completamente investita dall'ultimo violento terremoto di Garfagnana che distrusse ogni edificio all'intorno senza che la minima crinatura si determinasse nella struttura della diga.

Sono egualmente caratteristiche la diga di Turrite (funzionante da alcuni anni) con mt. 40 di altezza e mt. 34 di raggio di estradosso, e la diga di Valla (costruzione) con mt. 43 di altezza e mt. 52 di raggio di estradosso, che sono a libera tracimazione dal ciglio per lo scarico delle piene, e la diga di Cismon, la prima importante costruita in Italia e che è a libera tracimazione con ben 2 metri di lama d'acqua.

Fra quelle in costruzione è da notarsi la diga della Chiusella di mt. 40 di altezza, la prima del tipo a raggio variabile studiato dall'Iorgensen.

Nelle calcolazioni delle dighe a volta costruite, in costruzione, o in progetto, si è seguito e si segue il concetto di fissare le dimensioni generali immaginando la struttura divisa con piani normali alle generatrici, in anelli di volta dei quali si studia l'equilibrio statico, e limitando la calcolazione nell'ipotesi di arco elastico deformabile agli anelli superiori fino a quella profondità a cui si può presumere ancora attendibile l'applicazione delle formole di elasticità.

I metodi di calcolo tendenti a scomporre la diga a volta in una serie di elementi verticali (mensole) e di anelli orizzontali che debbono avere nei punti corrispondenti lo stesso spostamento elastico, pur essendo stati considerati, discussi e applicati a qualche caso in progetto, non trovano da noi fautori convinti, e le stesse recenti norme governative per le dighe, stabilite da una commissione di specialisti in materia, prescrivono senz'altro il primo sistema di calcolazione come quello che in realtà, nella molta incertezza dell'effettivo comportamento della struttura, meglio avvicina i due punti di vista teorico e pratico. Con ciò la tecnica italiana viene a confermare l'opinione dell'illustre Wade, l'autore delle magnifiche dighe della Nuova Galles, che fin da altora ebbe la precisa visione come i nuovi metodi di calcolo mentre complicano enormente le varie calcolazioni non riducono l'incertezza dei risultati dovuta all'assoluto teorismo delle nuove ipotesi.

In effetto, come autorevolmente ha osservato il nostro Guidi, il vero comportamento resistente della diga a Volta unica è quello di lastra curva, di spessore variabile, col lembo superiore libero e il restante perimetro incastrato, cimentata dal peso proprio e dalla pressione idrostatica, e questo comportamento come lastra porta di conseguenza una non del tutto uniforme distribuzione della pressione idrostatica contro l'estradosso degli anelli di volta.

Il calcolo basato sulla determinazione degli spostamenti elastici, mentre richiederebbe logicamente una simmetria di diga che in pratica non si verifica, non tiene conto dell'effettivo comportamento come lastra che fa sensibilmente

risentire il suo effetto sulla deformazione elastica in modo da rendere illusori i risultati dei calcoli che si basano su tale deformazione nell'ipotesi di pressione idrostatica uniforme.

* * *

Nel campo degli sbarramenti a struttura leggera, è cioè a contrafforti con pareti di ritenuta a lastroni oppure a volte, abbiamo in Italia per ora tre esempi. La prima diga a contrafforti costruita fu quella a lastroni di Comba Mala su di un affluente del T. Maira, di mt. 39 di altezza e del tipo americano Ambursen; seguì poi la prima diga a volte multiple di Scoltenna di mt. 20, e poco dopo la più grande diga esistente di questo tipo, cioè quella del Tirso di mt. 69 di altezza. Le dighe con pareti a lastroni, nonostante l'interessante esempio di comba Mala non hanno avuto ulteriore seguito, perchè in realtà esse rappresentano oggi un tipo ormai superato da quello a volte multiple.

Il tipo a lastroni se costruttivamente è più semplice, pratico e rapido, ha il suo punto debole nel limite troppo ristretto di interasse dei contrafforti, e nel costo di armatura dei lastroni; e questo ristretto limite di interasse con le nostre strette di sbarramento a fianchi ripidi e irregolari, avvicinando eccessivamente fra loro le fondazioni degli speroni, viene sovente ad annullare ogni termine vantaggioso di questo tipo di diga.

La caratteristica fondamentale delle dighe italiane a volte multiple, in contrasto assoluto coi tipi americani, è nel sistema costruttivo, cioè di archi in calcestruzzo resistenti per compressione e armati solo per tener conto degli effetti di temperatura, e di contrafforti di forte spessore in muratura o in calcestruzzo con paramenti in pietra; caratteristica derivata da un complesso di speciali fattori economici, di mano d'opera, di materiali e di trasporti propri del nostro paese.

Anche la diga di Comba Mala ha i contrafforti così costruiti, in contrasto col tipo Ambursen.

Tecnicamente si può osservare che questa concezione costruttiva è quella che in realtà consegue più spontanea nel primo passaggio dalle massiccie strutture piene al tipo a contrafforti, cioè a carichi concentrati; mentre il tipo leggiero americano totalmente armato è il risultato di un ulteriore perfezionamento col quale si raggiunge la maggiore razionalità di struttura e la sua maggiore stabilità.

La calcolazione di queste dighe viene fatta separatamente per gli archi e per i contrafforti su cui gli archi si appoggiano.

Gli archi sono di solito di sezione circolare e di spessore costante dalla chiave alle imposte nel piano normale all'inclinazione del paramento a monte, e vengono calcolati come archi elastici tenendo conto della pressione dell'acqua della componente normale del peso proprio e delle variazioni di temperatura—escludendo ogni sollecitazione di tensione.

L'inclinazione degli archi varia approssimativamente fra 35 e 45 gradi e si adottano di preferenza archi di ampiezza non inferiore a 160 gradi.

Per i contrafforti si segue lo stesso metodo di calcolo come per le dighe a gravità escludendo però ogni ipotesi di sottopressione.

* * *

Passando alle dighe in pietrame a secco dobbiano notare che esse hanno avuto da noi, alcuni anni fa, un periodo di grande favore. Gli esempi americani delle dighe di Lower Otay, di Morena, di Strawberry per accennare alle più importanti, il miraggio di realizzare rilevanti vantaggi economici per le dighe alpine e coloniali, la persuasione di non doversi preoccupare di

eventuali sottopressioni e di non dover temere le eventualità sismiche, hanno condotto molti tecnici a credere in una generalizzazione di queste strutture, e a ritenere quindi che con questo tipo di diga la costruzione dei serbatoi avrebbe avuto fortissimo incremento.

L'esperienza diretta delle prime dighe costruite non ha potuto che confermare le vivaci opposizioni di tecnici e costruttori specialisti sorte fin dall'inizio contro questa pericolosa corrente generalizzatrice, e dimostrare come anche il tipo di diga a secco, non certo ideale e tanto meno economico, può trovare conveniente applicazione, ma solo in casi determinati, e quando risulti impossibile o sconsigliabile ricorrere ad altri tipi.

La caratteristica principale delle dighe italiane in pietrame a secco sta nella ristrettezza del loro profilo derivata dal particolare sistema di costruzione. Non dighe di scogliera tipo americano a grossi blocchi gettati, liberi di una propria sistemazione, con abbondanti vuoti nella massa, e richiedenti lievi e decrescenti inclinazioni di paramento per assicurare il naturale assettamento d'equilibrio del pietrame; ma strutture di pietrame sistemato a mano, con minimo numero di vuoti e quindi di maggiore compattezza e stabilità, adattabili a località più ristrette e accidentate, e con le quali riesce possibile ridurre le dimensioni di profilo.

Sono quasi esclusivamente le condizioni di fatto topografiche e costruttive delle nostre località di sbarramento che hanno portato ai profili ristretti, compensati in questa riduzione dalla particolare sistemazione costruttiva del pietrame.

Fra gli esempi italiani va segnalato lo sbarramento sul T. Hone che é il più tipico ed importante (mt. 33 di ritenuta, mt. 37 di altezza, volume 150,000 me. con un serbatoio di 33 milioni di mc.) ed uno dei più gradi che esistono.

Le principali caratteristiche di questa diga stanno nel profilo trasversale e nella struttura di drenaggio del paramento a monte di cui è unico esempio.

Il profilo è simmetrico con le inclinazioni dei due paramenti calcolate in modo che la spinta idrostatica passi per il centro della base dove incontra anche la verticale risultante del peso proprio; condizione questa che assicura alla base di fondazione e in tutta la diga la migliore uniforme distribuzione delle pressioni sia a carico che a vuoto, per qualsiasi altezza di diga e che riduce le probabilità di ineguale assettamento del materiale.

La struttura di tenuta comprende un primo muro di rivestimento in malta di cemento che con speciali contrafforti interni distanziati di mt.12 circa si ammorza nel pietrame di massa.

Su questo muro di protezione appoggia con ammorzature ancora distanti 12 metri circa un rivestimento di cemento armato forato a canne d'organo di 20 cm. di diametro con interasse di cm. 40 che formano tanti pozzetti di drenaggio. Questi sono divisi in rapporto al carico d'acqua in tre gruppi, inferiore, medio e superiore, e ogni gruppo fa capo a due cunicoli longitudinali di accesso e di ispezione, uno inferiore e uno superiore.

Con questa disposizione ogni punto della parete a monte è accessibile e visibile, ogni eventuale filtrazione è controllabile.

Un'ultima particolarità di questa diga consiste nella protezione di tutto lo scavo di fondazione con un leggiero strato di calcestruzzo, e nell'esecuzione con malta del primo strato di fondazione del pietrame.

* * *

Nei riguardi della tecnica di studio preventivo e di costruzione si può parimenti affermare che in Italia si seguono già da alcuni anni i più moderni sistemi.

Molta importanza viene data agli studi preventivi di progetto che vengono condotti con larghezza di mezzi e grande accuratezza. Per il rilievo topografico ha trovato larga applicazione il sistema stereografico che è il più moderno e preciso, e che è particolarmente necessario per ben progettare l'impostazione delle dighe ad arco. Parimenti per l'esame geognostico delle strette disbarramento è ormai consueta l'indagine con gallerie o pozzi o con sistema di trivellazioni.

Per la costruzione, i mezzi meccanici hanno trovato la più larga applicazione nei cantieri, applicazione favorita nel dopo guerra dal sensibile aumento di costo della mano d'opera, dalla maggiore entità e importanza delle costruzioni, dalla necessità di una maggiore rapidità di esecuzione.

E questa applicazione sarebbe stata anche maggiore se essa non trovasse una naturale limitazione anche di convenienza economica nella particolari condizioni cui è possibile sviluppare in Italia la costruzione delle dighe.

Particolare favore hanno avuto ed hanno i macchinari speciali americani per intonaci, rivestimenti delle pareti di scavo ed iniezioni sotto pressione e per il trasporto del calcestruzzo a distanza, sia con elevazione a torre e discesa a gravità, sia per lancio ad aria compressa (Cement-gun e Ramsone Caniff).

In ogni cantiere di costruzione di dighe sono poi largamente sviluppati i laboratori completi per la documentazione fotografica e per le prove dei materiali.

La grande importanza e responsabilità di queste costruzioni è oggi anche ben compresa dagli organi tecnici dello Stato e le norme regolamentari che in Italia guidano lo studio dei progetti e la costruzione di queste opere sono indubbiamente fra le più complete e moderne che si abbiano.

* * *

Questo rapido sguardo allo sviluppo che ha avuto in Italia la costruzione delle dighe di sbarramento per i serbatoi artificiali varrà io spero, a far conoscere fuori dei confini, dove purtroppo per troppo tempo lo si è ignorato ciò che l'Italia con magnifica energia ha prodotto e produce anche in questo campo. E oso anche sperare che uno sguardo ai profili raccolti delle dighe costruite o in costruzione possa far desiderare ai tecnici specialisti d'oltr'Alpe di conoscere più da vicino queste nostre costruzioni e persuaderli che in esse l'Italia ha un magnifico campo di istruzione e di esperienza tecnica.

RÉSUMÉ.

Le développement toujours croissant des applications de l'électricité, de la navigation, de l'irrigation et des applications hydrauliques de toute nature ont impérieusement demandé et demandent encore l'utilisation de plus en plus intense et rationnelle des forces hydrauliques disponibles. On a donc développé le plus possible la construction des réservoirs artificiels destinés à régulariser le débit des eaux ainsi que celle des barrages qui les constituent; l'art de construire ces barrages, se développait parallèlement afin d'accroître leurs dimensions et leur facilité de construction.

En Italie, nation qui traverse actuellement une période magnifique d'évolution industrielle et agricole, on a, pendant ces dix dernières années, construit de nombreux réservoirs et des barrages d'une grande importance, mais tandis que le plus grand nombre d'entre eux sert à une utilisation rationelle des installations hydroélectriques, quelques uns ont été construits en vue d'un

triple intérêt économique de force motrice, d'irrigation et de régularisation des crues.

Les barrages construits en Italie appartiennent à tous les types, autant ceux qui existent au pied des glaciers, aux plus grandes altitudes, que ceux des Colonies.

En Sardaigne, sur le Tirso, existe le barrage le plus haut qu'il y ait actuellement du type à arcs multiples de 69 mètres de hauteur et qui forme le réservoir artificiel le plus vaste de l'Europe, un des plus vastes, sinon le plus vaste du monde, dont la capacité est de 460 millions de m.c.

En Sicile, sur le fleuve Hone près de Palerme, se trouve un barrage en enrochement qui compte parmi les plus importants et les plus élevés qui existent; son réservoir est de 35 millions de m.c. et dérive du versant sud au versant nord, le cours du Hone, dans la partie la plus élevée de son bassin, afin de l'utiliser à l'irrigation de la plaine palermitaine.

On construit actuellement sur le haut plateau de la Sila, en Calabre, des réservoirs de plus de 70 et 100 millions de m.c.

On possède, en outre, des applications importantes et caractéristiques de barrages en voûtes, à voûtes multiples et en enrochement, construits selon les principes de la technique la plus moderne; les projets de ces travaux ont été étudiés avec la plus grande attention et à l'aide des moyens d'investigation les plus parfaits et les plus étendus. D'autre part, ces projets, et les constructions consécutives des barrages, étaient soumis à des règlements de l'Autorite qui comptent à l'heure actuelle parmi les meilleures prescriptions techniques en existence.

Les tableaux et dessins à l'appui donnent une idée exacte de ce que l'Italie a su accomplir dans ce domaine particulier et qui mérite pleinement d'être également connu au-delà de ses frontières.

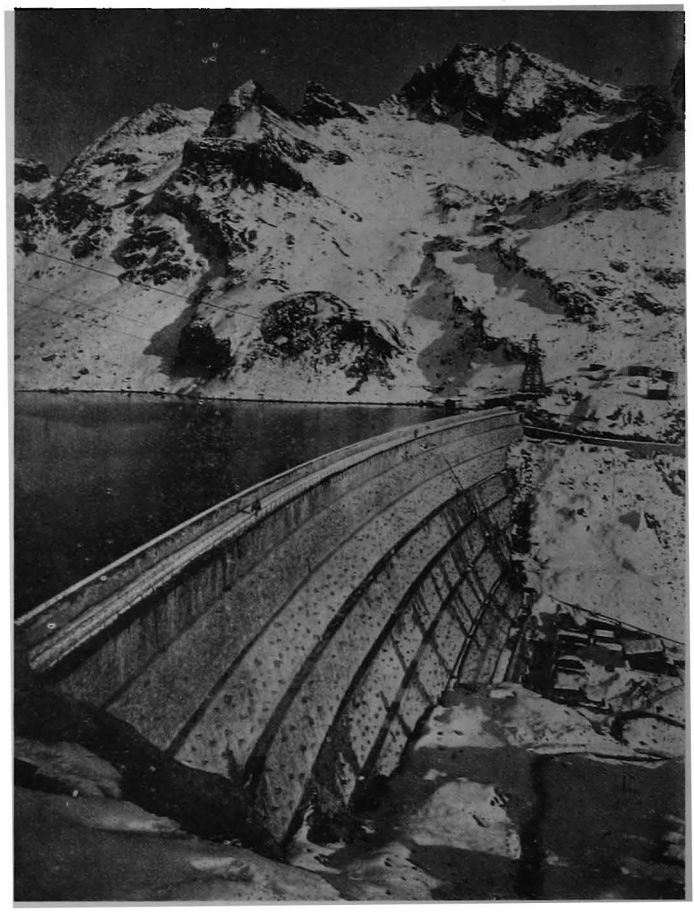

Plate 1.

Diga Lago Gabiet.

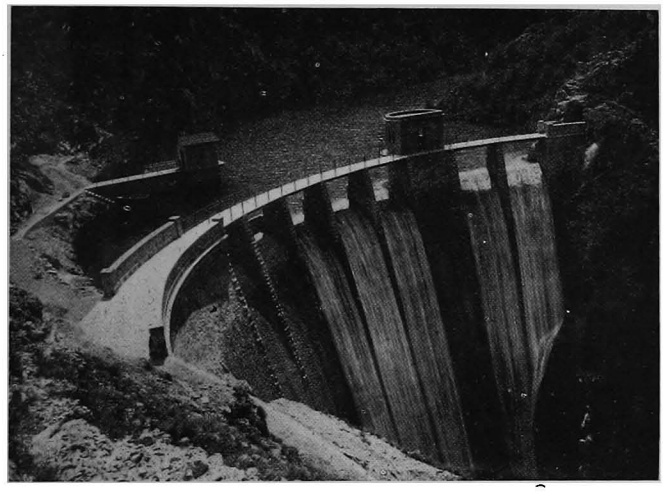

Plate 2
Diga della Turrite.

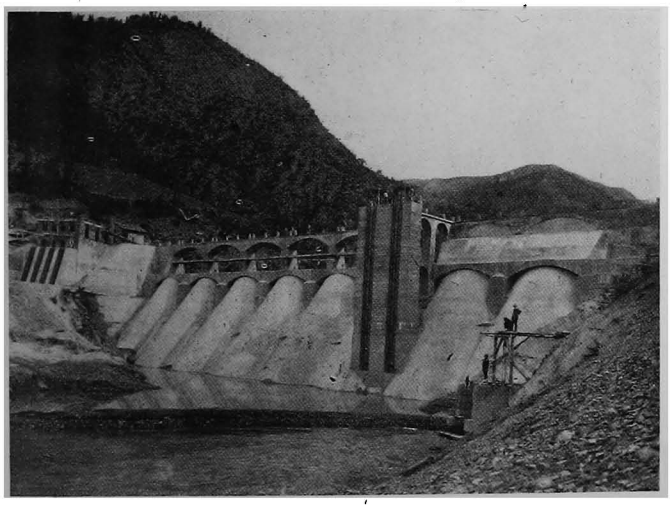

Plate 3.
Diga di Riolunato sul Torrente Scoltenna.

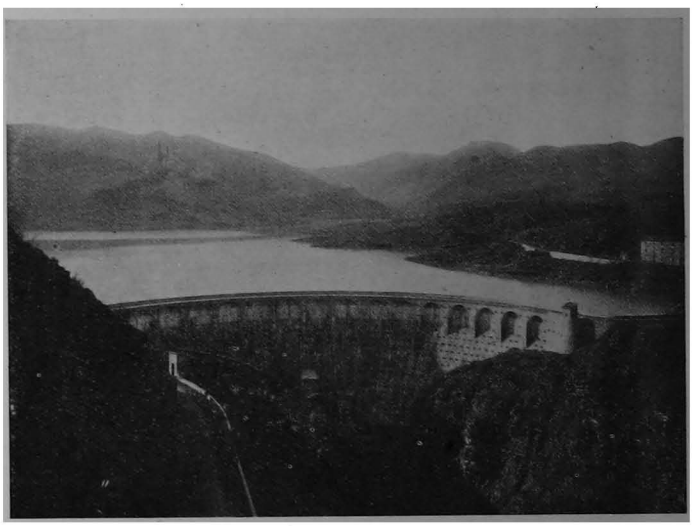

Plate 4

Diga del Brasimone.

Plate 5.
Diga Hone.

Plate 6.
Diga del Tirso.

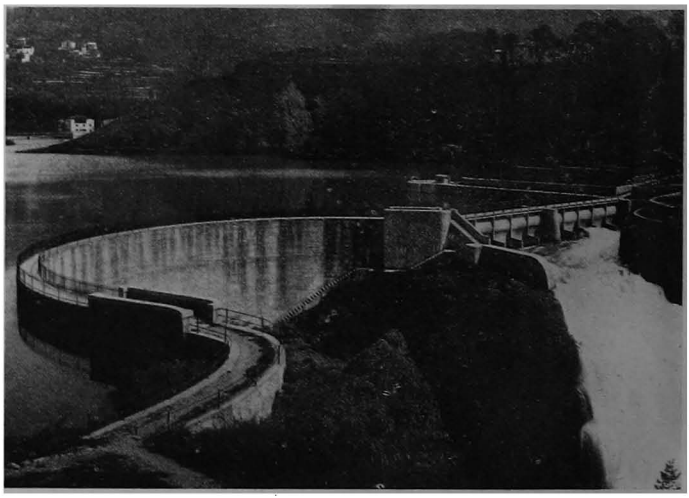

Plate 8.
Diga del Confino.

Plate 9.
Diga della Turrite.

Plate 10.
Diga sul T. Hone.

AMPOLLINO II

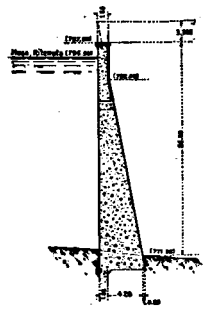

Fig. 1.

HÔNE

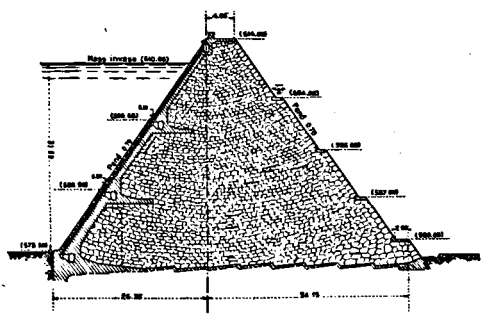

Fig. 2.

VARGNO

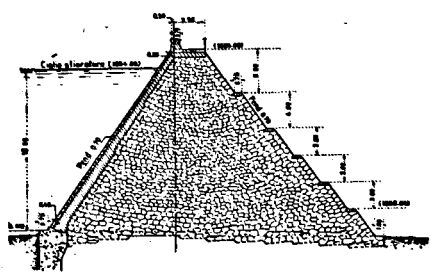

Fig. 3.

SCANDARELLA

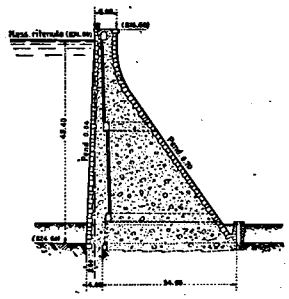

Fig. 4.

COGHINAS

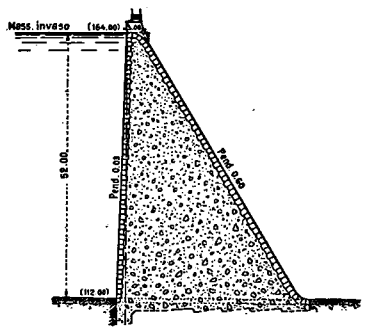

Fig. 5.

VALLA

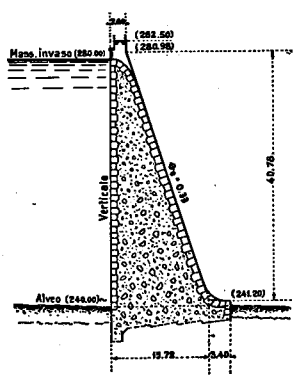

Fig. 6.

LIRO

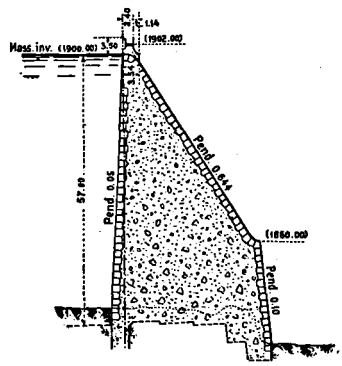

Fig. 7.

CENISCHIA
(Diga Ovest)

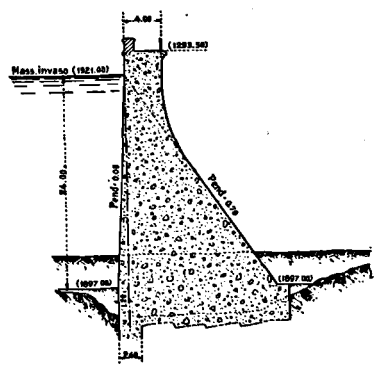

Fig. 8

AMPOLLINO I

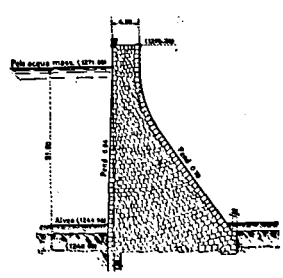

Fig. 9.

GENISCHIA
(Diga centrale)

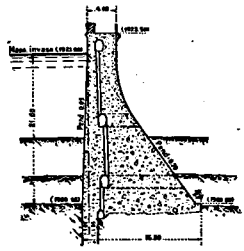

Fig. 10.

BRASIMONE II.

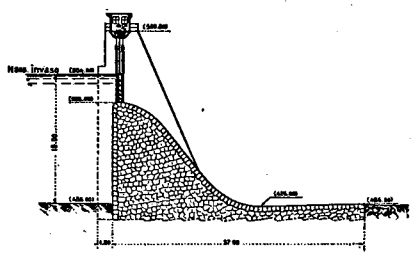

Fig. 11.

GABIET

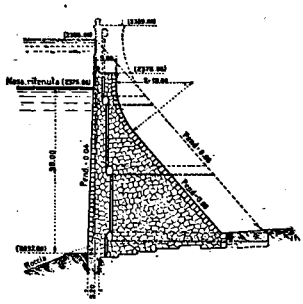

Fig. 12.

TURRITE

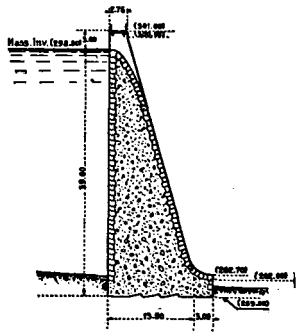

Fig. 13.

SERCHIO

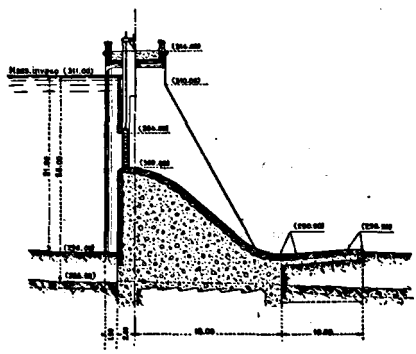

Fig. 14.

SCOLTENNA

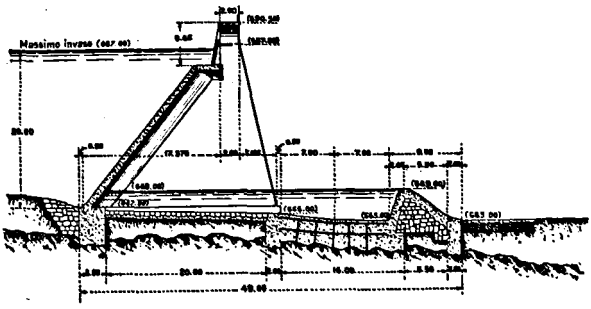

Fig. 15.

VENINA

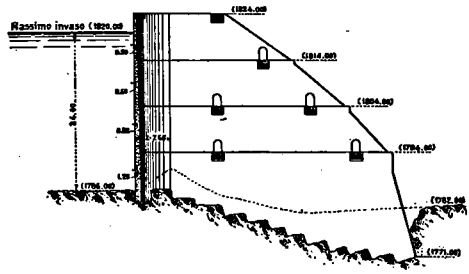

Fig. 16.

TRUZZO

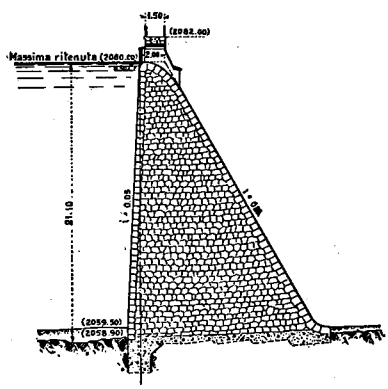

Fig. 17.

LETÉ

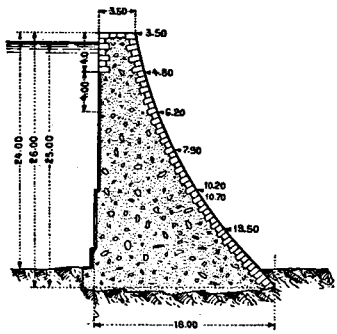

Fig. 18.

CISMON I

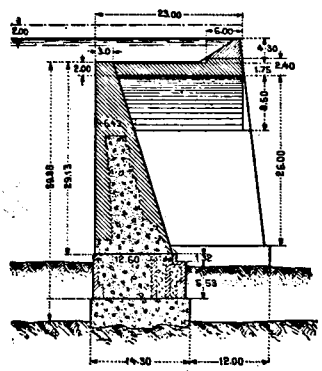

Fig. 19.

BRASIMONE I.

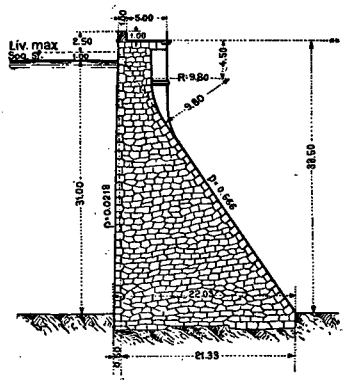

Fig. 20.

CORFINO

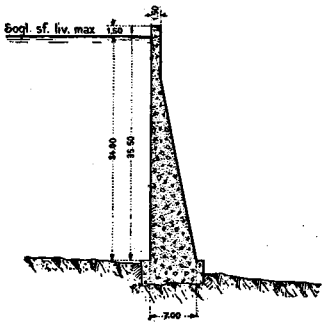

Fig. 21.

LAGO VANNINO

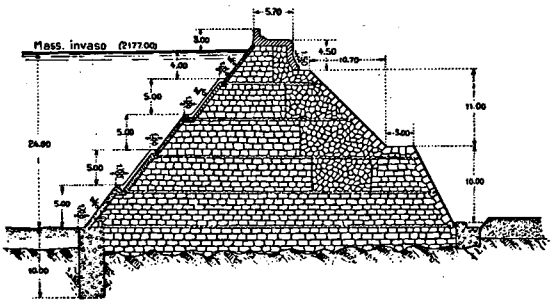

Fig. 22.

DEVERO

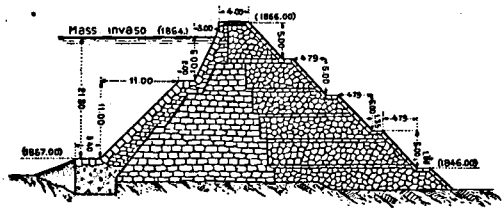

Fig. 23.

ROCHEMOLLES

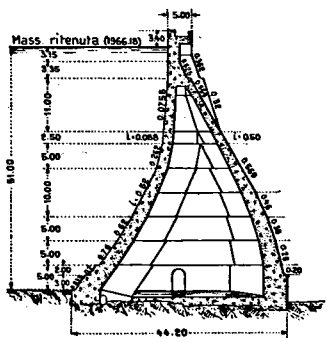

Fig. 24.

TIRSO

(o Busacchi)

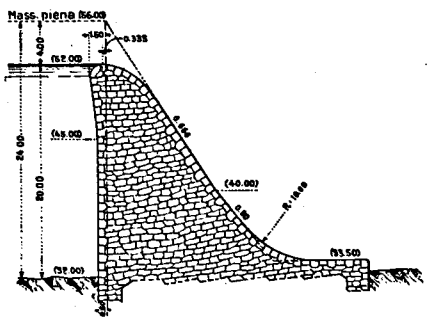

Fig. 25.

S.PIETRO

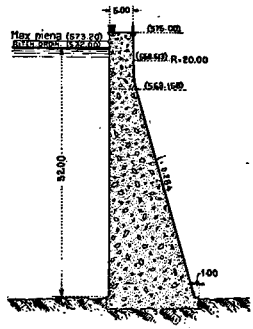

Fig. 26.

CORRONGIUS

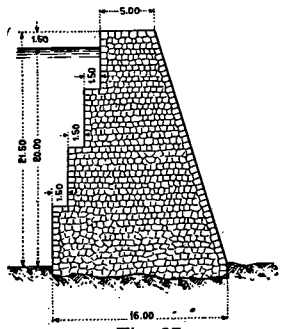

Fig. 27.

LAGO NERO

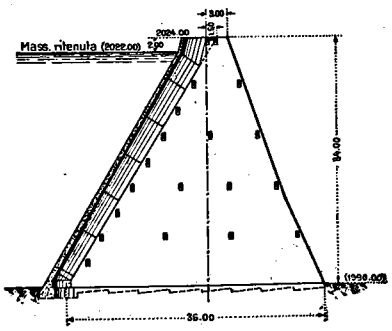

Fig. 28.

TORRE

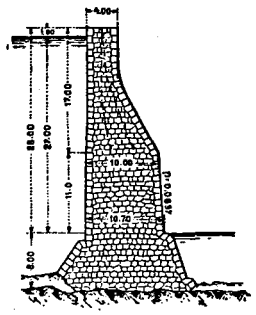

Fig. 29.

LAGO D'AVIO

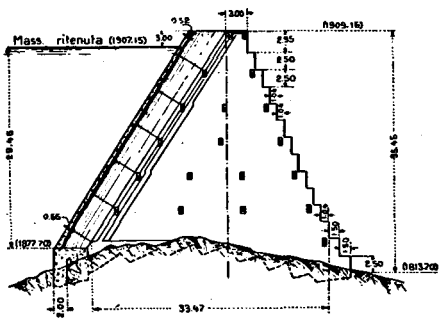

Fig. 30.

LAGO D'ARNO

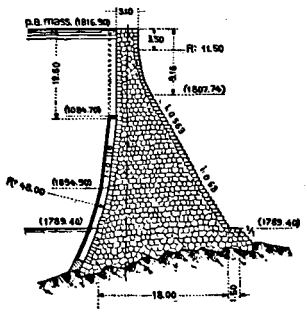

Fig. 31.

LAGOLUNGO

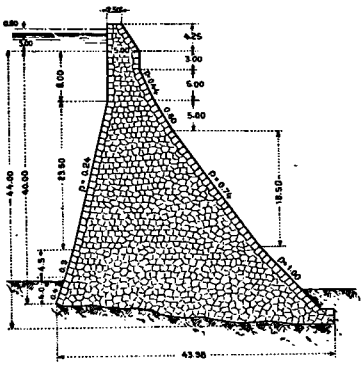

Fig. 32.

LAGO D'ELIO

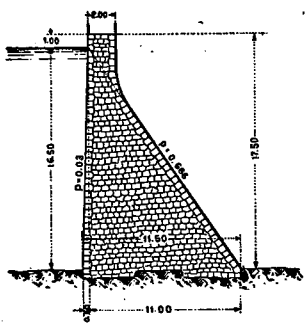

Fig. 33.

LAVEZZE.

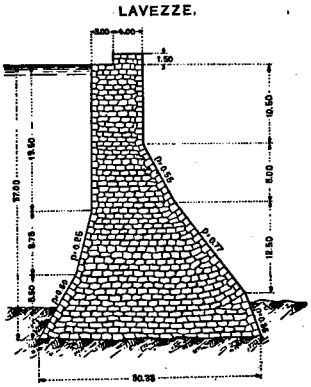

Fig. 34.

TIRSO

(a Santa Chiara)

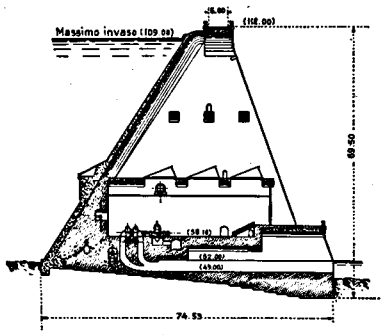

Fig. 35.

FURLO

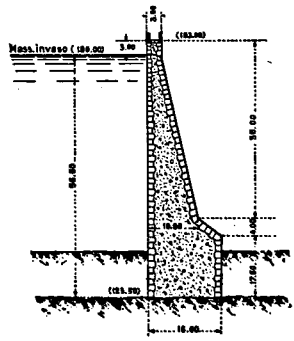

Fig. 36.

BADANA

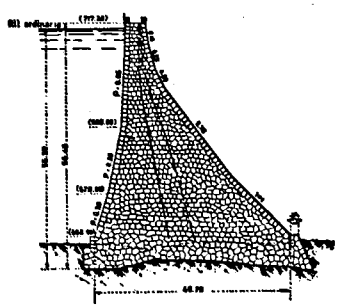

Fig. 37.

COMBAMALA

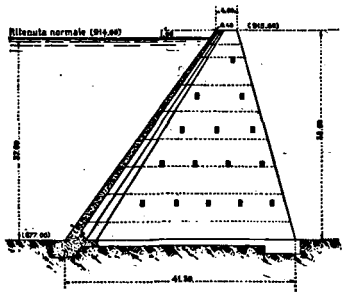

Fig. 38.

GAIOLA

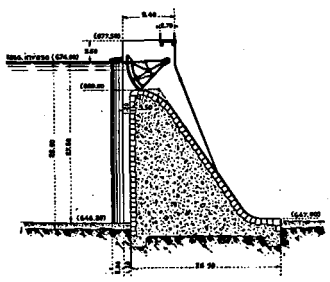

Fig. 39.

ZOLEZZI

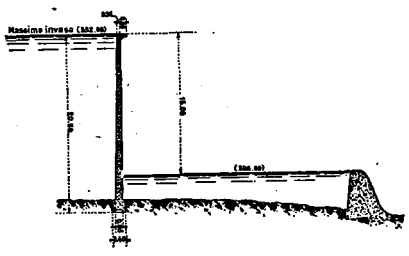

Fig. 40.

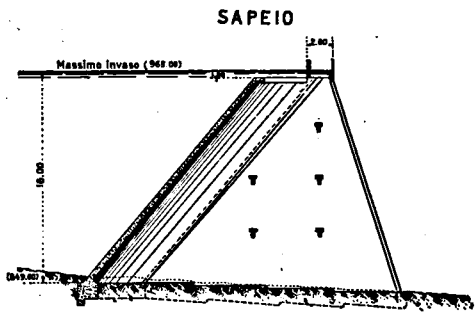

Fig. 41.

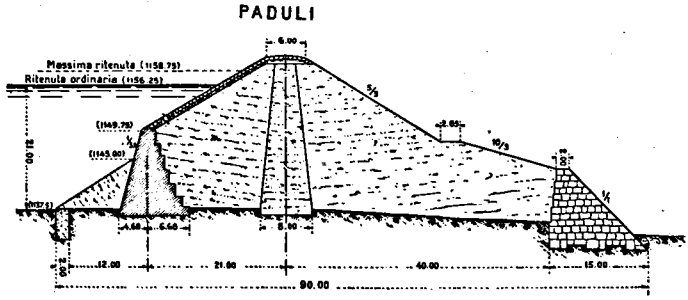

Fig. 42.

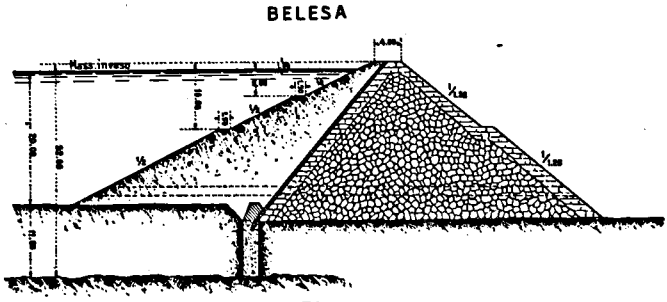

Fig. 43.

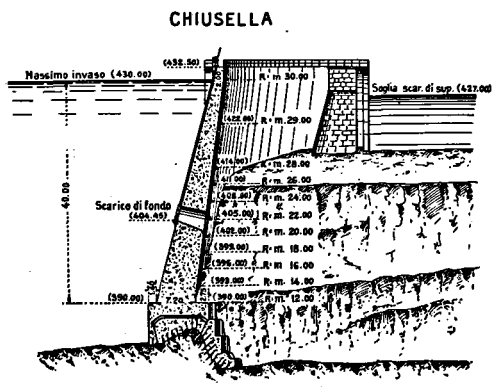
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Fig. 44.

RECENT DEVELOPMENTS IN ITALIAN WATER TURBINES

ING. GUIDO UCELLI

" Se ti addiviene di trattare delle acque consulta prima l'esperienza e poi la ragione. . . ."—*Leonardo da Vinci* (1452-1519).

A GENERAL RETROSPECTIVE SURVEY OF THE HYDRAULIC TURBINE INDUSTRY.

The building of hydraulic machinery has in Italy an age-long tradition. In fact, as far back as the fifteenth century, Leonardo da Vinci, while studying to improve the old water wheels, noted in his " Atlantic Code " conceptions having a striking resemblance to the modern principles of design.

The remarkable deficiency of coalfields has necessarily induced Italy—right from the early stages of hydraulic power utilisation—to direct her attention to her resources of " white coal," and this has favoured the rise of the modern hydraulic machinery industry, that has developed into one of the most characteristic of all the mechanical trades of the country.

Even before 1880, while the old-fashioned water wheels were still being erected, we had begun to construct hydraulic turbines in Italy. Generally speaking, however, the beginning of 1885 (after the passing of the " derivation of public waters " Bill of the 10th August, 1884), is regarded as the starting point of this industry which, within a short time, even before the utilisation of the power by means of electrical appliance, was able to assert itself with important local plants for the running of individual mills.

Special and general conditions (not least among which were the difficulties dependent upon the legislative measures referred to and others passed later and which, in some cases, rendered the development of steam power with imported coal both more convenient and economical) hindered the development of plants so that, after the promising period between 1905 and 1911, that carried the annual concessions to about 80,000 H.P. nominal average, the following fifteen years saw the average fall to some 45,000 H.P. of new installations a year.

Note.—In the paper power is given in H.P., instead of kW.—as decided by the International Electro-Technical Commission (Turin, 1911)—as the Government statistics and those of the various hydraulic machine builders in Italy are still expressed in H.P.

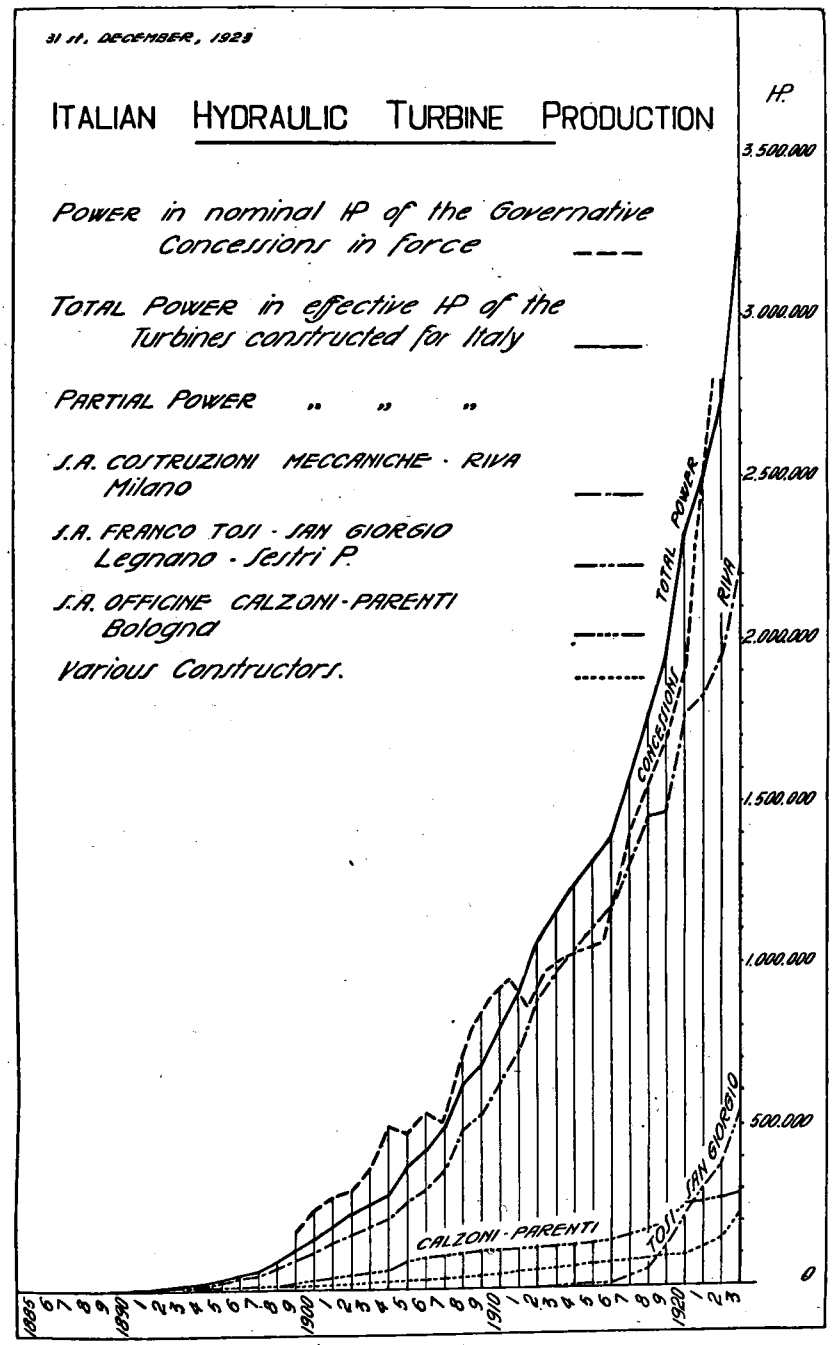

Fig. 1.
Italian Hydraulic Turbine Production (government concessions and turbines constructed.)

The new conditions created after the world conflagration, have now pushed Italy to a more intense utilisation of her water power and wise legislation has assisted this necessity so that, while there were in 1914 water concessions allowing for the development of some 1,000,000 H.P., from 1915 to 1923 this has been almost trebled, while the schemes afoot are growing both in number and volume.

Though in Italy there are to be counted many important plants constructed by reputable foreign houses, by far the greater number of the turbines installed (in spite of there being no special tariffs) are of Italian make. In pre-war times, imported turbines could be calculated as equal to 15 per cent. of the whole power; since 1915, importation has been reduced practically to nil. Against a total at the 30th June, 1922, of about 2,800,000 H.P. of government concessions, the statistics for 1923 already show a jump to over 3,250,000 H.P., which represents the turbine output for Italy by the home manufacturers (Fig. 1). When considering the change in time and also bearing in mind the inevitable discordance due to the different bases of calculation (which generally ascribe the power laid down at 3·2 of the average power of the concession) we perceive from these summary data how great is the value of the Country's industry.

Right from the very beginning, the most important Italian makers constructed special turbines for each plant, so that, whether large or small, the most suitable conditions of plant and operation were obtained.

The turbines constructed in Italy till recently, were nearly all destined to meet the home requirements. As a general rule, they have constructive characteristics corresponding to the special needs of Italian plants, and in these categories, since they are not restricted by standardisation to fixed types, they represent by gradual increase of power, by improvement in construction, detail, regulation and accessories, a technical and industrial evolution that fears no comparison with that of other nations.

The power per unit has been rapidly increasing parallel with the development of electrical constructions (Fig. 2). In 1896, for the historic Paderno plant (the first example in Europe of a turbine of great power and of long distance power transmission), an Italian firm, in competition with the most celebrated foreign specialised houses, was chosen for the construction of the seven Francis turbines of 2,160 H.P. each. The excellent results obtained by this plant—still running after more than twenty-five years of uninterrupted service—encouraged the construction of more important plants.

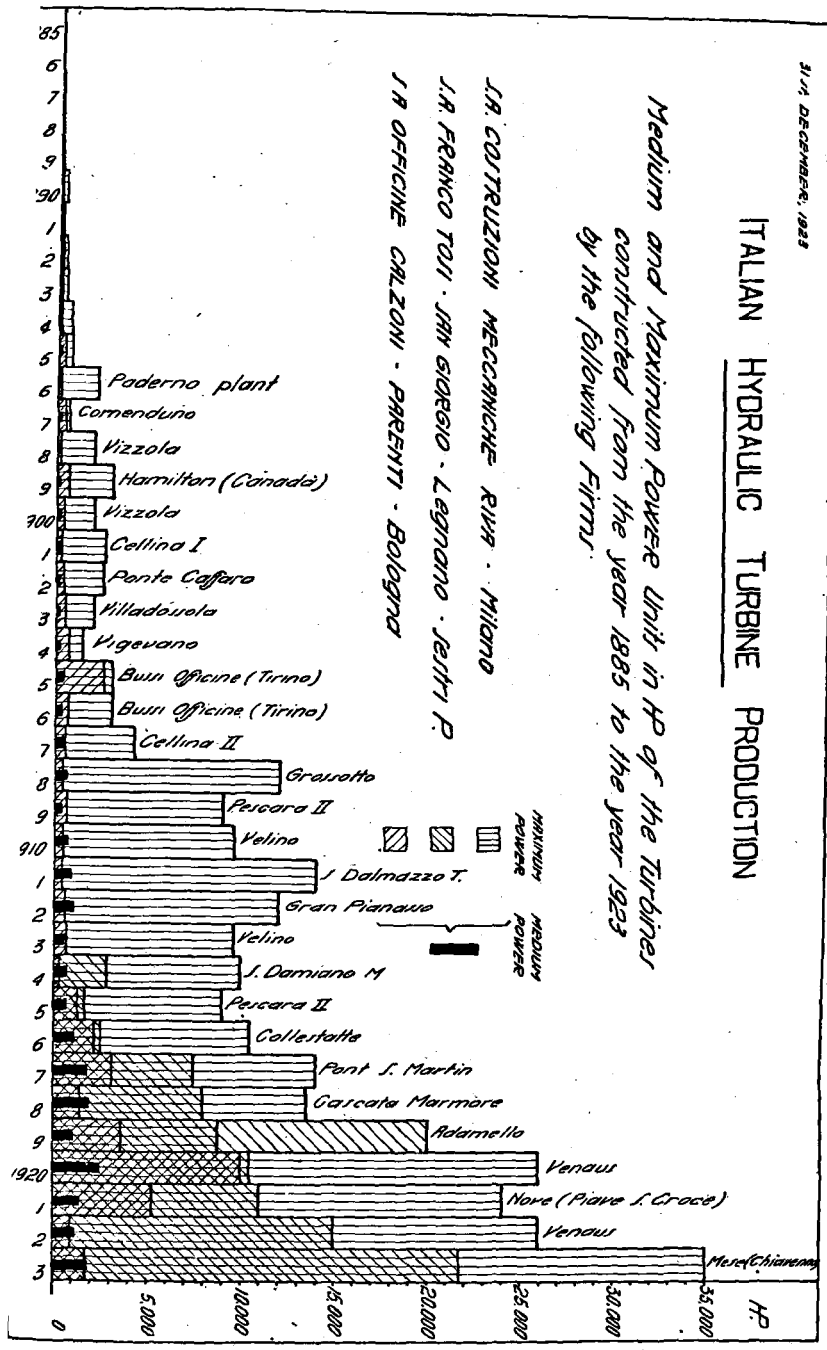

Fig. 2.
Italian Hydraulic Turbine Production (medium and maximum power units in H.P. of the Turbines constructed).

This marked the beginning of the great utilisation of water power that, in a short time, has become one of the greatest factors in the prosperity of the country.

In 1899, the great value of Italian engineering was recognised during an important international competition. The same Italian firm was entrusted with the construction of two 3,000 H.P. Francis turbines for the St. Catherine's plant, owned by the Hamilton Electric Light & Cataract Power Co., at the Niagara Falls (Fig. 3).

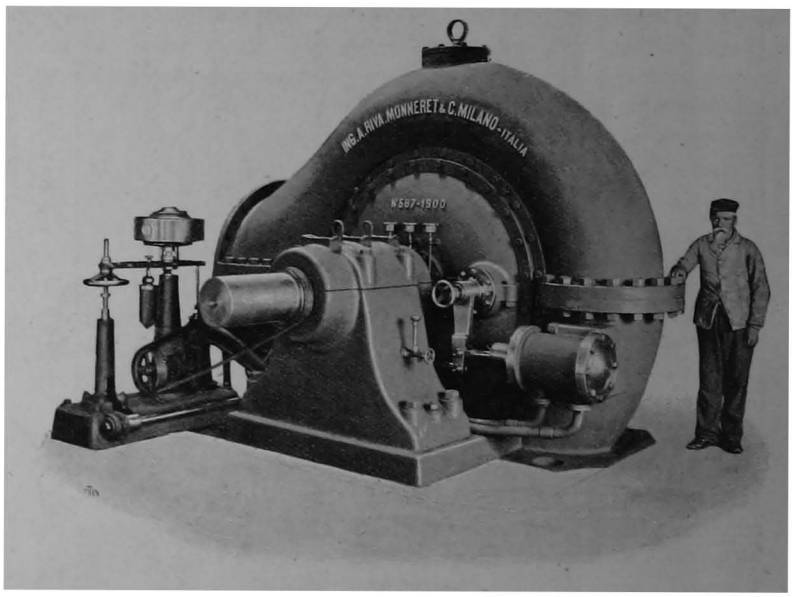

Fig. 3.

Niagara Falls Hydro-electric Plant—Francis Turbine for

Head	78 mtrs.
Discharge	3,850 lt/sec.
Output	3,000 B.H.P.
Speed	268 r.p.m.

(Costruzioni Meccaniche Riva.)

Since 1908, units of over 10,000 H.P. have been constructed. 1920 saw the beginning of a series of turbines of a power exceeding 20,000 H.P., while at the present time 35,000 H.P. units are in hand.

Of the turbines constructed till now, nearly all have been destined to be coupled with electrical generators, since electric current is used for the running of nearly all the Italian works, for irrigation and land improvements, for aqueducts and for a considerable part of the railway and tramway traction.

GENERAL CHARACTERISTICS OF TURBINE PLANTS IN ITALY.

Italy, for the most part mountainous, with but small plains, has no great water courses for the running of imposing plants of great discharge and with falls of only a few metres. Therefore, turbines of exceptional size are not required and there has been no call for turbines of extremely high speed.

Chronologically, plants with falls under 20 metres constitute the first utilisation. But though they are extremely numerous and of great industrial importance, as they are very often for the use of

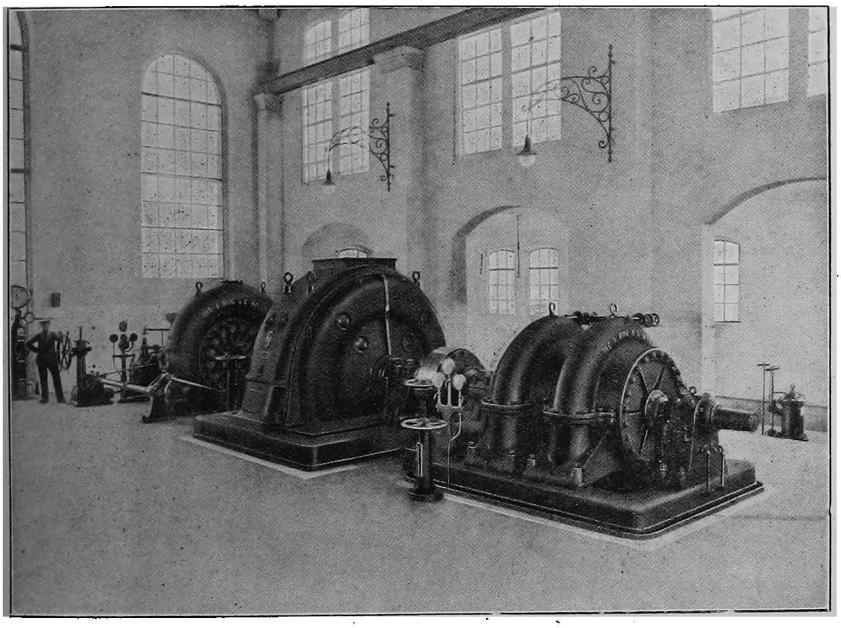

Fig. 4.

Hydraulic Accumulation Plant of Viverone (Piedmont), Francis Water turbines for

Head	134 m.
Discharge	3,600 lt/sec.
Output	4,800 B.H.P.
Speed	750 r.p.m.

(Costruzioni Meccaniche Riva.)

single factories, yet they are not prominent in the field of hydraulic utilisation (less than 10 per cent. of the total power).

More important are medium fall plants (from about 20 to 200 m.),

frequent in all parts of Italy. In this category the features of Italian designs are worthy of note.

In high and very high falls, of over 1,000 metres, there are likewise examples of utilisation of the greatest interest, the maximum unit power being reached here also.

A special series of medium and high fall plants is that for the utilisation of natural and artificial lakes, valuable reserves of power

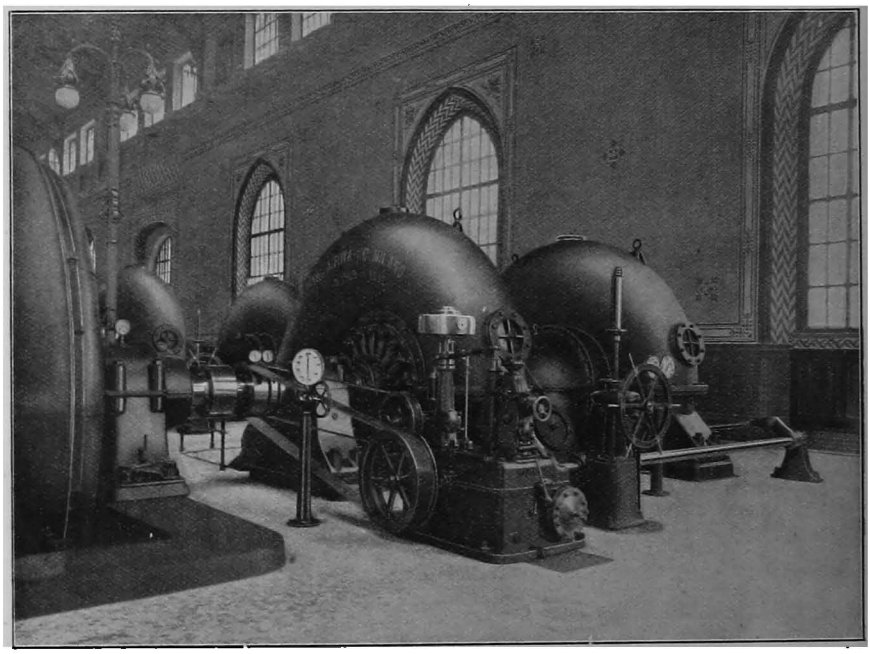

Fig. 5.

Robbiate Power Station (Lombardy).
Double spiral casing Francis turbines, single discharge, each for

Head	37 m.
Discharge	18,000 lt/sec.
Output	7,000 B.H.P.
Speed	315 r.p.m.

(Costruzioni Meccaniche Riva).

for the levelling of the uneven supply of central stations subject to seasonal changes. Among these, the first actuated in the Alpine group of the Adamello, still remains one of the most important examples, though surpassed by recent constructions, amongst which the most remarkable is that of Tirso in Sardinia, having a storage capacity of 460,000,000 cubic metres.

Characteristic applications, and of noteworthy importance, are to be found in the " hydraulic accumulation " plants in which, during the night or holidays, in order to store energy, pumps are driven for the refilling of an upper reservoir. The water so accumulated then feeds the turbines to furnish extra power during the hours of the greatest demand (Fig. 4). Interesting also are the centrifugal turbine pump units of which there are examples of considerable power for irrigation plants.

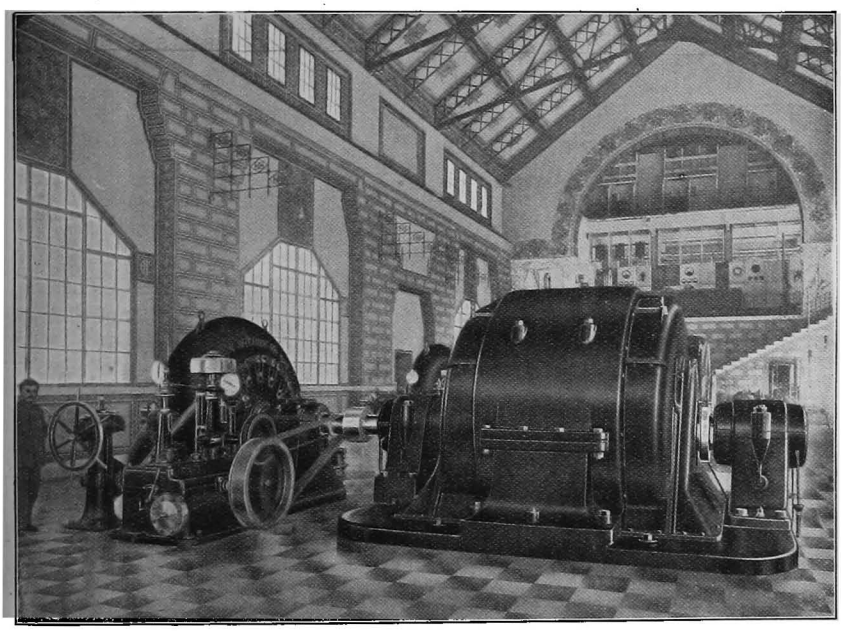

Fig. 6.
Crego Hydro-electric Station (Piedmont).
Single runner, single discharge Francis Turbines, each for

Head	188.50 m.
Discharge	3,900 lt/sec.
Output	8,000 B.H.P.
Speed	840 r.p.m.

(Costruzioni Meccaniche Riva).

Finally, we must note the growing importance of plants with automatic remote control which, though not having till now a large field of operation, have given an opportunity for ingenious characteristic solutions on the part of Italian engineers.

Italian plants are accurately studied in every detail and the choice

of machinery is the object of rigid specifications. The great care taken in the construction of the plants is often revealed by the pains taken to ensure the æsthetic beauty of the stations, some of which rise to the dignity and value of real architectural monuments; these impose upon the turbine constructors special considerations of an æsthetic nature. In fact, it must be recognised that the majority of Italian turbines are of a characteristic elegance which unites with solidity and economy of construction, harmony of design, perfect finish and accuracy in every detail. Figs. (5–6).

TURBINES IN OPEN CHAMBERS FOR LOW FALLS.

The turbines preferred for low falls are those in open chambers that allow of the maximum simplicity and economy of plant, while ensuring the greatest facility for inspection, maintenance and cleaning.

For many years the old impulse types (Girard and the like) have been completely abandoned in favour of the greater advantages presented by the reaction types that permit of excellent working even with notable variations in the feed and discharge levels. The falls utilised normally in open chambers do not exceed 10-12 metres. Rarely do they reach 15-20 metres with reinforced concrete chambers, and these limits are exceeded only in exceptional cases.

Vertical shaft installations are seldom used and are generally limited to cases of extremely low falls. However, there are a few examples of some importance. As early as 1894 there were constructed turbines for the " Crespi Spinning Mills " at Trezzo d'Adda with single wheel of a capacity of 13,500 litres per sec.; in 1904, the Crespi Electric Power plant at Trezzo d'Adda 10,000 H.P. aggregate, total consumption over 100 m^3; and in 1906 the Cerro al Lambro plant, with turbines of 12,000 litres per second. Among the modern plants those executed for France are notable (Union Electrique du Tarn) for four units of 25,000 litres each and four of 30,000 litres each. The big turbine for the Busachi Tirso Central Station with a wheel for 25,000 litres (Fig. 7) is in course of construction.

In most cases horizontal shaft turbines are preferred (Fig. 8). In multi-stage turbine plants, arrangements are generally introduced whereby, even while running, access may be obtained to the intermediate bearings.

For the better utilisation of the variable flows due to the seasons, in small plants it is sometimes convenient to place the units " in tandem," which allows the exclusion of part of the runners in order

to work under conditions corresponding to the best utilisation even by extremely reduced water discharges.

During the last few years several manufacturing firms, with the object of improving the efficiency of the low fall turbines, have carried out experiments on the design of the draft tubes, that have great importance in these plants, in which sometimes a greater part

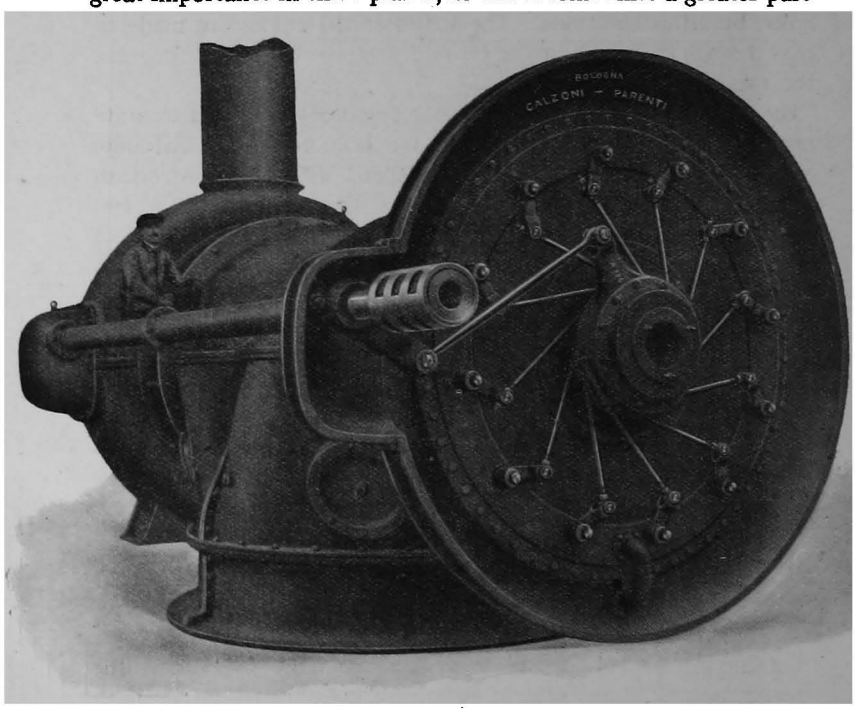

Fig. 8.

Ponte Fiume Plant (Southern Italy).

Double runner, single discharge Water Turbine in open chamber, for

Head	15·50 mts.
Discharge	33,800 lt/sec.
Output	5.500 B H.P.
Speed	250 r.p.m.

(S.A. Officine Calzoni-Parenti).

of the available fall is in suction rather than pressure. In some cases even the turbine shaft has been placed at a point higher than the surface of the feed water, thus utilising the entire fall in suction (syphon turbine).

In this field, constructive characteristics have been obtained which allow the best recovery of energy corresponding to the velocity

of the water discharged by the runners without having recourse, however, to any special forms of American origin (Hydrocones).

The gates have balanced wicket guides, with immersed driving mechanism, or this mechanism is placed outside when the water has encrusting or corrosive properties. The operating mechanisms are characteristic: by chain (jointed parallelograms), by connecting links, by adjustable rods. The shafts of the guides are made to pass through stuffing boxes or through suction chambers to prevent the escape of the water.

The design of the runners has been the object of special and accurate tests. It is known what efforts have been made by hydraulic engineers to overcome the specific speed n_s* of the American wheels "Slow" and "Normal" (which have their value n_s less than 300) with the object of attaining speeds suitable for direct coupling to electric machinery. Though in Italy we have not in general realised all the conditions that have drawn other designers towards the characteristics of high speed turbines, we have designed and subjected to numerous and rigorous tests different types of high speed wheels, *viz.*, diagonal reaction wheels, diagonal multi-rimmed runners, with cylindrical and conical gates, etc. In consideration, however, especially of the variations in the amount of available water to which the Italian plants are subject, we normally prefer the designs of wheels likely to ensure a good result even with a partial load and for this reason, Italian constructors have taken as a limit a specific velocity n_s = about 500.

TURBINES IN CLOSED PENSTOCK FOR MEDIUM FALLS.

Considering 20 to 200 metres as average falls, these form the greater part of those utilised in the plants constructed in Italy almost until 1908. Even to-day in this category, which represents about 50 per cent. of the total power installed, are to be numbered constructions deserving of notice for the power reached and for their technical perfection.

The leading position of the Italian industry in this branch was recognised as far back as 1899 when there were ordered in Italy the 3,000 H.P. Francis turbines for a plant at the Niagara Falls.

Apart from the various and interesting examples of Schwamkrug

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$$n_s = \frac{n\sqrt{N}}{H\sqrt[4]{H}}$$

n = number of r.p.m.
H = fall in metres.
N = power in H.P.

type of impulse turbine for falls of 150 and 170 metres (Spoleto and Piedimulera); a type that has been abandoned for some fifteen years, the " reaction " types of Francis turbines are particularly notable, especially for big power units.

The horizontal shaft design is generally preferred in Italy. Nevertheless several vertical shaft plants worthy of attention have been executed and others are in the course of construction (Castelnuovo

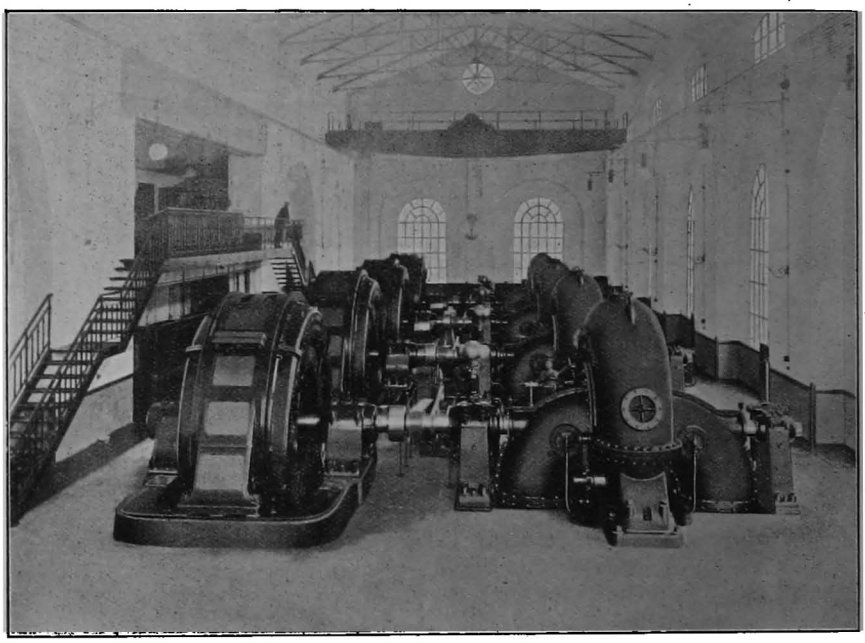


Fig. 9.

Pescara II. Power Station.

Double runner, double discharge Francis turbines, each for

Head	73·50 m.
Discharge	12,000 lt/sec.
Output	9,000 B.H.P.
Speed	420 r.p.m.

(S.A. Costruzioni Meccaniche Riva.)

Garfagnana, S. Pietro d'Orzio and a unit of exceptional importance of 24,000 H.P. for the Velino plant at Terni).

The arrangements most frequently adopted with horizontal shafts are: single wheel, single discharge (amongst the most notable plants, Niagara (Fig. 3), Bussi, Cedegolo, Velino, Fadalto, Volturno,

Maira, Farfa, Crego (Fig. 6), Corfino, Tanagro, Susa). With double discharge (Cellina, Zogno, Giais, Pescara II. (Fig. 9), Cismon, Serchio, Poschiavino, Aymavilles, Furlo, Coghinas).

Two wheels with single central discharge (Pennarossa, Robbiate (Fig. 5), Castelmadama, Boffetto, Nera Montoro, Brasimone II. (Fig. 10), Fadalto Nuovo, Rossi Arsiero).

And, finally two wheels with separate discharges (Tirso, Molare, Borzonasca, etc.).

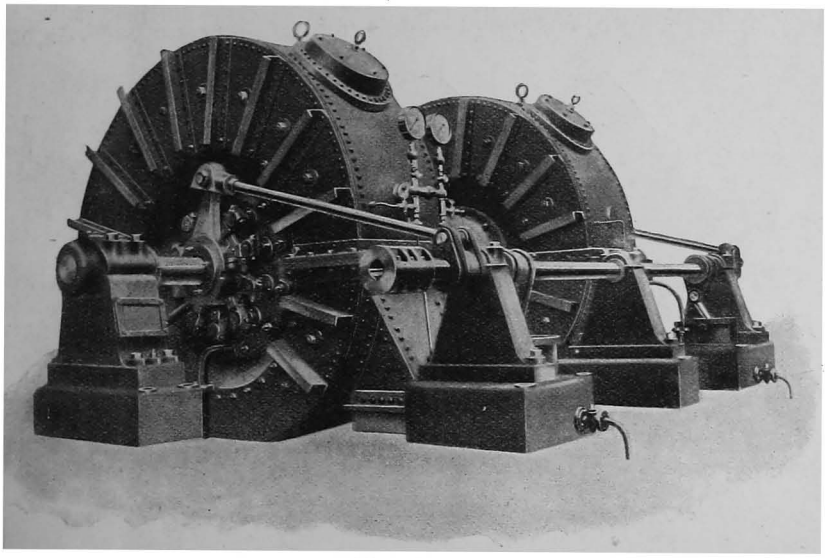


Fig. 10.

Brasimone Hydro-electric Plant.

Francis turbine for	
Head	38 m.
Discharge	6.000 lts.
Output	2,500 B.H.P.
Speed	630 r.p.m.

(S.A. Franco Tosi—S.A. San Giorgio.)

Turbines with the last-named arrangement are sometimes of special interest for the conditions of Italian plants, as they allow working with only one wheel in case of a big drop in the volume of water, analogous to what is done with the tandem arrangement of open chamber turbines (Fig. 11).

A noteworthy arrangement is one with runner overhung on the alternator shaft, an arrangement which, by eliminating the necessity for passing the shaft through the suction elbow in those cases

where the hydraulic balance of end thrust is sufficient, besides reducing the number of bearings for each hydro-electric unit to two only, ensures good working with the greatest facility of assembling. It reduces the floor space of the machinery to a minimum and allows a considerable saving in the cost of the machine room building.

Important examples of this arrangement are the turbines of the Velino plant (Terni) of 10,000 H.P. each, running at 900 revolutions with 190 metres fall.

The arrangement with " wheels in series," patented in 1908, calls

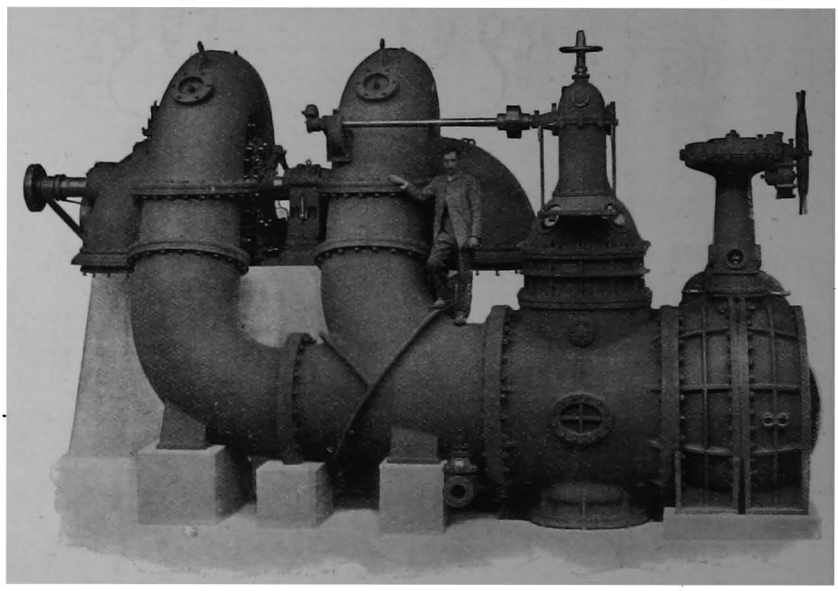


Fig. 11.

Barcelona Power Plant (Spain).

Double spiral casing, double discharge Francis hydraulic turbine, for

Head	56 m.
Discharge	8,000 lts/sec.
Output	4,675 B.H.P.
Speed	750 r.p.m.

(S.A. Franco Tosi—S.A. San Giorgio)

for attention. It has for its object the sub-dividing into two or more steps the available head in cases where it is high but not yet suitable for Pelton wheels.

In recent times there has also been introduced in Italy the design of the " Turgo " turbines for application in fields analogous to those already mentioned.

The enclosed chambers for Francis turbines, generally spiral, are usually of cast iron ; for great water discharges, sometimes of sheet steel (Brasimone, Tronto, Nera Montoro, with a fall of 23 metres and a total volume of water of about 120,000 litres) ; and for high heads, of cast steel (Velino, Volturno).

The plant recently put into service which utilises the source Piave-Santa Croce, is worthy of special remark since under particularly

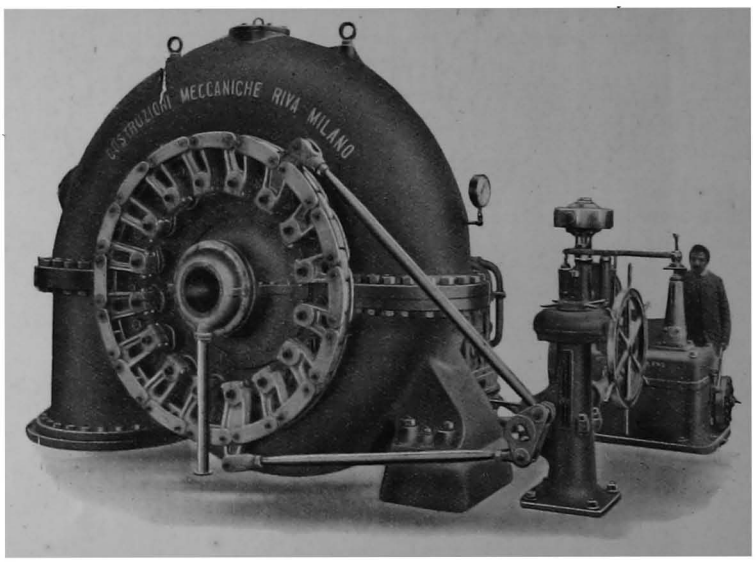


Fig. 13.

Velino Hydro-electric Plants (Terni).

Single runner, single discharge Spiral Francis turbine, for

Head	190 m.
Discharge	5,200 lts/sec.
Output	10,000 B.H.P.
Speed	900 r.p.m.

(Costruzioni Meccaniche Riva.)

favourable conditions it is able to take advantage of a natural lake as head reservoir.

This source, when the work is completed, will feed a group of plants for a power of over 300,000 H.P. Already three units of 24,000 H.P. each have been installed with Francis turbines at 420 r.p.m. with two spirals and one central discharge, utilizing a fall varying from 84 to 110 metres. These are the largest reaction units in operation in our country (Fig. 12).

The runners of the different types, fast, normal, slow ($n_S = 300$

to 50) are made of cast iron or with inserted steel buckets, and for high falls, of bronze or even of cast steel.

For the gate, with wicket guides, the old internal link-operating system has been given up and the driving mechanism is now always placed outside, the first notable application dating back to 1905. The original design, with inward radial levers, commanded by a central ring (Giaumà) has, little by little, been improved by individual constructors, sometimes with double set of levers, sometimes with outward radial levers also worked from an external ring (Pescara). Recently there has been applied the so-called "link-chain" operating mechanism and that with adjustable connecting rods as in the designs already mentioned for open chamber turbines. (Fig. 13).

The hydraulic balance against end thrust is generally obtained automatically, without having recourse to the application of special steps or auxiliary balancers. In special cases, oil pressure balancers are adopted.

On the rim surfaces of the runners and sides of the gate, renewable linings are introduced in order to reduce the cost of maintenance. In important units where, owing to the quality of the water, the hydraulic balancing rings are subject to rapid wear, provisions are made for their adjustment without dismantling the machine.

IMPULSE WHEELS FOR HIGH FALLS.

In Italy, the utilisation of high falls was definitely initiated about 1908; before that date there were but rare and modest plants with heads not much more than 200 metres.

To-day the impulse wheel of the "Pelton" type, a truly perfect machine in every respect for the high power obtained and for the notable simplicity of construction, represents a category of really conspicuous importance (about 40 per cent. of the total power of Italian plants) and permits the utilisation of the highest falls practically realisable (1,000-1,500 metres).

The volume of water in the utilisation of high falls is always comparatively limited, little more than 10,000 litres being the maximum in actual plants, but it allows very considerable power to be developed with single units.

When one requires a high number of revolutions in relation to the fall and to the quantity of water available, double or multi-jet turbines are constructed, all jets acting upon the same wheel, and also multiple wheel turbines with one or more jets per wheel (Fig. 14). The arrangement adopted is always with horizontal shaft. Units

of great power on vertical shafts are being studied for new Alpine plants. The arrangement with wheel overhung on the alternator shaft are also not infrequently met with.

The Pelton wheel runner requires particular care with regard to calculation, design, choice of materials in all principal details, owing to the high peripheral speed, in order to withstand with absolute security any exceptional stresses that might occur through some unforeseen circumstance (runaway speed, etc.).

The rectangular nozzle with pivoted tongue regulation, represents

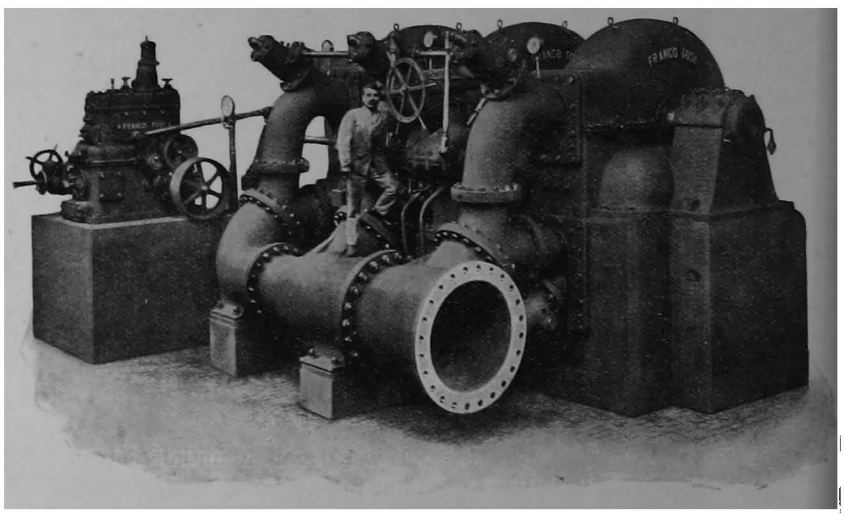


Fig. 14.

Ozola Power Plant.

Triple wheel Pelton turbine designed for

Head	220 m.
Discharge	4,000 lts/sec.
Output	9,000 B.H.P.
Speed	500 r.p.m.

(S.A. Franco Tosi—S.A. San Giorgio).

a design almost completely abandoned. In 1906, after accurate experiments and tests, carried out in an experimental plant on different designs, the most suitable nozzle with needle regulation, also the best shape of buckets for Pelton wheels operated by circular section water jets were ascertained. Such forms, studied by Italian engineers, present differences in comparison with the Abner-Doble design and ensure a jet of water perfectly cylindrical and homogeneous with whatsoever grade of gate opening, besides insuring the highest efficiency and the maximum resistance to erosion.

The buckets of cast iron, steel or bronze, are generally made separate, and secured by special arrangements to the disc or hub-keyed to the shaft, or are sometimes cast in one piece with the wheel hub. The two faces over which the water flows, are polished. In more important and recent plants, in order to facilitate the renewal, the buckets are fixed to a disc that in turn is bolted to a central hub. This is solidly keyed to the shaft and the dismounting of the runner is thus facilitated.

The hand-operating mechanism with which the turbines are generally provided, is often replaced in the big units by a hydraulic cylinder actuated by the pressure of the pipe line.

The Pelton wheel plants that are always fed from pipe lines of great importance, require the application of special apparatus to prevent danger from water ramming. In place of the synchronous discharge valves, a special appliance is now generally used for the automatic deviation of the jet, combined with the automatic slow closing of the nozzle needle, according to the scheme patented by an Italian firm in 1908. The governor maintains the constant speed of the turbine for any variation of load by means of a deviator that instantaneously diverts the jet from the wheel, without affecting the discharge; then, by the slow reclosing of the needle there is established (after a certain time, which can be adjusted at will) the opening of the nozzle corresponding to the new load, without provoking any sensible increase of pressure. The reclosing of this needle generally takes from 20 to 30 seconds and the quantity of water deviated and not used is practically negligible, which is of great advantage in reservoir plants. Furthermore, the automatic deviator has the advantage of the utmost simplicity coupled with strength, being made up of few mechanical parts, connected one to another in such a way that, once adjusted, no displacement is to be feared.

With this extremely important improvement, well known in technical literature, and applied with variations by different constructors, a perfect solution is obtained of the problem of regulation of impulse wheels, whilst the maximum safety of the high pressure pipe lines is attained and the practical utilisation of more elevated falls has been greatly facilitated.

The deviation of the jet is effected in different ways by various manufacturers. Among the modified patents there is one that offers special points of interest. It is a deviation arrangement by which part of the deviated jet is directed against the back of the buckets, thus acting as a wheel brake. An extremely simple split needle

device for obtaining the deviation, though applied and still working, has demonstrated no special advantages in practice.

The characteristic ratio $d : D$ between the diameter d of the jet and the tangent diameter D of the wheel has been used in some constructions, in order to attain a high speed, up to $\frac{1}{8{\cdot}5}$ without too much sacrifice of efficiency. The maximum dimensions have been reached with jets of 20 cms. and buckets 65 cms. wide.

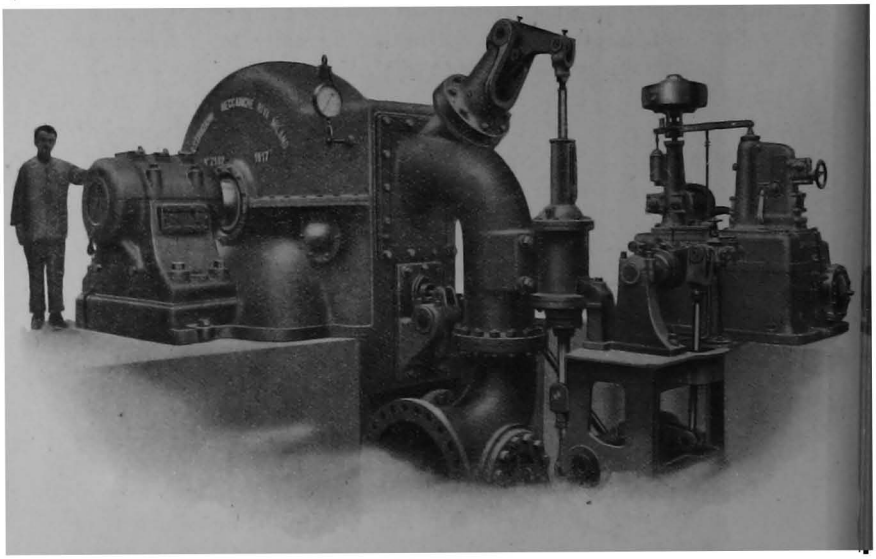


Fig. 15.

Pont St. Martin hydro-electric plant, Pelton turbine for

Head	525 m.
Discharge	2,600 lts/sec.
Output	15,000 B.H.P.
Speed	504 r.p.m.

(Costruzioni Meccaniche Riva.)

The installation of big units in Italy may be considered as having been initiated in 1908 with the construction of the 12,000 H.P. Pelton turbines for the Grossotto plant of the Municipality of Milan. These were followed in 1911 by the 14,000 H.P. units for the San Dalmazzo di Tenda ; in 1917, by that of 15,000 H.P. for Pont Saint Martin (Fig. 15) ; in 1919, by the 20,000 H.P. Pelton for the Adamello (Lake Arno) with a 900 metres fall (Fig. 16) ; while in 1920 were installed the noted turbines of the Venaus plant (Moncenisio) which, with a 1,020 metres fall, develop with a single wheel and with a

single jet a power of 26,000 H.P., this constituting, we believe, a unique example in the world, of such important characteristics (Figs. 17-18). This power, however, has already been exceeded by the 35,000 H.P. turbines in construction for the Mese plant, at the foot of the Spluga.

Among the plants of special interest for their exceptional features, is to be noted that of Bardonecchia for the State Railways, which

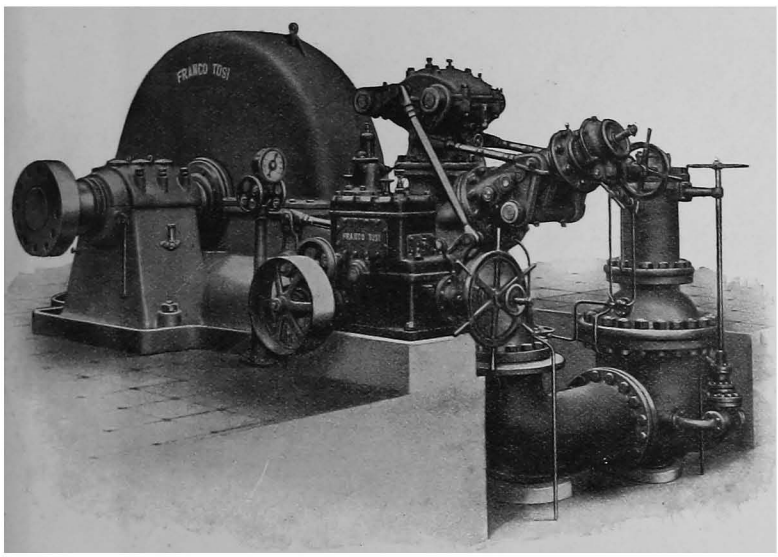


Fig 16.

Adamello (Lago d'Arno) plant, Pelton turbine for

Head	900 m.
Discharge	1,960 lts/sec.
Output	20,000 B.H.P
Speed	504 r.p.m.

(S.A. Franco Tosi – S.A. San Giorgio.)

has been the object of study by foreign engineers. It is composed of a set of 6,000 H.P. Pelton wheels, each made up of two wheels on the same shaft, one fed by two jets with 200 metres fall, the other by a single jet with a 600 metres fall, and a common velocity of 500 revolutions (Fig. 19).

CORROSION AND INCRUSTATION OF TURBINES.

Special care and attention are needed in order to reduce to a minimum the causes and consequences of corrosion and encrustation.

Turbines running under apparently identical conditions have behaved in very different ways because of the different physical or chemical properties of the water, which are sometimes hardly perceptible. From this it follows that where the best steel rapidly wears out, bronze or other alloys will resist well, or *vice versa.* In some plants in Central Italy, the water leaves calcareous encrustations which, in a relatively short time, reach a considerable thickness.

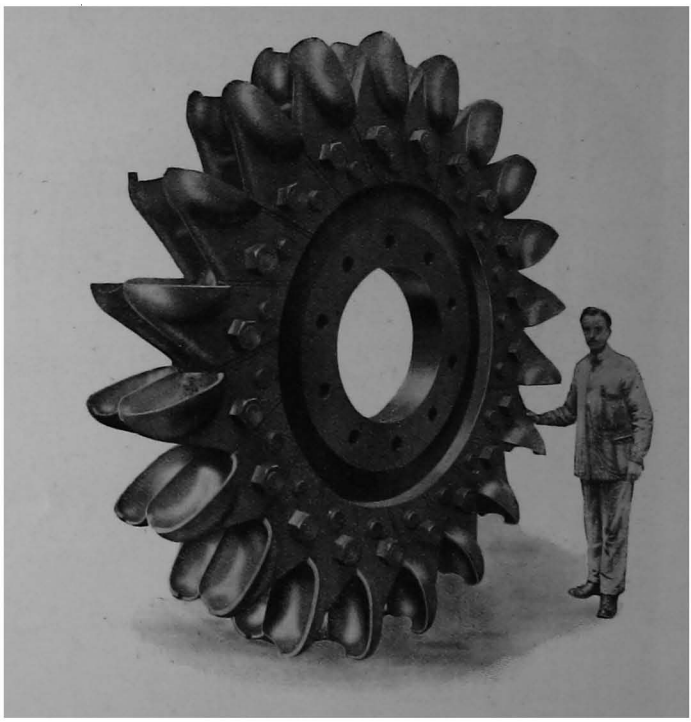


Fig. 17.

Venaus power plant (Moncenisio), Pelton wheel designed for

Head	1,020 m.
Discharge	2,400 lts/sec.
Output	26,000 B.H.P.
Speed	500 r.p.m.

(Costruzioni Meccaniche Riva).

For this reason, the shape of the wheels and gates has been carefully studied with a view to reducing to a minimum the deposits and the wearing away, and to facilitate the necessary renewal of parts. At the same time experiments are being diligently carried out with various materials and alloys.

To repair corrosions, autogenous welding has been frequently used with success both for Pelton and Francis wheels.

REGULATION OF TURBINES.

The difficulty of obtaining an exact regulation, *viz.*, of automatically proportioning the power developed to the load absorbed without affecting the speed, was one of the gravest obstacles that in the past limited the development of hydraulic turbines.

The first governors constructed had mechanical servo-motors. Later, governors with hydraulic servo-motors were largely used

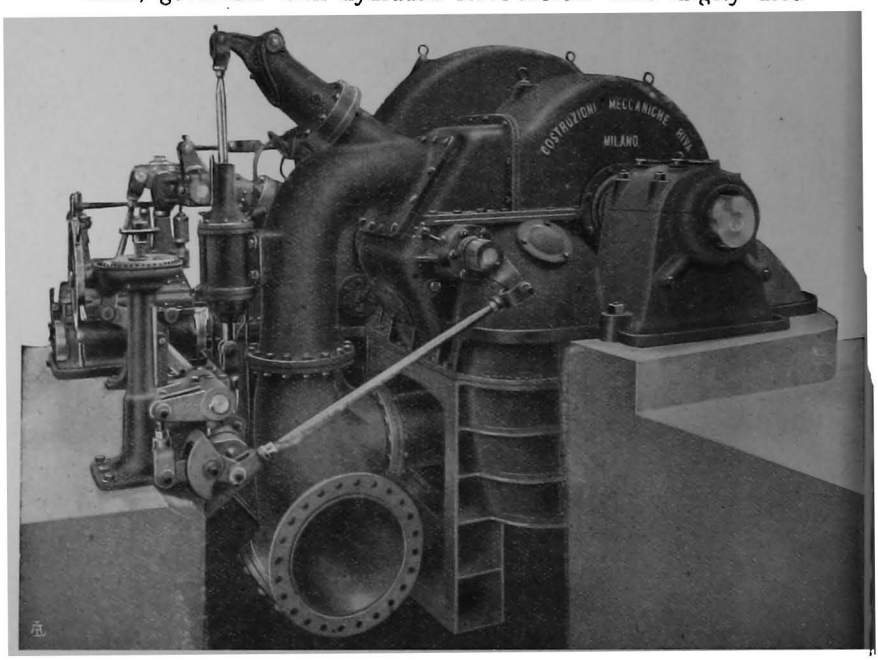


Fig. 19.

Bardonecchia power plant (Italian State Railways).
Set of two Pelton wheels mounted on the same shaft,

the one for	Head	600 m.
	Discharge	500 lts/sec.
the other for	Head	200 m.
	Discharge	1,200 lts/sec.

total output 6,000 B.H.P. ... Speed 500 r.p.m.

(Costruzioni Meccaniche Riva.)

whenever the pressure was sufficient for the purpose. Then, in order to avoid the well known difficulties of running with impure water, governors with oil pressure servo-motors were used which, however,

because of the high cost of the pumping outfit for the production of oil under pressure, could only be applied to big plants.

Only in 1900, due to an able Italian engineer, was a radical solution found of the difficult problem that, for years, had been the object of searching study on the part of many constructors and inventors. This was the creation of the noted self-contained Oil Pressure Governor, which, by collecting into a single unit of small size and moderate cost everything necessary for its working, represented a new and complete solution of the problem (Fig. 20).

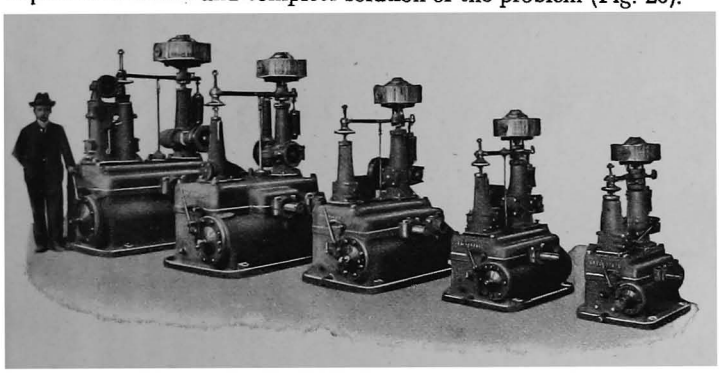


Fig. 20.
Series of oil-pressure self-contained automatic speed governors.
(Costruzioni Meccaniche Riva.)

The principle of this governor was, little by little, adopted by all turbine constructors, both in Italy and abroad, with but simple variations in form, and it has answered the purpose so perfectly that, in spite of experiments made for over twenty years, it is still the best construction of its kind.

The present governors, also in the different forms attempted by other constructors, still maintain the fundamental features of the first example, though they have been improved and completed with special apparatus in order to meet the needs of the various applications, *viz.* :—

To put in parallel the different groups from the electric central switchboard ;

To regulate the opening of the turbines in proportion to the volume of water usable ;

To regulate the difference of revolutions from full load to no load (statics) from a given maximum positive or negative to zero (isodromy) ;

To prevent runaway of the turbine by stopping it in case of the snapping of the governor driving belt ;

To run, at will, at such pre-arranged speeds as may be required by the two or more frequency plants ;

To start and stop the turbines from a distance, etc.

The governors are generally constructed in standard sizes, of powers varying from about 50 kgm. to 4,000 kgm. Special sizes are made only for turbines of exceptional power.

The regulation time, that is to say, the time required by the servo-motor for the complete stroke, generally varies from 2 to 4 seconds

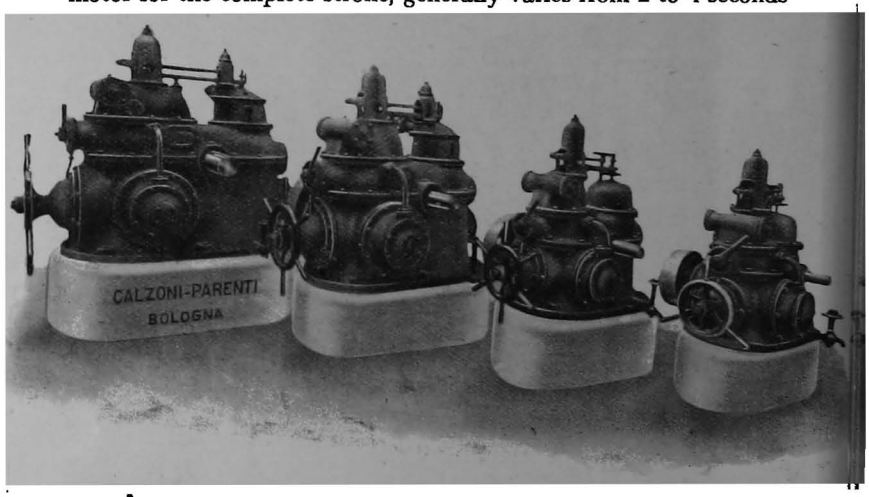


Fig. 21
Series of oil-pressure self-contained automatic speed governors.
(S.A. Officine Calzoni-Parenti).

and gives a perfect regulation of the speed with a low value of the inertia (GD^2) of the revolving masses, without too great danger for water ram in turbines fed from pipe lines. The static value is generally contained within limits of 4-5 per cent.

Among the different Italian modified types, one must notice particularly the pressure gauge bell governor which, instead of utilising the centrifugal pendulum for actuating the servo-motor, utilises the static pressure of a liquid column whose pressure is generated by a centrifugal pump driven by the turbine shaft, this pressure varying with the square of the number of revolutions. In this governor are likewise to be noticed the oil pressure rotary servo-motor and various other details that render its construction one of the most interesting of the kind (Fig. 21).

Another Italian firm constructs a type characterised principally by the command of the control valve through a servo-motor, and by the arrangement of the centrifugal pendulum on the same shaft as the governing valve, thus realising great simplicity in the whole mechanism (Fig. 22).

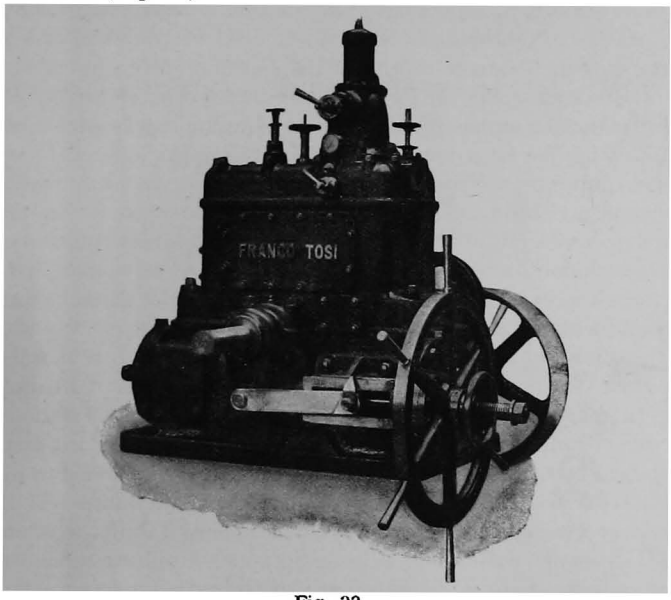


Fig. 22.
Oil-pressure self-contained automatic speed governor.
(S.A. Franco Tosi—S.A. San Giorgio).

Particular study is required for plants supplied by long pressure conduits with regard to the working of the governors, to avoid the phenomenon caused by the quick opening and closing of the gates.

It is the boast of Italian science that, through the masterly studies of Prof. Lorenzo Allievi, of Rome, the theory of this phenomenon was completely developed. Practical experiments have thoroughly confirmed the theory and definite rules have been laid down for calculating the pipe lines and for constructing the synchronous valves on the pressure regulators.

In order to appreciate the value of the progress attained in this important branch of regulation, it will suffice to recall that, during tests recently carried out with the Pelton turbine of Venaus, a sudden cutting off of about 26,000 H.P. load caused a speed variation

of less than 5 per cent. of the normal (500 revolutions), whilst the jet deflector, with which the turbine is equipped to prevent ramming in the high-pressure conduit, acted so perfectly that the pressure gauge showed an almost imperceptible variation from the normal service pressure of 102 kgms.

SPECIAL INSTALLATIONS FOR AUTOMATIC CENTRAL STATIONS.

The automatic remote control of the machinery of hydro-electric central stations obtained in some cases by means of exclusively electric apparatus, has been the object of various applications, but till now has not been developed to a great extent.

This difficult problem was also brilliantly solved with hydro-dynamic apparatus by a talented Italian engineer who used rotary servo-motors, previously studied and patented for other applications.

The solution consists in applying the rotary servo-motors to actuate the opening and closing movements of the gates in connection with the standard governor.

The control of the rotary servo-motors, when it has to be effected at great distances, is carried out electrically by means of a simple electro-magnet. Also in the case of asynchronous central stations, a general solution of the problem of automatic working has been obtained by the use of a special hydro-dynamic device added to the speed governor, which is electrically driven from a distance. Thus, one may automatically throw the automatic central station in or out of the network while running, and still automatically continue the ordinary speed control, the opening of the turbine in proportion to the volume of water available, etc.

A notable example of plant with remote control is that of Turbigo Inferiore, where there is a 2,000 H.P. group completely controlled from the main power house at a distance of nearly one kilometre, and an interesting example of an automatic asynchronous plant is that of the Firm Camerini, of Piazzola, on the River Brenta, with a set of about 300 H.P.

Complete and patented schemes also exist for the application of the same system of hydro-electro-dynamic apparatus to the automatic control of hydro-electric stations having synchronous generators.

ACCESSORIES FOR HYDRAULIC PLANTS.

For the completion of the plants all the parts and accessories are constructed on normal lines.

Sluice gates and valves of various types (automatic valves, synchronous valves, closing or integrating discharge valves) with the

suitable mechanical driving apparatus, by hand, by hydraulic servo-motor, by electric motor, with hydro-electro-dynamic apparatus for automatic or distance working, with interesting equipments (some of which have been the object of original patents), high pressure water pipings of the various kinds, riveted, welded, and shrunk rings lined; these are the productions of a few turbine builders and also of renowned specialised industries.

ORGANISATION OF PRODUCTION—EXPORTATION.

The turbine industry, which has been developing in Italy for several decades, has produced various works specialising in this production and in the construction of kindred hydraulic machinery, and has likewise interested the activities of firms which, at the same time, occupy eminent positions in other fields of machine production.

Both in the one category and in the other, the extended means of production allow every construction problem to be faced with ease; and they can meet the largest demands of the Italian market. They are also able to reserve a large part of their production for exportation. Experimental stations and testing plants are attached to the works of the most important constructing firms which, with technical staffs of recognised ability, largely contribute to the progress of hydraulic mechanics.

It will not be out of place to draw attention to the initiative of Italian technical men for the subjecting of mains and pipings of hydraulic plants to legislative control analogous to that which has been imposed for steam boilers, with the aim of guaranteeing the best security of plants. It would be certainly of the highest utility that such initiative were assumed internationally.

Exportation, since the years prior to the world war, has not been greatly developed, though, for some time various Italian plants have been built for foreign countries, both turbines and governors. Remarkable, however, are the constructions undertaken recently for the huge hydro-electric plants of France and her Colonies and for an interesting plant of hydraulic accumulation, with turbines and centrifugal pumps, for a noted English company in Chile (Fig. 23), and there are now new organisations being developed for a more intensive activity abroad.

The Italian industry, which in this work certainly has a greater name for its high technical value than for the great masses of material employed, flatters itself that it will be able to collaborate more and more intensively in the advancement of the world's water power development by the contribution of its technical men,

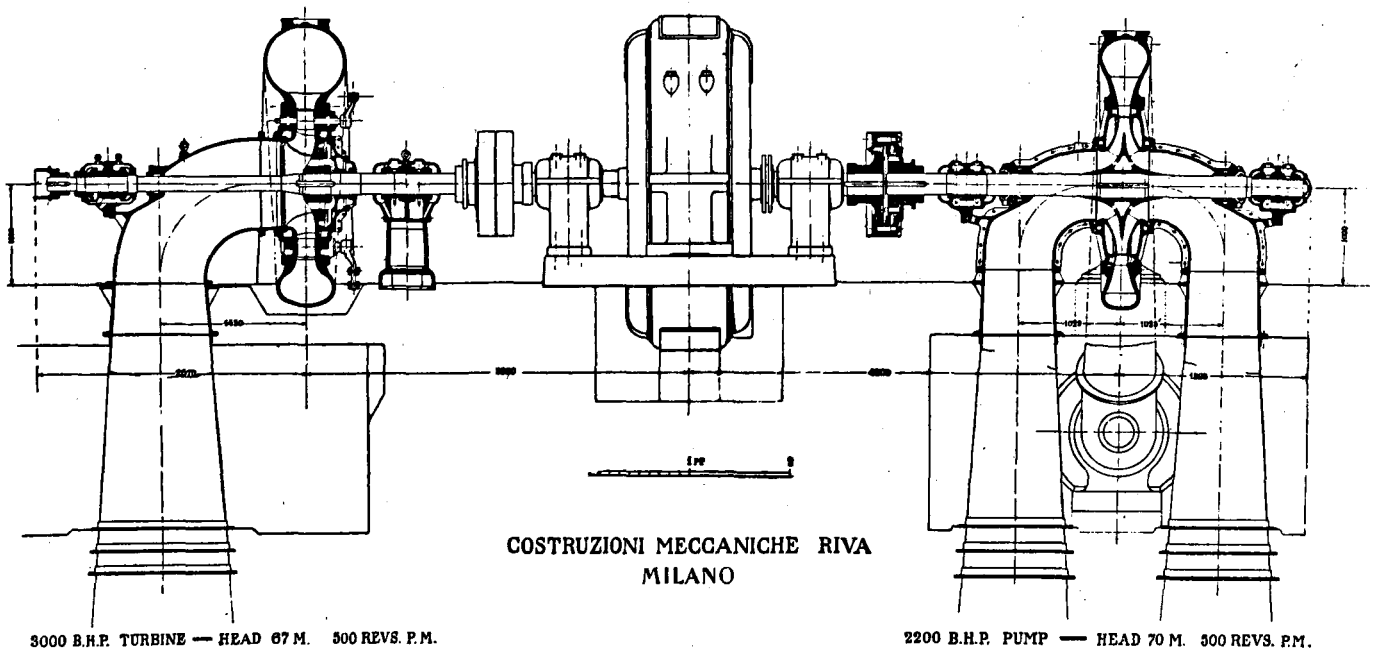

COSTRUZIONI MECCANICHE RIVA
MILANO
3000 B.H.P. TURBINE — HEAD 67 M. 500 REVS. P.M.
2200 B.H.P. PUMP — HEAD 70 M. 500 REVS. P.M.

Fig. 23.

whose worth has been demonstrated by the progress made; by its skilled labour whose ability is well appreciated in this special production; and finally, by its experience obtained with plants of exceptional interest and importance.

To prove more conclusively the soundness of the national organisation for the production of hydraulic turbines, we would point out the services rendered by this industry to Italy at the time of the world war when, during the anxious crisis arising from the lack of coal and with exceptionally reduced means, she was able, amid the greatest difficulties of supply and labour, to maintain in full operation all the turbines and to provide new hydro-electric plants for the war industries and to ensure the indispensable activities of the country in arms,—a contribution of no little value to the great Allied Victory.

ITALIAN CONSTRUCTORS OF HYDRAULIC TURBINES

(Total production for Italy & Abroad)

Firms	Offices	Year when Turbine-construction initiated	Turbine built by each Firm	Total Power in HP of Turbines constructed till the 31/12/1923
S.A.Costruzioni Meccaniche Riva Ditte Riunite A.Riva - A.Calzoni	Milan	1885	2.699	2.258.729
S.A. Franco Tosi S.A.. San Giorgio	Legnano Sestri-Ponente	1913	204	567.000
S.A.Officine Calzoni - Paronti Transformed the 1st.January 1924 to:- S.A. Officine Parenti, late Officine Riunite Calzoni-Parenti	Bologna	1885	2.218	288.575
Ing. S. De Pretto & C. (1893 - 1916 = 771 Turb.=48.990 HP.) S.A.De Pretto - Escher Wyss (1921-1923 = 165 Turb.= 108048 HP.)	Schio	1893	936	157.038
S.A. Cantieri Navali & Acciaierie di Venezia	Venice	1908	3 00	22.000
S.A. Ing. Moncalvi & Co.	Pavia	1905	719	19.42
S.A.Officine Riunite Italiane	Brescia	1892	349	14.705
S.A.Officine Meccaniche & Fonderi Ing. Pietro Veraci	Florence	1905	164	9.800
TOTAL PRODUCTION AT THE 31st DECEMBER 1923			7589	3.337.274

MOST IMPORTANT ITALIAN PATENTS IN USE BY HYDRAULIC TURBINE BUILDERS

Year	Number	Patentees	Patent	Property
1892	32130	Ing.ALBERTO RIVA	Step bearing for vertical water Turbines	S.A.Costruzioni Meccaniche Riva
1892	32230	do.	New regulating device for gate of Turbines	do.
1894	37444	Ing.A.RIVA-MONNERET & C°	"Zodel"'s elastic coupling for shafts	do.
1899	52226	do.	New pressure balancing arrangement for end-thrust of centripetal reaction Turbines by means of holes through the guides.	do.
1900	56394	do.	"Foresti"'s driving mechanism for guides of Turbine gates	do.
1901	57730	do.	"Ratti"'s Oil-pressure self-contained speed governor for Turbine	do.
1907	91887	do.	Arrangement of hydraulic turbines in series	do.
1908	93872	Ing.A.RIVA & C.	Jet deflector for high pressure impulse Wheels to avoid water ramming	do.
1911	-----	S.A.FRANCO TOSI S.A.IND.SAN GIORGIO	Arrangement for the automatic control of speed governors (O.E.M.'s make).	S.A.Franco Tosi S.A.Ind.S.Giorgio
1913	128073	Ditta ALESSANDRO CALZONI	Pressure gauge bell governor	S.A.Officine Calzoni-Parenti
1913	133895	Ing.A.RIVA & C.	Central deviator of the jet for impulse wheel nozzles	S.A.Costruzioni Meccaniche Riva
1914	144578	S.A.COSTRUZIONI MECCANICHE RIVA	Automatic flow regulator for water turbine plants	do.

Year	Number	Patentees	Patent	Property
1916	154098	S.A.COSTRUZ.MECC.RIVA	Deflecting arrangement for multi nozzle impulse wheels	S.A.Costruzioni Meccaniche Riva
1916	141731	Ditta ALESSANDRO CALZONI	New compensating device for governors	S.A.Officine Calzoni-Parenti
1916	141630	do.	Hand driving mechanism for the remote control of governors	do.
1916	153807	S.A.COSTRUZ.MECC.RIVA	Arrangement for preventing dangerous water ram in the delivery pipe of a pump in case of a sudden cut off.	S.A.Costruzioni Meccaniche Riva
1918	208/485	S.A.FRANCO TOSI S.A.IND.SAN GIORGIO	New arrangement for the regulation of the speed combined with the regulation of the water discharge of the impulse water wheels.	S.A.Franco Tosi S.A.Ind.S.Giorgio
1918	75/487	do.	New arrangement of horizontal shaft double reaction Turbine	do
1918	78/488	do.	Arrangement for the utilization of the energy of the deflected water in the impulse wheels for braking purposes.	do.
1918	170998	Ing.ALFREDO CALZONI	Reversible oil-pressure rotary servo-motor.	S.A.Costruzioni Meccaniche Riva
1918	170999	do.	Multi-speed reversible arrangement by means of oil-pressure rotary servo-motor.	do.

LA TECNICA MODERNA DELLE TURBINE IDRAULICHE ITALIANE.

Se ti addiviene di trattare delle acque consulta prima l'esperienza e poi la ragione . . . .

Leonardo da Vinci (1452-1519).

GENERALITÀ E CENNI RETROSPETTIVI SULLA COSTRUZIONE DELLE TURBINE IDRAULICHE.

La tecnica delle macchine idrauliche ha in Italia tradizioni secolari, tantochè ginel quattrocento Leonardo da Vinci, studiando perfezionamenti ed applicazioni delle antiche ruote, segnava nelle sue tavole del " Codice Atlantico " concezioni che hanno una impressionante analogia con le moderne costruzioni.

La nota deficienza di giacimenti di combustibili fossili ha necessariamente indotto l'Italia, sin dal primo sviluppo della moderna Tecnica delle utilizzazioni delle forze idrauliche, allo sfruttamento del suo carbone bianco e questa condizione ha favorito il sorgere della Industria delle costruzioni del macchinario Idraulico, che costituisce ora una delle più caratteristiche produzioni meccaniche nazionali.

Già prima del 1880, in aggiunta alla fabbricazione delle antiche ruote ad acqua, si cominciarono a costruire in Italia le prime Turbine Idrauliche ; ma si considera generalmente a partire dal 1885 (dopo l'entrata in vigore della Legge 10 Agosto 1884 sulla derivazione di acque pubbliche), l'inizio di questa Industria che in breve, anche prima dello sfruttamento attraverso le applicazioni elettriche, si affermò con notevoli Impianti di utilizzazioni locali, per azionamento di singoli Stabilimenti Industriali.

Condizioni generali e speciali,—fra le quali, non ultime, difficoltà dipendenti dalle disposizioni legislative citate e da altre emanate in seguito che rendevano, in qualche caso, più conveniente anche economicamente lo sviluppo dell'energia termica con combustibili d'importazione,—non favorivano però lo sviluppo degli Impianti tantochè, dopo il promettente periodo dal 1905 al 1911, che portò la media annua di Concessioni a circa 80.000 H.P. nominali medi,[1] nel quinquennio seguente si scese a una media di circa 45.000 H.P. di nuove installazioni all'anno.

Dopo la conflagrazione mondiale l'Italia ha però intrapreso una più intensa utilizzazione delle sue energie idrauliche, favorendola con provvide disposizioni legislative cosicchè, mentre sino al 1914 erano vigenti concessioni idrauliche per circa 1.000.000 di H.P., dal 1915 al 1923 questa potenza è stata quasi triplicata e sempre crescenti e ingentissime sono le richieste in istruttoria.

Pur contandosi in Italia importanti Impianti costruiti da reputate Ditte straniere, la grandissima maggioranza delle Turbine installate (non ostante la mancanza di speciali protezioni doganali) è di marca italiana. Nell'anteguerra l'importazione delle Turbine potevasi calcolare corrispondente al 15% ca. della potenza complessiva ; dopo il 1915 l'importazione si è praticamente ridotta a zero. Contro un totale al 30 Giugno 1922 di circa 2.800.000 H.P. di Concessioni Governative, le Statistiche a tutto il 1923 fanno già salire

(1) Nella memoria si é usata la indicazione delle potenze in HP. (anzichè in KW. come da deliberazione della Commissione Elettrotecnica Internazionale Torino 1911, essendo tuttora espresse in H P. le Statistiche Governative e quelle dei vari Costruttori di macchinario idraulico.

ad oltre 3.250.000 H.P. la potenza complessiva corrispondente alla produzione delle Turbine per l'Italia dei Costruttori nazionali (Fig. 1). Considerando lo sfasamento nel tempo e pur tenendo conto delle inevitabili discordanze dovute ai gruppi di riserva e alle diverse basi di calcolo (che generalmente fanno valutare la potenza installata a 3/2 della potenza media di concessione), già da questi dati sommari risulta evidente l'altissimo valore dell'Industria Nazionale.

Fin dall'inizio le più importanti Ditte italiane si imposero la costruzione delle Turbine caso per caso, dedicando, per le piccole come per le grandi potenze, speciali studi per ogni installazione, allo scopo di raggiungere le più convenienti condizioni di impianto e di esercizio.

Le Turbine costruite in Italia, destinate, sino a questi ultimi tempi, quasi esclusivamente a coprire il fabbisogno nazionale, hanno in massima caratteristiche costruttive corrispondenti alle speciali condizioni degli Impianti italiani e in queste categorie—non essendo vincolate, come detto, a limitati ed invariabili tipi di serie—rappresentano, col graduale aumento delle potenze, col perfezionamento della costruzione, dei dettagli, della regolazione, degli accessori, una evoluzione tecnica ed industriale che non teme confronto con quella conseguita dalle altre Nazioni.

Le potenze unitarie sono andate rapidamente aumentando, parallelamente allo sviluppo delle costruzioni elettriche (Fig. 2).

Nel 1896, per lo storico Impianto di Paderno—primo esempio in Europa di Turbine di grande potenza e di importanti trasporti di energia elettrica a distanza—una Casa Italiana, in gara colle più reputate Industrie Estere specializzate, venne prescelta per la fornitura delle sette Turbine da 2160 H.P. cadauna e l'ottimo risultato di questo Impianto—tuttora funzionante dopo oltre 25 anni di ininterrotto esercizio—incoraggiò a più importanti costruzioni, segnando l'inizio delle grandi utilizzazioni delle energie idrauliche, che si dimostrarono in breve fra i maggiori fattori della prosperità del Paese.

Nel 1899 l'alto valore della Tecnica Italiana era riconosciuto in una importante competizione internazionale: alla stessa Casa Italiana veniva affidata la costruzione di Turbine da 3.000 H.P. per l'impianto di St. Catharines Ontario alle Cascate del Niagara (Fig. 3).

Dopo il 1908 si eseguirono unità di potenza superiore a 10.000 H.P. col 1920 si arrivò ai gruppi di 20.000 H.P. ed oltre e attualmente sono in costruzione unità della potenza di 35.000 H.P.

Delle Turbine fin oggi costruite la quasi totalità è destinata ad accoppiamento con macchine elettriche, per il cui tramite sono ormai azionate quasi tutte le Industrie italiane, il maggior numero delle Bonifiche, delle Irrigazioni, degli Acquedotti e importanti linee ferroviarie e tramviarie.

CARATTERISTICHE GENERALI DEGLI IMPIANTI DI TURBINE IN ITALIA.

L'Italia, prevalentemente montuosa e con pianure poco estese, non ha i grandi corsi d'acqua che dànno luogo a imponenti impianti con grandissime portate e con cadute di pochi metri; non sono quindi richieste Turbine di eccezionali dimensioni e non è sentito il bisogno di Turbine estremamente veloci.

Gli Impianti con cadute inferiori a 20 metri che, cronologicamente, costituiscono le prime utilizzazioni, pure essendo numerosissimi e di grande importanza industriale perchè molto spesso adibiti al servizio di singoli Stabilimenti, non rappresentano una parte cospicua della potenza totale (ca. il 10%).

Più importante è il campo degli Impianti con medie cadute (da 20 a 200 metri circa) frequenti in tutte le Regioni d'Italia : in questa categoria notevoli sono le caratteristiche delle costruzioni italiane.

Nelle alte ed altissime cadute, sin oltre i 1000 metri, si contano infine esempi di utilizzazione del più grande interesse, raggiungendosi qui anche le massime potenze unitarie.

Una classe speciale di impianti a media o alta caduta, è quella per la utilizzazione di Laghi naturali o artificiali, preziosi serbatoi di energia per la integrazione dei diagrammi variabili delle Centrali influenzate dall'andamente stagionale. Fra questi il primo attuato, nel gruppo alpino dell'Adamello, rimane ancora uno dei più importanti esempi, pure essendo notevolmente superato dagli ultimi costruiti, fra i quali quello grandioso del Tirso in Sardegna per 460.000.000 di $m.^3$

Applicazioni caratteristiche e di notevole importanza si hanno pure negli Impianti di " accumalazione idraulica " nei quali, durante le ore notturne o festive, con energia di ricupero, si azionano Pompe pel riempimento di un serbatoio soprastante. L'acqua così accumulata alimenta poi le Turbine che formiscono l'energia necessaria per le " punte " del servizio, nelle ore di massima richiesta (Fig. 4). Interessanti sono pure i gruppi Turbine-Pompe Centrifughe di cui si hanno esempi, anche di cospicua potenza, per Impianti di Irrigazione.

Da ultimo notiamo la importanza crescente degli Impianti con comando automatico a distanza che, pur non avendo avuto finora un vasto campo di attuazione, hanno dato occasione a geniali caratteristiche soluzioni da parte di Costruttori Italiani.

Generalmente gli Impianti italiani sono accuratamente studiati in ogni dettaglio e la scelta del macchinario è oggetto di scrupolose prescrizioni. La grande cura posta nell' esecuzione degli Impianti si rivela spesso anche nella cura dedicata all'estetica delle Centrali, talune delle quali assurgono alla dignità e ricchezza di veri monumenti architettonici, (Fig. 5-6), ciò che impone anche ai Costruttori di Turbine speciale considerazione del problema estetico. Si deve infatti riconoscere alla maggior parte delle Turbine italiane una eleganza costruttiva caratteristica, che unisce alla solidità e sobrietà della costruzione l'armonia del disegno e la finitezza e perfezione dei dettagli semplici e accurati.

TURBINE A REAZIONE IN CAMERA LIBERA PER BASSE CADUTE.

Le Turbine preferite per le basse cadute sono quelle a camera libera, che consentono di raggiungere la massima semplicità ed economia d'impianto, assicurando anche la più grande facilità d'ispezione e di manutenzione.

Da molti anni sono stati completamente abbandonati i vecchi tipi ad azione (Girard e simili) per i rilevanti vantaggi presentati dai tipi a reazione, che permettono un ottimo funzionamento anche con notevoli variazioni nei livelli di arrivo e di scarico. Le cadute utilizzate in camera libera normalmente non oltrepassano i 10-12 metri ; raramente si raggiungono i 15-20 metri con camere in cemento armato e questi limiti si sorpassano solo in casi eccezionali.

Le installazioni ad asse verticale sono poco frequenti e si limitano generalmente a casi di bassissime cadute ; se ne hanno però esempi di qualche importanza : già nel 1894 si costruirono le Turbine della Filatura Crespi sull'Adda

con ruota unica per 13.500 litri al secondo; nel 1904 la Centrale elettrica di Trezzo per 10.000 H.P. complessivi, consumo totale oltre 100 m.³ circa e nel 1906 l'Impianto di Cerro al Lambro, con ruote da 12,000 litri al secondo; fra le costruzioni moderne sono notevoli quelle eseguite per la "Tarn" (Francia) 4 unità da 25.000 litri cadauna e 4 da 30.000; in costruzione è una grande Turbina per Busachi (Tirso) con ruota da 25.000 litri (Fig. 7).

Nella maggior parte dei casi si preferiscono Turbine ad asse orizzontale (Fig. 8); nei casi di Turbine multiple si adottano generalmente disposizioni speciali per poter accedere, anche durante il funzionamento, ai supporti intermedi. Per la miglior utilizzazione delle portate variabili a seconda delle stagioni, nei piccoli Impianti si rende a volte opportuna la disposizione dei gruppi "in tandem," che permette di escludere parte delle ruote per poter funzionare sempre nelle condizioni corrispondenti alla migliore utilizzazione dell'acqua disponibile.

In questi ultimi anni parecchie Case costruttrici, allo scopo di migliorare il comportamento delle Turbine a bassa caduta, eseguirono studi ed esperienze sullo sviluppo e sulle sezioni dei condotti aspiranti, che hanno grandissima importanza in questi Impianti, nei quali talvolta la maggior parte del salto disponibile è in aspirazione, anzichè in pressione. In qualche caso si è persino arrivati a collocare l'asse della Turbina ad una quota superiore al pelo di arrivo utilizzando l'intera caduta in aspirazione (Turbine a sifone).

Si sono così individuate caratteristiche costruttive che permettono di raggiungere il miglior ricupero dell'energia corrispondente alla velocità di uscita dell'acqua dalle giranti, pur senza ricorrere alle forme speciali di origine americana (idroconi).

I distributori sono a pale direttrici equilibrate, girevoli, a comando immerso, oppure a "comando esterno" quando l'acqua ha proprietà incrostanti o corrodenti. I dispositivi di manovra sono caratteristici: a catena (paralellogrammi articolati) a glifi, a tiranti registrabili ecc.; i perni delle pale attraversano pressastoppe registrabili, oppure camere in aspirazione per evitare l'uscita dell'acqua.

La costruzione delle giranti è stata oggetto di studi speciali e di accurate esperienze: è noto lo sforzo dei Costruttori per superare la velocità specifica n_s* delle ruote "americane lente" e "normali" (che hanno valori n_s inferiori a 300) allo scopo di raggiungere velocità atte all'accoppiamento diretto con macchinario elettrico. Pur non realizzandosi generalmente in Italia tutte le condizioni che hanno spinto altri Costruttori verso le caratteristiche delle ruote velocissime, vennero costruiti ed assoggettati a numerose e rigorose prove diversi tipi di ruote veloci,—cioè diagonale centrifugo a reazione, diagonale con ruote a diverse corone, con distributore, cilindrico, conico, ecc.

In considerazione però specialmente delle variazioni di portata alle quali sono soggetti gli Impianti italiani, vengono normalmente preferiti tipi di ruote atti ad assicurare un buon rendimento anche a carico parziale e per questo i Costruttori italiani si sono limitati ad una velocità specifica $n_s = 500$ circa.

$$*n_s = \frac{n\sqrt{N}}{H\sqrt{H}}$$

n = numero dei giri al 1'.
H = caduta in metri.
N = potenza in H.P.

TURBINE A REAZIONE IN CAMERA FORZATA PER MEDIE CADUTE.

Considerando le medie cadute comprese fra i 20 ed i 200 metri circa, si contano fra queste quelle utilizzate nella maggior parte degli Impianti eseguiti in Italia fin verso il 1908 e ancor oggi in questa categoria, che rappresenta circa il 50% della potenza complessiva installata, si annoverano costruzioni notevolissime per la potenza raggiunta e per i perfezionamenti tecnici applicati.

La posizione di primo ordine dell'Industria Italiana in queste costruzioni era riconosciuta fin dal 1899, anno in cui furono ordinate all'Italia Turbine Francis da 3000 H.P. per l'Impianto già citato alle Cascate del Niagara.

Prescindendo dai vari, per quanto interessanti, esempi di Turbine " ad azione " tipo " Schwamkrug " per cadute di 150 e 170 metri (Impianti Spoleto e Piedimulera)—tipo abbandonato da una quindicina d'anni—sono invece particolarmente notevoli gli Impianti di Turbine " a reazione " tipo Francis, specialmente per gruppi di grande potenza.

La disposizione ad asse orizziontale è generalmente preferita in Italia. Si sono però eseguiti anche Impianti di qualche importanza ad asse verticale ed altri sono in corso di esecuzione (un gruppo di 24.000 H.P. per la Centrale Velino Terni, tre unità da 3000 H.P. per Castelnuovo Garfagnana, ecc.).

Le disposizioni più frequentemente adottate ad asse orizzontale sono :—con ruota unica a scarico semplice : Niagara (Fig. 3), Bussi, Cedegolo, Velino, Fadalto 1°, Volturno, Maira, Farfa, Crego (Fig. 6), Corfino, Tanagro, Susa, ecc.—a doppio scarico : Cellina, Zogno, Giais, Pescara II° (Fig. 9), Cismon, Serchio, Poschiavino, Aymavilles, Furlo, Coghinas, ecc.—con due ruote a scarico unico centrale : Pennarossa, Robbiate (Fig. 5), Castelmadama, Boffetto, Nera Montoro, Brasimone II° (Fig. 10), Fadaldo Nuovo, Arsiero (Rossi), ecc. ; —infine a due ruote con scarichi separati : Tirso, Molare, Borzonasca, ecc.

Fra le Turbine con quest' ultima disposizione è di speciale interesse la costruzione con dispositivo per funzionare con una sola ruota, in caso di forte riduzione della portata, analogamente a quanto praticato con le Turbine " in tandem " a camera libera (fig. 11).

Caratteristica è la disposizione con ruota montata di sbalzo sull'asse del l'alternatore, disposizione che elimina la necessità di attraversare coll'asse il gomito aspirante nei casi ove basta la semplice equilibratura idraulica della spinta assiale e, limitando a due soli i supporti del Gruppo idroelettrico, riduce al minimo l'ingombro del macchinario con notevole economia anche nella costruzione del fabbricato.

Importante applicazione di questa disposizione sono le Turbine del 1° Impianto Velino (Terni) da 10.000 H.P. ciascuna, funzionanti a 900 giri con 190 metri di salto (fig. 13)

Notevole infine la disposizione con " ruote in serie," brevettata nel 1908, colla quale si suddivide su diversi elementi la caduta disponibile nei casi in cui questa fosse notevolmente elevata, ma non ancora adatta per l'applicazione di ruote Pelton.

Di questi ultimi tempi si è pure introdotta in Italia la costruzione delle Turbine " Turgo " per applicazioni in campi analoghi a quelli di cui sopra.

Le camere forzate per le Turbine Francis, generalmente a spirale, sono il più spesso in ghisa,—in caso di grandi portate in lamiera : Nera Montoro caduta 23 metri portata 120.000 litri smaltita da 4 gruppi, Brasimone (fig. 10), Tronto, ecc.—e per alte pressioni in acciaio fuso : Velino, Volturno, ecc.

Degno di speciale rimarco è l'Impianto ultimamente messo in esercizio che utilizza la derivazione Piave-Santa Croce, in condizioni particolarmente favorevoli, usufruendo di un Lago naturale come bacino di carico.

Questa derivazione alimenterà, a lavori ultimati, un complesso di Impianti per una potenza di oltre 300.000 H.P.; attualmente sono già eseguiti tre Gruppi da 24.000 H.P. cadauno con Turbine Francis a 420 giri con due spirali e scarico unico centrale, utilizzanti una caduta variabile da 84 a 110 metri, che rappresentano le maggiori unità a reazione in servizio nel nostro Paese (fig. 12).

Le ruote mobili nei vari tipi veloce, normale, lento (n_s da 300 a 50) vengono costruite in ghisa, oppure con pale riportate in lamiera di acciaio e per le cadute più elevate in bronzo, od anche in acciaio fuso.

Per il distributore, a pale girevoli, abbandonate le vecchie costruzioni a glifo interno, viene oramai adottato sempre il comando a manovra esterna, la cui prima notevole applicazione risale al 1905. La costruzione originaria con leve convergenti comandate da un anello centrale (Giaumà) è stata man mano modificata dai singoli Costruttori, talvolta con un doppio rimando di leve, tal'altra con leve divergenti, pure azionate da un anello esterno (Pescara): ultimamente si è applicato il comando cosidetto " a catena " (fig. 13) ed il comando con tiranti registrabili indipendenti, come nei tipi già citati di distributori delle Turbine a camera libera.

L'equilibratura della spinta assiale è in genere ottenuta idraulicamente in modo automatico, senza ricorrere cioè all'applicazion e di speciali supporti di controspinta od equilibratori sussidiari. In casi speciali sono anche adottati dispositivi con equilibratori indipendenti a circolazione d'olio sotto pressione.

Sulle superfici di tenuta delle ruote e dei coperchi si riportano anelli intercambiabili per semplificare le manutenzioni e, nelle unità importanti, si prevede anche la possibilità di registrare dall'esterno, senza smontare la macchina, gli anelli dell'equilibratura idraulica, laddove questi, per la qualità dell'acqua, sono soggetti a rapido deterioramento.

TURBINE AD AZIONE PER ALTE CADUTE.

Solo verso il 1908 si è in Italia decisamente iniziata l'utilizzazione delle alte cadute, giacchè prima di tale epoca si avevano solo rari e modesti Impianti con pressioni superiori ai 200 metri.

Oggi le Turbine ad azione tipo " Pelton," macchine veramente perfette sotto ogni rapporto per l'elevato rendimento e per la notevole semplicità di costruzione, rappresentano una categoria di importanza cospicua (circa il 40% della potenza totale degli Impianti italiani) e permettono l'utilizzazione delle più alte cadute praticamente realizzabili (1000-1500 metri).

Il volume d'acqua nelle utilizzazioni di elevate cadute è sempre relativamente limitato, arrivando ad un massimo di poco superiore ai 10.000 litri; si raggiungono tuttavia potenze molto considerevoli nelle singole unità.

Per ottenere un numero di giri elevato in rapporto alla caduta ed alla portata disponibili, si costruiscono Turbine a getti multipli (due o più) agenti sulla stessa ruota ed anche Turbine a ruote multiple, con uno o più getti per ruota (fig. 14). La disposizione adottata è sempre ad asse orizzontale: sono peró ora in istudio anche unità di grande potenza ad asse verticale, per un nuovo

Impianto alpino. Notevoli sono le applicazioni con ruota a sbalzo sull'asse dell'Alternatore.

Le Turbine Pelton richiedono particolari cure nello studio, nel disegno, nella scelta dei materiali e nei dettagli esecutivi, per ottenere la più assoluta sicurezza anche in caso di eccezionali sollecitazioni che si dovessero eventualmente verificare per imprevedibili circostanze (velocità di fuga, ecc.).

I distributori a sezione rettangolare con regolazione a lingua mobile sono da tempo quasi completamente abbandonati. Nel 1906, dopo studi e prove accurate eseguite in un Impianto sperimentale su diversi tipi, venne determinata la forma più opportuna della spina, dei bocchelli e delle pale Pelton per il getto d'acqua a sezione circolare. Tali forme, studiate dai Costruttori Italiani, differiscono dal tipo originario Abner-Doble ed assicurano un getto d'acqua perfettamente cilindrico e omogeneo con qualunque grado di apertura del distributore, la migliore utilizzazione dell'energia sulla ruota e la massima resistenza alle corrosioni.

Le pale in ghisa, in acciaio o in bronzo, sono generalmente costruite separatamente e solidamente fissate al disco calettato sull'asse con dispositivi speciali, oppure, a volte, fuse in un sol pezzo col disco. Le superfici percorse dall'acqua sono lavorate a lucido. Negli Impianti più importanti, ultimamente eseguiti, il disco a sua volta è applicato su un mozzo centrale riportato che viene calettato sull'albero in modo definitivo, restando facilitato lo smontaggio della ruota per i ricambi.

La manovra a mano per l'avviamento, di cui sono generalmente provviste le Turbine, è spesso costituita nelle grandi unità da un servo-motore idraulico, funzionante colla pressione della condotta forzata.

Le Turbine Pelton alimentate da tubazioni di grande importanza richiedono l'applicazione di dispositivi atti ad impedire la formazione di colpi d'ariete pericolosi. A questo scopo, in sostituzione degli apparecchi di " scarico sincrono " si usa ora generalmente il dispositivo di " deviazione automatica del getto combinata colla chiusura lenta automatica della spina di regolazione" secondo lo schema brevettato da un Costruttore italiano nel 1908.

Il Regolatore mantiene costante la velocità della Turbina per qualsiasi variazione di carico, intervenendo col deviatore a togliere istantaneamente il getto dalla ruota, senza influire sulla portata, mentre, colla successiva richiusura lenta della spina si stabilisce—dopo un certo tempo regolabile a volontà—l'apertura del distributore corrispondente al nuovo regime, senza provocare aumenti sensibili di pressione. La richiusura della spina si compie generalmente in un periodo di tempo variabile da 20 a 40 secondi e la quantità d'acqua deviata e non utilizzata risulta pertanto del tutto trascurabile, ciò che costituisce un grande vantaggio negli Impianti a serbatoio. Il deviatore automatico presenta inoltre il pregio della massima semplicità e robustezza, essendo costituito da pochi organi meccanici, fra loro collegati in modo tale che, una volta registrati, non permettono nessun spostamento.

Con questo importantissimo perfezionamento, ben noto nella letteratura tecnica ed applicato con varianti dai diversi Costruttori, si è ottenuta una soluzione perfetta del problema della regolazione delle Turbine ad azione e, raggiunta la massima sicurezza per le condotte forzate, fu grandemente facilitata la pratica utilizzazione delle cadute più elevate. La deviazione del getto è attuata in diverse forme dai vari Costruttori ; fra i brevetti derivati può presentare interesse il dispositivo di deviazione mediante un tegolo che

dirige parte del getto deviato contro il dorso delle pale, esercitando azione frenante sulla ruota. Un dispositivo di grande semplicità per ottenere la deviazione mediante scomposizione centrale della spina, pur avendo avuto applicazioni funzionanti da diversi anni, non ha dimostrato in pratica vantaggi speciali.

Il rapporto caratteristico d/D fra il diametro d del getto e quello D della ruota è stato spinto in qualche costruzione, per realizzare elevata velocità, sino a 1/8,5 conservando le caratteristiche di buon rendimento. Le massime dimensioni sono state raggiunte da getti di 20 cm. e da pale della larghezza di 65 cm.

La costruzione delle grandi unità in Italia si può considerare iniziata nel 1908 con le Turbine Pelton da 12.000 H.P. per l'Impianto di Grossotto; seguirono nel 1911 le unità da 14.000 H.P. per San Dalmazzo di Tenda; nel 1917 quelle da 15.000 per Pont Saint Martin (fig. 15); nel 1919 la Pelton da 20.000 H.P. per l'Adamello (Lago d'Arno) con 900 metri di salto (fig. 16) e nel 1920 le note Turbine dell' Impianto di Venaus (Moncenisio) che sotto una caduta statica di 1100 metri raggiungono, con una sola ruota ed un solo getto, la potenza di 26.000 H.P. costituendo, credesi, esempio primo nel mondo con caratteristiche di pari importanza (fig. 17-18). Questa potenza però è oggi già superata dalle Turbine da 35.000 H.P. in costruzione per l'Impianto di Mese, ai piedi dello Spluga.

Fra gli Impianti di speciale interesse per le sue caratteristiche eccezionali è da notare quello di Bardonecchia delle FF. SS.— oggetto di studio anche da parte dei Tecnici stranieri – si tratta di gruppi di ruote Pelton da 6.000 H.P. cadauno, costituiti da due ruote sul medesimo asse, una alimentata da due getti con un salto di 200 metri, l'altra da un solo getto caduta 600 metri, velocità comune 500 giri (fig. 19).

CORROSIONI E INCROSTAZIONI DELLE TURBINE.

Cure e studi speciali sono richiesti per ridure al minimo le cause e le conseguenze delle corrosioni e delle incrostazioni.

Turbine in condizioni apparentemente identiche hanno comportamenti assai dissimili per diverse proprietà fisiche o chimiche dell'acqua, talvolta appena percettibili: ne segue che là ove il miglior acciaio si consuma rapidamente, resistono bene il bronzo od altre leghe, oppure viceversa. In taluni Impianti dell'Italia Centrale invece l'acqua lascia delle incrostazioni calcaree, che in tempo relativamente breve raggiungono spessori considerevoli.

Si sono quindi studiate delle forme di ruote e di distributori atte a ridurre al minimo le usure ed i depositi e a facilitare i necessari ricambi, mentre si esperimentano sempre diligentemente i comportamenti dei vari materiali e delle varie leghe.

A riparare le corrosioni si usa pure frequentemente con brillante successo la saldatura autogena, sia per le ruote Pelton che per le Francis.

REGOLAZIONE DELLE TURBINE.

La difficolta di ottenere una precisa regolazione, mantenendo inalterata la velocità e proporzionando automaticamente al carico assorbito la potenza sviluppata, fu uno dei più gravi ostacoli che in passato limitarono lo sviluppo delle Turbine idrauliche.

I primi Regolatori costruiti ebbero servomotore meccanico; più tardi furono largamente usati i Regolatori a Servomotore idraulico tutte le volte

che la pressione disponibile era sufficiente allo scopo ; infine, ad evitare le ben note difficoltà d'esercizio con acque impure, si usarono i Regolatori con servomotori a pressione d'olio, che però, a cagione del costo elevato dell'Impianto per produzione dell'olio in pressione, potevano essere applicati esclusivamente nelle grandi Centrali.

Solo nel 1900, per merito di un valente Tecnico Italiano, si ebbe la soluzione radicale del difficile problema che da anni era l'oggetto di studio da parte di tanti Costruttori ed Inventori, colla creazione del noto Regolatore Autonomo a pressione d'olio che, raccogliendo in un solo aggregato di piccole dimensioni e di costo moderato tutto quanto occorreva al suo funzionamento, rappresentò la soluzione completa del problema (fig. 20).

Il principio di questo Regolatore venne man mano adottato da tutti i Costruttori di Turbine, sia in Italia che all'Estero, con semplici varianti di forma e si dimostrò così rispondente allo scopo e perfetto che, pur attraverso oltre un ventennio di studi ed esperienze, informa tuttora invariato le migliori costruzioni del genere.

I Regolatori attuali, anche nelle diverse forme studiate da Costruttori italiani, mantengono le caratteristiche fondamentali del primo esemplare citato, pur essendo stati perfezionati e completati con dispositivi diversi per corrispondere alle esigenze delle varie applicazioni e cioè :

per la messa in parallelo di diversi gruppi con manovra dal quadro delle Centrali Elettriche,

per la regolazione dell'apertura delle Turbine in proporzione alla portata d'acqua disponibile,

per regolare la differenza di giri da pieno carico a vuoto (staticità) da un dato massimo, positivo o negativo, sino a zero (isodromia),

per impedire la " fuga " delle Turbine provocandone l'arresto in caso di rottura della cinghia di comando del regolatore.

per funzionare, a scelta, a diverse velocità prestabilite come è richiesto dagli Impianti a due o più frequenze,

per la messa in marcia e l'arresto delle Turbine a distanza, ecc.

I Regolatori sono generalmente costruiti in serie normali di varie grandezze, con potenze crescenti da circa 50 Kgm. a 4000 Kgm. : modelli speciali sono eseguiti solo per Turbine di eccezionale importanza.

Il tempo di regolazione, richiesto dal servomotore per fare tutta la sua corsa, varia generalmente da 2 a 4 secondi e consente una perfetta regolazione della velocità con un piccolo valore del GD^2. delle masse rotanti, mentre esclude la possibilità di pericolosi colpi d'ariete nelle Turbine alimentate da tubazioni. La staticità è generalmente contenuta nel limite del 4-5%.

Fra i diversi tipi italiani derivati è da notare in modo particolare il Regolatore "a campana manometrica regolatrice " che invece di utilizzare il pendolo centrifugo per il comando del servomotore, utilizza la pressione statica di una colonna liquida, la cui pressione è generata da una pompa centrifuga e varia col quadrato del numero dei giri.

In questo Regolatore sono pure notevoli il " servomotore rotativo a pressione d'olio " e vari altri dispositivi che rendono la costruzione una delle più interessanti fra le congeneri (Fig. 21).

Altro rinomato Costruttore italiano eseguisce un tipo caratterizzato principalmente dal comando della valvola distributrice a mezzo di un servomotore e dalla disposizione del pendolo centrifugo coassiale con la valvola

di regolazione, realizzando per tale modo notevole semplicità negli organi di comando del servomotore (fig. 22).

Studi particolari esigono, in relazione al funzionamento dei Regolatori, gli Impianti muniti di lunghe condotte forzate ad evitare i fenomeni di colpi d'ariete dovuti ad aperture od a chiusure troppo veloci dei distributori.

È vanto della Scienza italiana, per merito degli studi magistrali del Prof. Lorenzo Allievi, lo sviluppo completo e rigoroso della teoria di questo fenomeno ; la pratica sperimentale ha esattamente confermato i risultati previsti dal calcolo e poterono cosi stabilirsi regole sicure per la costruzione delle tubazioni, delle valvole sincrone e dei regolatori di pressione.

A permettere una valutazione del progresso raggiunto nell'importante campo della regolazione basterà ricordare che nel collaudo recentemente effettuato sulle Turbine Pelton di Venaus, (Fig. 17-18) il distacco repentino del carico di circa 26.000 H.P. ha dato luogo ad una variazione di velocità inferiore del 5% della normale di 500 giri, mentre il deviatore del getto, applicato alla Turbina per impedire la formazione dei colpi d'ariete nella condotta forzata, ha esplicato un'azione cosi perfetta che al manometro registratore fu constatata una variazione quasi impercettibile nella pressione normale di servizio di 102 Kg. cmq.

CENTRALI AUTOMATICHE.

Il comando automatico a distanza del Macchinario di Centrali Idroelettriche, realizzato in taluni casi mediante dispositivi esclusivamente elettrici, è stato oggetto di varie applicazioni, ma non ebbe finora notevole sviluppo.

Anche questo difficile problema venne brillantemente risolto con dispositivi idrodinamici da un geniale Tecnico Italiano, usando " servomotori rotativi " già da lui studiati e brevettati precedentemente per altre applicazioni : la soluzione consiste nell'applicare detti servomotori alle manovre di apertura e di chiusura delle Turbine a mezzo del loro Regolatore normale,—il comando dei servomotori rotativi, quando deve essere eseguito a grande distanza, viene effettuato elettricamente mediante un semplice elettromagnete.

Anche nel caso di Centrali asincrone si è ottenuta una geniale soluzione del problema dell'automaticità mediante un apparecchio speciale " idrodinamico," in aggiunta al regolatore di velocità, azionabile elettricamente a distanza. Si possono così effettuare automaticamente le manovre per l'inserzione o per il disinnesto della Centrale automatica della rete, mentre durante il funzionamento continuano, sempre automaticamente, le ordinarie manovre di regolazione della velocità, di apertura della Turbina in proporzione alla portata d'acqua disponibile, ecc.

Un esempio notevole di impianto con comando a distanza è quello di Turbigo Inferiore, in cui funziona un Gruppo da 2.000 H.P. completamente controllato dalla Centrale superiore, lontana quasi un Km.— ed un interessante esempio di Centrale automatica asincrona è quella di Piazzola sul Brenta (Amm. Camerini) con un Gruppo da ca. 300 H.P.

Studi completi e brevetti esistono anche per applicare lo stesso sistema di comandi elettro-idro-dinamici per il completo automatismo di Centrali Idroelettriche con normali alternatori.

ACCESSORI PER IMPIANTI IDRAULICI.

Per il completamento degli Impianti i Costruttori italiani forniscono normalmente tutti gli organi accessori : Paratoie e Valvole di vari tipi (Valvole automatiche, Valvole sincrone a richiusura o ad efflusso integratore) con appropriati meccanismi di comando—a mano,—a servomotore idraulico—a motore elettrico,—con apparecchi elettro-idro-dinamici per funzionamento automatico, o a distanza, con dispositivi interessanti, taluni dei quali oggetto di originali brevetti.

Le Tubazioni forzate nei vari tipi chiodati, saldati e " blindati " sono oggetto dell'attività di alcuni Costruttori di Turbine ed anche di rinomate Industrie particolarmente specializzate.

ORGANIZZAZIONE PRODUTTIVA—ESPORTAZIONE.

L'industria delle Turbine che si è venuta sviluppando in Italia da parecchi decenni, ha fatto sorgere varie Officine specializzate in questa produzione e costruzioni di macchinario affine ed ha pure interessato l'attività di Azienche occupano contemporaneamente posizione eminente in altri campi della produzione meccanica.

Tanto nell'una come nell'altra categoria i larghi mezzi di produzione consentono di affrontare con tranquillità ogni problema esecutivo e possono corrispondere alle più grandi richieste del Mercato italiano, con notevolissima disponibilità per l'Esportazione. Stazioni sperimentali e Sale di prova sono annesse alle Officine delle più importanti Case costruttrici che, con Tecnici di riconosciuto valore, dànno largo contributo al progresso della meccanica idraulica.

Si crede qui opportuno far cenno di una iniziativa di Tecnici italiani per assoggettare la conduzione degli Impianti idraulici a norme legislative analoghe a quelle da tempo imposte per le caldaie a vapore, allo scopo di garantire la maggiore sicurezza degli Impianti: sarebbe certamente utilite che tale iniziativa fosse assunta internazionalmente.

L'esportazione sino agli anni precedenti la guerra mondiale non ha avuto grande sviluppo, pur contandosi da tempo forniture italiane eseguite per l'Estero sia di Turbine che di Regolatori. Notevoli però sono le costruzioni assunte in questi ultimi tempi per grandiosi impianti idro elettrici in Francia e nelle Colonie francesi e per un Impianto caratteristico di accumulazione idraulica nel Cile, con Turbine e Pompe Centrifughe, per conto di una Compagnia inglese (Fig. 23);—sono inoltre in sviluppo nuove organizzazioni per una più intensa attività all'Estero.

L'Industria italiana specializzata in questa caratteristica produzione, che ha certo più importanza per l'alto valore tecnico che per l'impiego di grandi masse di materiali, si lusinga pertanto di poter sempre più intensamente collaborare alla messa in valore delle energie idrauliche mondiali col contributo dei suoi Tecnici, il cui valore è documentato dai progressi conseguiti,—delle sue Maestranze, la cui abilità è bene apprezzata in questa produzione speciale,—della sua esperienza infine, provata in impianti di eccezionale importanza e interesse.

A migliore e completa documentazione della saldezza della organizzazione nazionale per la produzione delle Turbine idrauliche, si vuole da ultimo

ricordare il servigio reso da questa industria all'Italia durante la guerra mondiale allorquando, nella angosciosa crisi per la deficienza del combustibile, con mezzi eccezionalmente ridotti riusciva, fra le più grandi difficoltà di approvvigionamento e di lavoro, a mantenere la piena efficienza di tutte le Turbine in esercizio e a creare nuovi Impianti idroelettrici per alimentare le industrie belliche e assicurare le attività indispensabili del Paese in armi: contributo di valore non secondario alla grande Vittoria alleata.

COSTRUTTORI ITALIANI DI TURBINE IDRAULICHE
PRODUZIONE COMPLESSIVA PER ITALIA ED ESTERO.

Ditta.	Sede.	Inizio Costruz Turbine	Numero Turbine	Potenza complessiva Turbine costruite al 31-12-1923 H.P
S. A. COSTR. MECCANICHE RIVA Ditte Riunite A. Riva-A. Calzoni	Milano	1885	2699	2.258.729
S. A. FRANCO TOSI S. A. SAN GIORGIO	Legnano Sestri P.	1913	204	567.000
S. A. OFFICINE CALZONI-PARENTI (trasformata nella S. A. OFFICINE PARENTI già Off. Riunite Calzoni-Parenti 1-1-1924)	Bologna	1885	2218	288.575
Ing. S. DE PRETTO & C. (1893-1916 : 771 Turb. = 48990 H.P.) S. A. DE PRETTO-ESCHER WYSS (1921-1923 : 165 Turb. = 108048 H.P.)	Schio	1893	936	157.038
S A. CANTIERI NAVALI-ACCIAIERIE già Soc. Veneta di Costruzioni Mecc. e Fond. Treviso	Venezia	1908	300	22.000
S. A. Ing MONCALVI & C.	Pavia	1905	719	19.427
S. A. OFFICINE RIUNITE ITALIANE	Brescia	1892	349	14.705
S. A. OFF MECCANICHE e FONDERIE Ing. PIETRO VERACI	Firenze	1905	164	9.800
Produzione complessiva al 31 Dicembre 1924			7589	3 337.274

PRINCIPALI BREVETTI ITALIANI APPLICATI DAI COSTRUTTORI DI TURBINE IDRAULICHE.

Anno.	Numero	Richiedente.	Ritrovato.	Proprietà.
1892	32130	Ing. ALBERTO RIVA	Perno di sospensione per Turbine ad asse verticale.	S. A. Costr. Meccaniche Riva
1892	32230	idem	Nuova regolazione a valvole piane per Turbine.	idem
1894	37444	Ing. A. RIVA-MONNERET C.	Giunto elastico Zodel per Alberi motori.	idem
1899	52226	idem	Nuova disposizione per equilibrare le pressioni sulle due faccie del disco delle Ruote mobili delle Turbine centrifughe a reazione mediante l'apertura di luci attraverso le pale del distributore.	
1900	56394	idem	Distributore Foresti a parallelogrammi per Turbine.	idem
1901	57730	idem	Regolatore automatico Ratti per Turbine autogeneratore di pressione.	idem
1907	91787	idem	Disposizione di Turbine idrauliche in serie.	idem
1908	93872	Ing. A. RIVA C.	Apparecchio deviatore per Turbine ad alta pressione allo scopo di evitare i colpi d'ariete.	idem
1911	444252	S. A. FRANCO TOSI S. A. IND. SAN GIORGIO	Dispositivo per il controllo automatico dei Regolatori di velocità (Costruzione O.E.M.)	S. A. Franco Tosi S. A. Ind. San Giorgio
1913	128073	DITTA ALESSANDRO CALZONI	Campana Manometrica regolatrice.	S. A. Offic. Calzoni-Parenti.

Anno.	Numero.	Richiedente.	Ritrovato.	Proprietà.
1913	133893	Ing. A. RIVA C.	Deviatore centrale del getto Ruote Pelton.	S. A. Costr. Meccaniche Riva
1914	144578	S. A. COSTR. MECCANICHE RIVA	Regolatore automatico di deflusso per impianti di Turbine idrauliche.	idem
1915	154098	idem	Turbina Pelton c/ deviatore per l'acqua di più getti.	idem
1916	141731	S. A. COSTR. MECCANICHE RIVA	Nuovo sistema di compensazione nei Regolatori.	S. A. Offic. Calzoni-Parenti
1916	141630	idem	Colonnetta di comando a distanza per regolatori.	idem
1916	153807	S. A. COSTRUZ. MECCANICHE RIVA	Dispositivo per attutire i colpi d'ariete nella tubazione premente di Pompe nei casi di improvvise fermate.	S. A. Costr. Meccaniche Riva
1918	208/485	S. A. FRANCO TOSI S. A. IND. SAN GIORGIO	Nuovo dispositivo per la regolazione della velocitá combinata colla regolazione della portata nelle Turbine idrauliche ad azione	S. A. Franco Tosi S. A. Ind. San Giorgio.
1918	73/487	idem	Nuova disposizione di Turbina idraulica a reazione doppia a asse orizzontale.	idem
1918	78/488	idem	Dispositivo di utilizzazione dell'energia dell'acqua deviata nelle Turbine idrauliche ad azione a scopo di frenatura.	idem
1918	170998	Ing. ALFREDO CALZONI	Servomotore rotativo a circolazione d'olio ed inversione di marcia.	S. A. Costr. Meccaniche Riva
1918	170999	idem	Cambio di velocità ad inversione di marcia per mezzo di rotativa a servomotore d'olio	idem

RÉSUMÉ.

La construction des turbines hydrauliques, dont les débuts en Italie datent de quelques années avant 1880, et qui a atteint depuis longtemps un remarquable développement, joue aujourd'hui un rôle particulièrement important dans la production mécanique du pays.

Cette branche de l'industrie italienne a toujours suffi pour couvrir les besoins du pays car, pour un total de 2.800.000 chevaux concédés par le gouvernement au 30 Juin 1922, la puissance totale des turbines fabriquées et installées en Italie par des maisons italiennes dépasse, d'après les statistiques, 3.250.000 H.P. à la fin de 1923.

La construction des turbines s'est développée parallèlement à celle des machines électriques, car en Italie l'utilisation des forces hydrauliques a presque toujours eu pour but la production de l'énergie électrique.

Les caractéristiques des turbines italiennes, étudiées spécialement pour chaque cas particulier et jamais suivant le système de construction en série, correspondent aux conditions hydrauliques du pays, caractérisées par le manque de rivières à très grand débit et l'existence d'un grand nombre de cours d'eau de moyennes, hautes et très hautes altitudes.

De ce fait, et bien qu'il ne manque pas d'importants exemples de turbines à chambre ouverte pour faibles chutes, ce sont en Italie les turbines Francis ou Pelton pour hautes chutes qui présentent le maximum d'intérêt, turbines qui, par leur perfection, peuvent être classées sur le même rang que celles sortant des ateliers les plus connus de l'Étranger.

Parmi les installations importantes ou intéressantes, il y a lieu de mentionner celles de Trezzo et de Busachi pour faibles chutes ; du Pescara, du Velino, de Robbiate, de Fadalto, du Tirso pour chutes moyennes ; de l'Adamello, de Venaus, etc., pour très hautes chutes.

Dans cette dernière installation, notamment, chaque turbine développe une puissance de 26.000 H.P. avec une seule roue et un seul jet, ce qui paraît être un exemple unique dans les annales de la construction hydraulique.

A l'heure actuelle, les ateliers italiens construisent des turbines de 35,000 H.P. et d'autres plus puissantes sont à l'étude.

Les Ingenieurs et Constructeurs italiens ont été les premiers à apporter des perfectionnements importants aux turbines hydrauliques et, à ce point de vue, il y a lieu de rappeler l'exceptionnelle contribution faite par l'Italie en 1900, à la solution du problème du réglage des turbines hydrauliques par la création du premier régulateur autonome à pression d'huile, universellement adopté maintenant par tous les constructeurs étrangers.

De nouveaux systèmes de commande à distance ont été créés pour le réglage des centrales automatiques, et, parmi les dispositifs les plus intéressants, nous citerons le déviateur automatique du jet pour turbines Pelton, réalisant le maximum de sécurité et de précision avec un système cinématique fort simple, assurant un réglage parfait de la vitesse sans coup de bélier dangereux pour les conduites forcées.

L'exportation de la production italienne en turbines hydrauliques, bien qu'elle se soit affirmée déjà en 1899 par la livraison de deux puissantes turbines pour les chutes du Niagara, n'a pas atteint jusqu'à présent une grande mportance.

Toutefois, dans ces derniers temps, plusieurs livraisons remarquables ont été

faites à l'Etranger et il y a lieu d'espérer que l'industrie italienne, bien spécialisée dans ce genre de construction, puisse contribuer à l'exploitation de l'énergie hydraulique mondiale, en y apportant son expérience et le fini irréprochable de sa construction.

CONSTRUCTEURS ITALIENS DE TURBINES HYDRAULIQUES
(Production totale des Turbines installées en Italie et à l'Étranger).

Constructeurs.	Usines.	Construction des Turbines commencée en	Nombre de Turbines.	Puissance totale des Turbines installées au 31/12/1923
S. A. COSTRUZIONI MECCANICHE RIVA Ditte Riunite A. Riva—A. Calzoni	Milan	1885	2699	2.258.729
S. A. FRANCO TOSI S. A. SAN GIORGIO	Legnano Sestri P.	1913	204	567.000
S. A. OFFICINE CALZONI-PARENTI, transformée le 1er. Janvier '24 en S. A. OFFICINE PARENTI ci-devant Off. Riunite Calzoni-Parenti	Bologne	1885	2218	288.575
ING. S. DE PRETTO & C. (1893, 1916=771 Turb = 48.990 H.P.) S A. DE PRETTO-ESCHER WYSS (1921/1923=165 Turb. =108,048 H.P.)	Schio	1893	936	157.038
S. A. CANTIERI NAVALI E ACCIAIERIE di VENEZIA—ci-devant Soc. Veneta di Costruzioni Meccaniche e Fonderia Treviso	Venice	1908	300	22.000
S. A. ING. MONCALVI & C.	Pavia	1905	719	19.427
S. A. OFFICINE RIUNITE ITALIANE	Brescia	1892	349	14.705
S. A. OFFICINE MECCANICHE & FONDERIE ING. PIETRO VERACI	Florence	1905	164	9.800
Production Totale Jusqu'au 31 Déc., 1923			7589	3.337.274

CANAUX À MI-FLANC

EMILIO AZAROLA

OBJET DE LA COMMUNICATION.

La particularité du développement des applications de l'électricité en Espagne a été la généralisation précoce de l'éclairage électrique dans les villages peu peuplés. Les autres applications suivent la marche, peu accelérée, du progrès industriel en Espagne; mais, dans beaucoup de régions, spécialement dans le Nord, l'éclairage dépassa le degré du progrès industriel, et se généralisa jusque dans les villages peu peuplés, qui passèrent de l'éclairage rudimentaire à huile et des torches de résine à celui de l'électricité par l'incandescence dans le vide.

La raison était double; d'abord le prix des autres systèmes d'éclairage était excessivement élevé à cause des restrictions douanières; et ensuite dans ce pays accidenté et montagneux, il y a, en abondance, des emplacements appropriés pour des utilisations, petites et subdivisées, de ces ruisseaux et de ces rivières torrentielles. L'éclairage électrique était non seulement le meilleur, mais encore le meilleur marché, et sa propagation fut très rapide.

La brusque différence de niveau dont on a besoin pour la création de la centrale électrique, pouvait être produite de deux façons dans les ruisseaux de grandes pentes et d'étroites vallées: au moyen d'une prise de grande hauteur, ou en dérivant le courant par un des flancs de la vallée, dans un canal qui suit à peu près la ligne de niveau. La première façon est la meilleure, parce qu'elle crée, en même temps que le ressaut, une réserve emmagasinée pour amortir les oscillations de régime du courant; mais elle est généralement plus chère, et plus aléatoire par suite de l'imperméabilité douteuse des terrains où les réservoirs doivent être placés; et de plus elle s'est peu généralisée en Espagne à cause d'une raison légale. La loi des eaux prévoit la dérivation par canal, et afin que l'utilisation soit toujours possible, elle a établi l'imposition de la servitude obligatoire d'aqueduc pour les terrains qu'elle doit traverser; mais elle a oublié d'en faire autant pour la servitude des réservoirs des hauts barrages.

L'imposition obligatoire de la servitude d'aqueduc a multiplié les utilisations de canaux de dérivation en Espagne et a propagé une industrie dont les particularités sont les suivantes :

1o Adaptation des moyens techniques à des chiffres peu élevés.

2o La technique des conduites forcées, pour les applications de force.

3o La technique des canaux à mi-flanc, dans les parties inférieures des montagnes de grande pente transversale.

Dans tout le reste, comme, par exemple, dans la construction de machines ou de stations secondaires, l'Espagne, par suite du degré modeste de son industrie mécanique, a suivi l'exemple que lui donnait l'étranger, et c'est à peine si elle a essayé de satisfaire directement ses besoins, ce qu'elle a plutôt réalisé par importation et échange avec d'autres pays plus industrialisés.

L'objet de cette communication est d'exposer sommairement les particularités de la technique des canaux à mi-flanc.

VÉRIFICATION IMMÉDIATE DE LA DIFFICULTÉ DE CETTE SORTE DE TRAVAUX.

Les constructeurs espagnols de travaux publics, habitués à la construction de routes et de chemins de fer, et, quoique sur une moindre échelle, à celle de canaux dans le fond des vallées, se sont lancés sans réflexion et sans précautions spéciales à construire, par les principes courants, ces canaux à mi-flanc; mais bientôt survinrent des déceptions qui causèrent de graves troubles à beaucoup d'entreprises.

Nous avons dû en déduire qu'il s'agit d'une technique spéciale qui offre beaucoup de difficultés. Rien ne démontre, comme ces petits canaux, l'instabilité d'équilibre de la surface de la terre, qui cherche perpétuellement ses assises définitives, même en omettant les actions de la dynamique interne du globe, et en se rapportant seulement aux agents superficiels.

L'obstacle décisif dans ces travaux est le glissement des flancs. Les travaux que l'on exécuta au début étaient très souvent endommagés par des glissements qui paralysaient le service et causaient des pertes par la réfection des travaux, par arrêt des recettes de l'enterprise et les grandes difficultés pour en former de nouvelles, par le discrédit que la fréquence de ces difficultés jetait sur l'industrie hydro-électrique même.

La particularité du canal à mi-flanc, c'est qu'il ne peut supporter le moindre mouvement du sol. Un affaissement du terrain ou un

glissement du flanc de la montagne, qui passent presque inaperçus dans une voie de communication, et qui sont immédiatement réparés par les travaux ordinaires de conservation, sont, au contraire, de graves empêchements dans un canal.

Les glissements des déblaiements, ou du terrain situé au dessus des travaux, entraînent les mêmes conséquences que sur une voie, aggravés par la paralysie complète du service, qui, dans un chemin de fer, se fait par transbordement.

Mais ce qui est particulièrement grave dans ces travaux, c'est le glissement inférieur. En général, il se produit parce qu'une fuite dudit canal, inonde et humecte d'une façon anormale et inaccoutumée les strates du terrain, qui se trouvent peut-être en équilibre précaire, par suite du frottement entre des surfaces sèches, et qui ne peuvent se maintenir quand elles s'humectent.

Pour cette raison dès le commencement des exploitations, on s'est rendu compte que dans les versants, il était indispensable de revêtir tout le canal avec de la maçonnerie au fond et sur les côtés.

NOUVELLES DIFFICULTÉS.

Mais ces revêtements furent peu de chose, car dans aucun cas, on ne parvint à obtenir l'imperméabilité, et, en beaucoup d'occasions, le moindre filet d'eau que laisse échapper un canal, suffit pour provoquer des avaries qui, en apparence, sont disproportionnées avec la petitesse de la cause.

Une petite veine d'eau qui échappe en certains terrains, dissout la terre, la délaie ou la mouille, et peut faire glisser une montagne entière.

Le canal ne peut être imperméable par le seul revêtement, pour deux raisons: 1o parce que les variations de température auxquelles il est exposé dilatent et contractent alternativement une maçonnerie, qui ne peut résister à cet effort et se fissure transversalement. 2o parce que, si les murs latéraux sont limités à une épaisseur de revêtement, et n'ont, ainsi que l'impose l'économie, ni des fondations ni une épaisseur suffisante pour ne pas éprouver le moindre mouvement, il en résulte, qu'après avoir été construits en contact avec un terrain qui n'est pas de roche dure, obéissant à la poussée de l'eau, ils se meuvent imperceptiblement et en masse pour chercher un appui sur le terrain latéral, et il se produit une fissure longitudinale dans les maçonneries, généralement dans l'arête de rencontre du parement intérieur du mur et du fond. (Fig. 1).

Pour obvier à ces difficultés, on dût imaginer des dispositions qui fournissent l'imperméabilité indispensable ou admettre le risque d'avarie, et, ce qui est encore plus grave, une vie limitée de l'ouvrage.

En effet, la vie de cette sorte de canal découvert est beaucoup plus courte que nous ne l'imaginons, et ces travaux vieillissent rapidement. Les dilatations produisement des fissures; celles-ci s'ouvrent par les temps froids, et se remplissent d'eau qui se gêle, ce qui augmente le dégat de la maçonnerie, pendant l'été suivant, les maçonneries se dilatent, et les superfices des crevasses en contact, s'éboulent, ce qui en augmente l'importance. Et ces effets se succédant alternativement, ces travaux en arrivent à présenter un aspect déplorable, et à remplir leur mission d'une façon très défectueuse.

C'est ainsi que nous avons vu beaucoup de canaux à mi-flanc vieillir et devenir inutilisables.

DIVERS CAS QUI SE PRÉSENTENT DANS LA PRATIQUE.

1o Dans des terrains granitiques primitifs ou d'émanation interne.

Les versants des ravins granitiques peuvent être et sont très souvent constitués par une épaisse couche d'une vingtaine de mètres ou plus, de cailloux de granit, de formes arrondies, enterrés dans des sables de quartz. On trouve cette structure quand les micas et le feldspath ont été attaqués par l'eau météorisée, selon l'action si connue. Sur le versant à grande pente, le terrain reste soutenu comme une maçonnerie cyclopéene, de gros cailloux avec un magma de sable de quartz.

Il est très difficile de faire les travaux dont nous parlons dans ces sortes de terrains, parce que la moindre fuite d'eau entraîne les sables sur le flanc en pente, et déchausse les gros modules du sol, qui roulent alors facilement sur le flanc en entrainant avec eux tous les travaux, et en laissant des excavations énormes qui exigent des réparations coûteuses et lentes.

2o Quant aux terrains sédimentaires, tous ceux de la première série (qui se métamorphosent sous l'action des agents atmosphériques, en perdant leur dureté et en devenant mouvants), sont trés dangereux. Il en est de même de tous ceux qui sont composés de roches gélies.

Il ne sert à rien de remuer la première couche du sol constituée par des pièces séparées ou par des roches à moité altérées, parce qu'on ne parvient qu'à dépouiller le sous-sol de sa protection

naturelle, et à laisser les fondations sous l'action des agents qui les attaquent.

3o Parmi les terrains plus modernes, il faut mentionner plus particulièrement les gypseux. Les filets d'eau dissolvent les parois des conduits par où ils s'échappent, augmentent et redoublent sa section, en augmentant le debit de la fugue, lequel à son tour dissout plus de gypse, jusqu'à former des cavernes où s'enfonce la totalité de l'ouvrage.

Un effet analogue est produit par quelques argiles très friables, qui sont délayées par le courant de l'eau, s'il acquiert une certaine vitesse, et entrainées jusqu'à former de grands vides dans les sous-sol.

4o Dans tout terrain sédimentaire, il faut observer très attentivement la stratification et le sens de son inclinaison. Les infiltrations, en s'introduisant entre deux strates, peuvent délayer son appui on lubrifier l'un d'eux, ce qui produit alors un glissement. C'est dans ces cas qu'une cause minuscule produit les effets les plus disproportionnés.

Les terrains qui sont surtout à craindre sont ceux qui abondent tant dans les pays montagneux, et où les strates sont brisés et ébranlés par les mouvements orogéniques. Et cela, parce qu'il est fréquent que deux plans de stratification se coupent en formant un dièdre, dont l'arête est une ligne de forte pente sur le flanc. Dans ce cas, si les deux plans de stratification s'humectent, le glissement est presque inévitable.

On en voit presque toujours un exemple dans les flancs des montagnes où affleurent des roches éruptives, comme les ophites d'émanation interne dans nos Pyrénées. Les filons d'ophite émergèrent à une température très élevée, et calcinèrent les roches adjacentes, qui se convertissent fréquemment en argiles bigarrées extrêmement onctueuses. Si deux de ces filons émergent à proximité l'un de l'autre sur le flanc, la partie située entre les deux est en forme de coin, et, à la moindre humectation profonde, tout le prisme glisse.

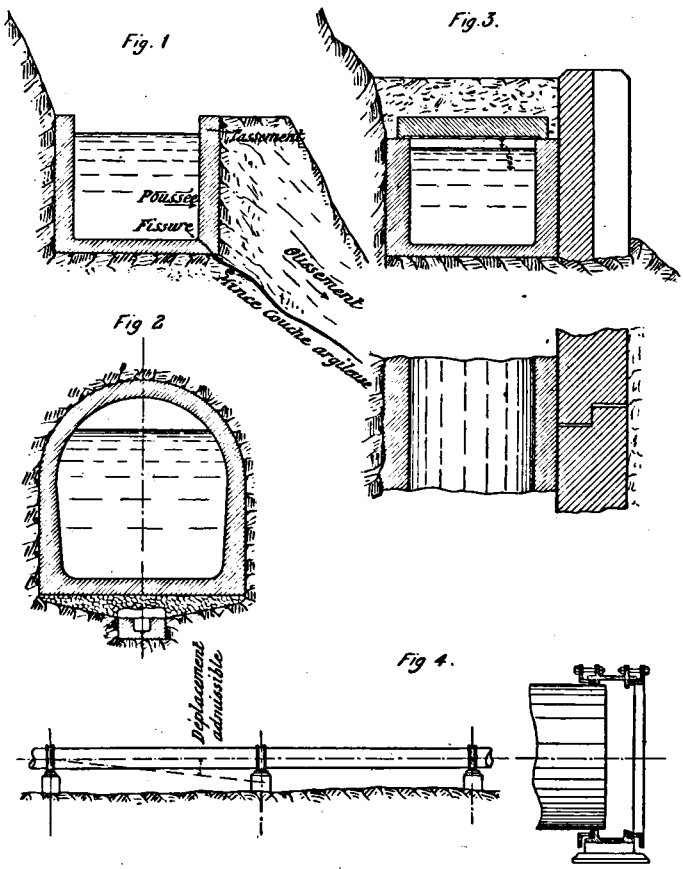
5o Il y a des terrains qui sont permanents lorsqu'ils sont sans contact avec l'air, mais lorsqu'ils sont découverts ils s'exfolient ou se ramollissent, comme quelques argiles dures, ou quelques anhybrides qui n'ont pas été complètement hydratées, et qui se gonflent lorsqu'on y ouvre une tranchée.

6o Et, enfin, il faut observer si le terrain est mouvant par lui-même, indépendamment des travaux qu l'on projette d'y réaliser,

car, ainsi que nous l'avons dit, cette sorte de construction n'admet pas le moindre mouvement.

LES TENDANCES ACTUELLES DANS LE TECHNIQUE DE CES CANAUX.

Le remède héroïque pour obvier à tous ces inconvénients, est de construire les canaux couverts et souterrains.



Autant qu'on le peut, on les construit en tranchées, et on les couvre avec une épaisseur suffisante de terre, qui dépend de la variation et de la rigueur du climat.

En général, trente centimètres suffisent pour obtenir des travaux qui ne se dilatent ni ne se fissurent, et qui soient complètement imperméables.

Au début, nous repoussions la couverture par économie, mais nous avons reconnu qu'il est meilleur marché de recouvrir les canaux, et que, pour plusiers raisons, cela ne cause pas de frais additionnels.

Parce qu'on économise, ainsi, sur l'épaisseur des murs, les fissures longitudinales dont nous avons parlé ne se produisent pas dans des canaux recouverts parce que le toit rattache les murs latéraux, l'un à l'autre, et la consistance des travaux en est bien plus grande. Il nous est arrivé de voir de grandes avaries dans des canaux ouverts par suite d'une coïncidence de stratification dangereuse, au pied du mur de revêtement, lequel, en se fendant imperceptiblement, laissa passer une très petite fuite d'eau. La couverture aurait évité cette avarie. (Fig. 1).

De plus on économise également sur le prix des terrains, le canal ouvert coupe les propriétés, enlève des terrains à la culture, et rend les communications plus difficiles. La couverture diminue les indemnités ainsi que l'opposition éventuelle des propriétaires.

Il est aussi meilleur marché de recouvrir les canaux parce qu'on épargne ainsi une multitude de pontons et de passages que le canal ouvert oblige à construire; parce qu'on peut employer, dans les travaux, des maçonneries, et spécialement des enduits, meilleur marché, par suite de la protection contre les gelées; parce que la section nécessaire est moindre, car, dans le canal ouvert, il faut prévoir une section augmentée parce qu'il y tombe des pierres et d'autres corps, qui augmentent le coefficient de rugosité des parois.

Et enfin, parce que les canaux ouverts causent des accidents réels ou figurés, dont sont victimes des bestiaux passagers qui se noient, et pour lesquels il faut payer des indemnités.

Une variation très favorable du canal recouvert est celle qui consiste à le construire en tunnel ou en galerie. Pour les canaux à mi-flancs, les tendances actuelles sont décidemment pour cette dernière forme, la plus sûre.

On revêt toujours la section mouillée: le reste, selon les conditions. Dans des roches exceptionnellement compactes, il suffit de rejoindre les fissures du terrain.

Les tunnels de ces travaux sont généralement pour traverser des contreforts du flanc, et sont faciles à exècuter parce qu'on prophétise avec certitude les couches que l'on doit traverser et, grâce à des galeries latérales, on a plusieurs points d'attaque.

Ainsi donc, dans tous les tracés, il faut examiner attentivement toutes les variantes possibles en tunnel.

En certains cas difficiles, il convient d'assurer encore davantage les travaux en drainant le terrain. A cet effet, nous avons employé une disposition très efficace, qui consiste (Fig. 2) à laisser à la base de l'excavation une petite rigole centrale qui est construite avec un couvercle perméable.

On étend une couche de pierre concassée, bien tassée, sur le canal et sur le sol, que l'on dispose en deux plans inclinés vers la ligne centrale, et sur cette couche on moule le béton du revêtement. On construit ainsi un drainage qui assainit le terrain et le consolide. Et comme le canal inférieur du drain sort à l'extérieur, on se rend immédiatement compte de n'importe quelle fissure à l'intérieur, parce que la quantité d'eau qui sort augmente soudainement et prévient le danger.

Afin que les tunnels soient mieux isolés, il convient de fermer leurs ouvertures.

Quand la construction à mi-flanc est imposée, avec un mur de soutènement à la partie extérieure, comme dans le cas de grande pente transversale et de longues lignes de flancs rocheux, on ne peut pas espèrer que les travaux soient d'une durée indéfinie parce que le mur extérieur est soumis aux intempéries.

Pour ce cas-là, nous avons proposé la solution suivante. (Fig. 3.)

Construire sur le bord extérieur de l'excavation un mur de soutènement avec des joints de dilatation en saillant, chaque douze mètres, et que ce mur soit un simple appui du revêtement du canal, qui est construit adossé, mais séparé. On finit et on enduit le mur extérieur pas sa face intérieure, et, dans le fossé formé par l'excavation et ledit mur, on moule ensuite le revêtement du canal, généralement en béton. Généralement, on arase le mur extérieur à 40 centimètres sur le toit de couverture, et on peut couvrir les travaux avec cette épaisseur de terre. Les dilatations sont ainsi limitées aux travaux externes, qui ont des joints et ne sont pas mouillés.

Enfin, quand le sol est mouvant de lui même, nous avons adopté (Fig. 4) un recours extrême qui nous a donné un bon résultat.

Nous formons la conduite d'eau avec un tube métallique en morceaux de dix mètres de longueur, appuyés sur des massifs isolés. Les tubes sont unis au moyen de rotules qui permettent un certain jeu. Les rotules purement métalliques sont chères, et nous les avons faites avec une pièce en fonte, en forme de manchon avec beaucoup d'ampleur, qui se fermait avec un gros cordon en caoutchouc, serré avec une pièce en forme de presse-étoupe.

Cette façon d'union permet au massif d'appui de descendre de plus d'un mètre sans qu'il se produise aucune fuite d'eau. De temps en temps, selon la mobilité du terrain, on lève le tube avec des crics, et on recale le contrefort d'appui, sans, pour cela, interrompre le service. Le canal remplit sa mission, en se déformant comme une chaîne, et le terrain glisse peu à peu sur le versant, et dans quelques cas expérimentés, il a parcouru de grands espaces, sans qu'on ait eu à regretter la moindre interruption.

DÉTAILS DE CONSTRUCTION.

En résumé, le canal à mi-flanc est une oeuvre délicate qui exige une étude minutieuse et préalable du terrain d'emplacement et l'adoption de beaucoup de précautions, comme nous venons de l'indiquer.

La construction doit être réalisée sans aucune solution de continuité. Derrière les équipes qui ouvrent l'excavation définitive doivent venir celles qui construisent le revêtement et les enduits, et, aussitôt après, celles qui tendent la couverture et la recouvrent de remblais. Ainsi, les influences extérieures ne nuisent pas à la maçonnerie. Nous n'avons jamais observé qu la rétraction produise des fissures quand on construit de cette façon là.

La section transversale choisie doit surtout avoir en vue une construction pratiquement facile plutôt qu'une économie théorique par diminution de la section mouillée. Pour les canaux moyens et petits, au lieu de cintres mobiles pour la couverture, il est généralement préférable de les faire en planches que l'on abandonne dans la construction, qui, ainsi, avance plus rapidement. Quand la planche se pourrit, elle tombe, et elle est facilement entrainée et extraite.

La pente longitudinale doit être suffisante pour produire une vitesse supérieure à un mètre, ou, mieux encore, un mètre et demi par seconde, et cela, afin d'éviter des sédimentations dans les travaux fermés. On laisse, de loin en loin, un regard bien conditionné et couvert. Pour des canaux petits et de grande longueur, il est difficile d'obtenir la rasante suivie selon le profit adopté. Cependant, par l'adoption de précautions, à la description desquelles nous ne pouvons pas nous arrêter maintenant, on obtient toute l'exactitude suffisante pour que les erreurs n'atteignent pas un centimètre, et l'on peut ainsi remplir toute la section du canal jusqu'à une faible distance de la couverture.

RÉSUMÉ

The author reviews the development of electrification in Spain and emphasises the necessity for the general use of electric lighting in small towns and remote sparsely populated villages. This is due to the high cost of the other systems of lighting and to the large number of small hydraulic powers which can be utilised.

Details are then given of the various systems used for conveying the water from the upper reaches of the mountains to the power plants in the valleys, and among these canals on sloping ground are fully described.

Great difficulties have been encountered in the erection and maintenance of these canals. Owing to the bad formation of the soil, percolation of water, etc., many accidents have occurred, involving almost in every case the closing down of the plant and long and costly repairs to the canal.

Information is given in the various cases which have been dealt with, how the difficulties were solved, and how finally the decision was made to build covered canals, as it was found that with one foot of earth on top of the ceiling of the canal, the walls of the canal were not subject to expansion and contraction, therefore fissures were avoided and accidents to canals eliminated.

Sections are given of various types of covered canals, also of a system of metallic piping with flexible joints which enables the pipe to follow any movement of the soil and to sink at each joint by over 3 ft. without any leaks occurring. From time to time the joints are raised by means of jacks and brought back to their original position.

Reference is made to the construction of the canals; great care must be taken that the excavations remain uncovered for the least possible time in order to prevent any damage to the soil.

MODERN TENDENCIES IN WATER-WHEEL DESIGN

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Sweden is, for the most part, a country of small hills and dales, and the available sources of water power are, as a rule, distinguished by low heads. Natural lake reservoirs are common, facilitating daily or weekly regulation, and by the aid of special dam constructions they are very often of great assistance to the annual equalisation of flow. The proportion of the available water power which can be made use of is, therefore, considerable, and in the greater rivers the discharge attains important dimensions; for instance, in the Dalälven about 400 cu. metres per second, and for the Göta älv up to 900 cu. metres per sec.

These conditions have influenced the design of the water turbines employed, in that it has been of importance to devise turbines with as high a speed as possible in order to reduce the cost of the electric generators used, and latterly have led to the construction of very large units with the object of gaining the greatest possible simplicity in design and operation.

The development of turbine engineering has for natural reasons been closely associated with the question of electric transmission of power by means of alternating current over long distances, introduced in the nineties. The first relatively high speed turbines of the Francis type were constructed in the United States of America. The runner is defined by the specific speed, n_S, which expresses the number of revolutions of a model turbine, developing exactly one horse-power at a head of one metre. For a turbine which under a head of H metres will develop N H.P. and runs at n revolutions per minute, we obtain the equation

$$n_S = \frac{n\ \sqrt{N}}{H\ \sqrt[4]{H}} \ *$$

At the beginning of this century a specific speed of $n_S = 300$ or

* In the British system of units, the figure refers to one English foot, for which reason n_s metric $= 4{\cdot}44\ n_s$ British.

somewhat more had been obtained in America, chiefly on the basis of experiments carried out at the testing institute in Holyoke, with quite a good efficiency.

At this time a number of American turbines were imported to Sweden, and the need of testing institutes in this country also soon became pressing. As the attempt at the establishment of an official government institute did not lead to any results, the manufacturers took up the matter themselves and all of them started small testing stations. The first more or less complete one was that of the Finshyttan Co., at Finshyttan, which was completed in 1904. This was soon followed by the station of the Verkstaden in Kristinehamn Co. and others. These testing stations came to be of paramount importance to the development of turbine design in Sweden, and supplied a sound basis upon which further development has been built. Some years later Verkstaden in Kristinehamn also built a hydraulic laboratory, where model turbines of small size could be tested at a head of about 1 metre, while, on the other hand, special facilities were available, such as a suction tube made partly of glass to permit of a close study of the eddies in the water, etc. At the Royal Institute of Technology (Kungliga Tekniska Högskolan) in Stockholm, a small experimental plant was also installed at an early stage, although it was chiefly used for training purposes.

The Finshyttan Co., as a result of the work in the testing station, succeeded, in 1905-06, in manufacturing fast running Francis turbines with $n_S = 320\text{-}350$, and with a maximum efficiency of 85-87 per cent. for runners of about 1 m. outside diameter. The efficiency below full capacity was also relatively good. Sweden could now supply her own requirements of turbines, and very soon appeared as an exporting country on the world market, specially with regard to the products of Verkstaden in Kristinehamn.

Where the available head permitted it, double turbines with a horizontal axle have been preferred in Sweden, and even what are termed "quadruple turbines" have been installed, in order to increase the speed. Even where a vertical arrangement has for some reason or another been chosen, double turbines and sometimes triple turbines have been erected in order to obtain at the prevailing low falls a speed more suitable for direct coupling. The specific number of revolutions was gradually increased to about 400 whilst in the main the old type was adhered to.

Fig. 1 shows a typical horizontal double turbine, of which four were built for the Stockholm municipal power works at Untra on

the Dalälven during 1915-18 by the Kristinehamn works. These were at the time the largest turbines of their type in the world, and distinguished by a turbine shaft joined in the centre by a coupling forged to the shaft, free of bearings throughout the entire length between front bearing and rear bearing. The efficiency obtained by tests in the plant will be seen in Fig. 2. Still larger turbines have since been installed at the Raanaasfos plant on the river Glommen (in Norway).

The development in America had, however, followed different

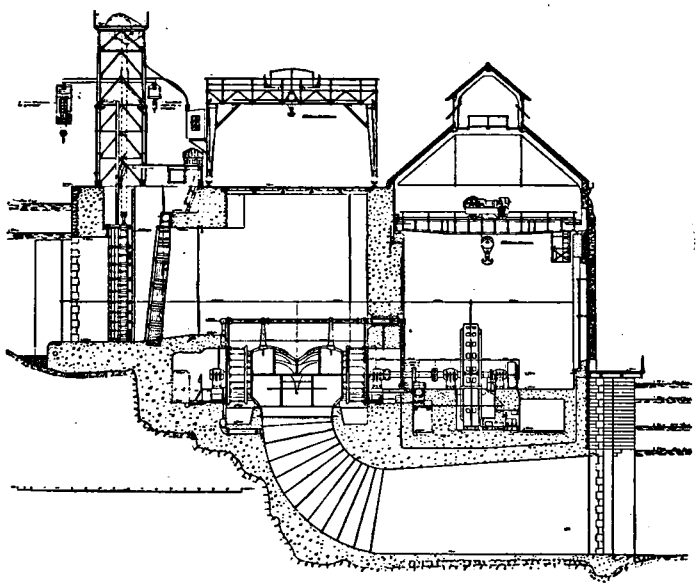

Fig. 1.
The Untra Power Station.

lines as, after the completion of the large Keokuk plant in Mississippi, the single-runner vertical turbine with spiral casing of concrete, was quite generally adopted and became almost standard practice. The runners of the Keokuk plant have a diameter of about 5 m. and the overall dimensions thus became most imposing. The large dimensions and the simple direct inlet and outlet for the water made for good efficiency, a circumstance which in combination with the simplicity of the design is given as a reason for the choice of this type. As yet, it has not been possible to obtain

higher specific speed than about 400, a figure which for most cases is rather low and leads to a high cost for the generator, with a decrease in the efficiency, often to such a degree that the gain in the turbine is lost in the generator. Stora Kopparbergs Bergslags Aktiebolag, however, chose this type for their power station at Forshuvudforsen in the Dalälven, built 1917-21 (see Fig. 3). The runners, made in one piece with a diameter of 4-4·1 m., gave a certain amount of difficulty with regard to manufacture and transport under Swedish conditions.

The Royal Board of Waterfalls (Kungliga Vattenfalls-styrelsen) which, in Sweden, attends to the development of State water power,

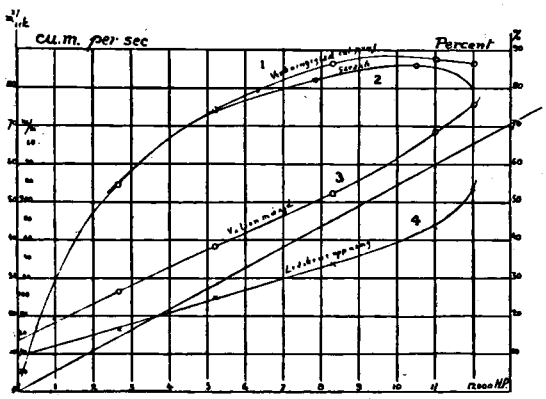

Fig. 2. Efficiency of the Untra Turbines.
(1) Efficiency on test.
(2) Guarantee.
(3) Discharge.
(4) Guide vane opening.

had already in its earlier installations at Trollhättan, Porjus and Älvkarleby given a strong stimulus towards the development of better turbines, but this is especially true of the plant now under construction at Lilla Edet on the Göta älv below Trollhättan; and an account of the preliminary work for this installation will at the same time give an idea of the recent development of turbine engineering in Sweden. The Royal Board of Waterfalls, in a publication entitled "Statens Kraftverk vid Lilla Edet" (The State Power Station at Lilla Edet), and published on the 6th of August, 1923, has given a very complete account of the reports and experiments which have been prepared in connection with this installation. The account given below will, therefore, in the main be a summary of this report.

The head at Lilla Edet normally varies between 5·6 and 6·8 m. with a normal average of 6·5 m. The first installation will use somewhat more than 400 cu. m. per second, while in the final stage of development about 900 cu. m. per second will be utilised.

The first investigations from the year 1917 concerned a number of alternative solutions: vertical single rotor turbines of 5,400 or 3,300 H.P., vertical double turbines of 4,000 H.P. and horizontal quadruple turbines of 4,400 or 3,900 H.P. In each case only fast running Francis turbines were considered, with n_s from 330 up to

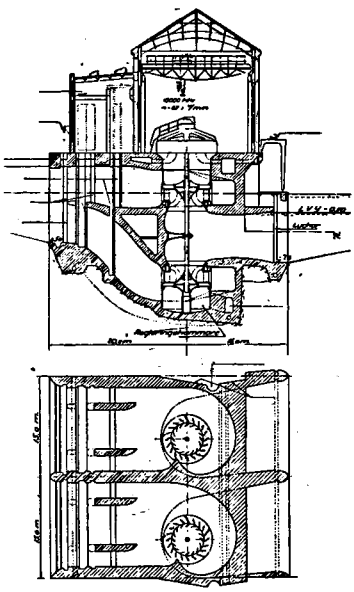

Fig. 3.
One alternative considered for rhe Lilla Edet plant.

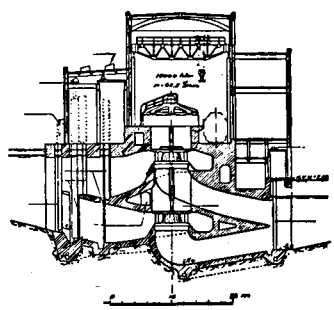

Fig. 4.
Another possibility for the Lilla Edet plant.

415. It was soon found that horizontal turbines had to be abandoned in this case, on account of the large space occupied by them and their large dimensions in proportion to the head and the variations in the water level. Of the vertical turbines, the single runner type offers greater simplicity, and probably a somewhat higher efficiency. The vertical double turbine gives a higher number of revolutions and therefore permits of a cheaper generator, in addition to which, with the sacrifice of efficiency, higher water speeds can

be employed and a greater power obtained in a smaller space, thus reducing building costs. This last consideration is naturally of the greatest importance when the power is to be used for a comparatively short period. Having regard to the situation at that time, the proposition considered a first installation of five double turbines of 6,600 H.P. at 6·5 m. head and 68·3 r.p.m., corresponding to $n_s = 380$ and then, as a first extension, the installation of four single turbines of 5,400 H.P. and 53·7 r.p.m. with the object of taking care of the minimum load of the station, with the best possible efficiency.

The end of the war, however, resulted in a rapidly diminishing demand for electric power, before the machinery had been ordered. As, therefore, the time for the completion of the power station could be extended, the Royal Board of Waterfalls decided to continue the work of investigation.

With special regard to the electric equipment, and in consideration of the future operation, it was considered desirable to have fewer and larger units, and plans were accordingly prepared for vertical double turbines of 10,000 H.P. at 62·5 r.p.m. By this arrangement the total length of the power station could be considerably reduced, a circumstance which, for considerations of space, was of great importance. It was, at that time, considered impossible to construct single turbines of great size and speed, on account of the very large dimensions which would be necessary. An extensive economic comparison between aggregates of various sizes suggested that the above-mentioned power of 10,000 H.P. in a double turbine would be most advantageous. Such turbines, constructed as double turbines with a single suction casing or as tandem turbines, could have been built at the Kristinehamn works and by foreign turbine works.

In the meantime the Royal Board of Waterfalls had, in connection with the later work of investigation, built their own small turbine testing plant in an old canal lock at Lilla Edet, in order to be able to make comparative experiments, chiefly concerning the power plant at Lilla Edet, but also for later installations which might be built, for the purpose of trying various methods of installations and different shapes of the inlet and outlet for the water, and also for the study of various water speeds, all of which questions were of the greatest importance to the economic aspect of the plant, and could not be answered by tests with models in the testing stations of private workshops.

At this station, shown in Fig. 5, extensive trials such as those mentioned above, have been carried out by Dipl. Ing. Hugo Munding. Important results have been obtained with regard to the shape and dimensions of intakes and spirals, by which it has been possible to decrease the distances between aggregates and thereby effect considerable savings in the building costs at Lilla Edet.

After the programme for the tender on 10,000 H.P. double turbines had been distributed during the summer of 1921, a number of tenders were received for this type of turbine in respect of both

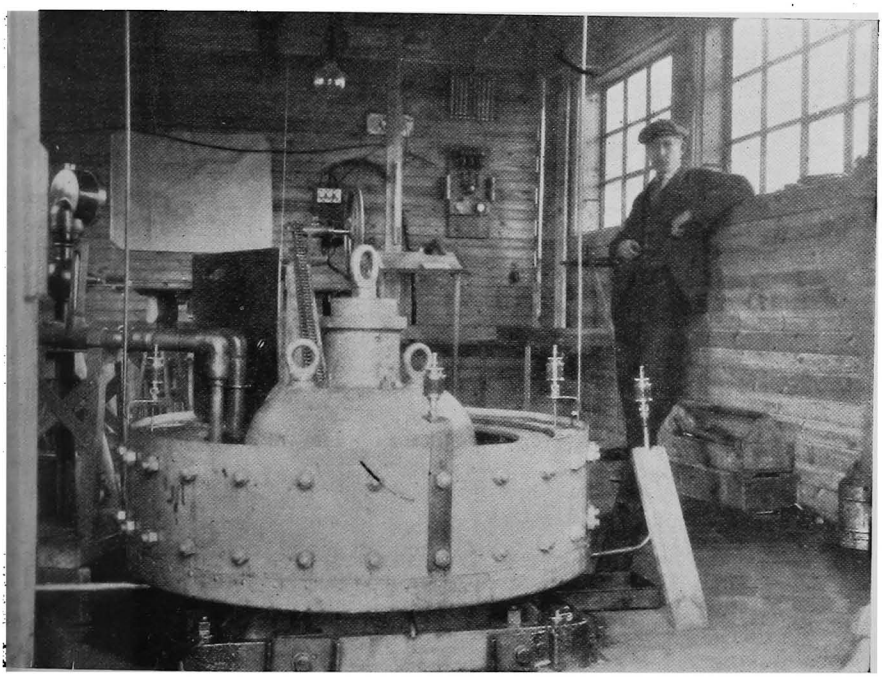

Fig. 5 .Testing station at L.E.

double turbines and tandem turbines, but, in addition, the surprising fact emerged that no less than three firms were now able, as an alternative, to offer single turbines for the same effect and speed and some of them even went so far as to propose the increase of the speed to 83·3 r.p.m. These values correspond to an n_S=600 or 800 respectively. The problem of fast running turbines appears lately to have developed very rapidly. On

account of the greater simplicity of single runner turbines, the Board of Waterfalls had every reason to investigate these proposals more closely.

The author made an interesting experiment at A. B. Finshyttan as early as 1906 with a small fast running water turbine and, with the relatively good efficiency of 75 per cent., attained a specific speed of 462. The turbine, however, through which the water passed, chiefly in an axial direction, and which had seven blades in the rotor, showed a comparatively rapid decrease in efficiency with a decreasing load. As there did not appear to be any particular interest in the matter, it was left for the time being. Professor Kaplan, of Brün, began a closer investigation into the problem of fast running turbines and succeeded, by shortening the blades and later removing the outer band connecting these blades, in attaining values for n_S of 800 and more. These runners, which had almost the appearance of propellers, gave with a certain load a high efficiency, but also showed with an altered gate opening a great reduction of efficiency. Mr. Kaplan then hit upon an idea which at first appeared fantastic but which in itself was good, *i.e.*, to design the runner blades so that they could be turned, whereby the efficiency could be maintained at a high value over a very large range of load. The number of blades was reduced to four or even to two. This work, which appears to have taken place chiefly during the years 1913-14, was broken off and delayed by the outbreak of war.

Verkstaden in Kristinehamn had already at this time made a preliminary agreement with Mr. Kaplan concerning his invention and commenced their own experiments on a somewhat larger scale. It proved, however, difficult to obtain the same good results as had been obtained with a straight and relatively long draft tube when connecting this turbine to a curved suction tube. As this workshop, shortly after the outbreak of war, was very busy, the matter was put aside. Professor Kaplan, however, continued his work and was successful in designing a suitable draft bend for the suction tube of the turbine, distinguished by a very much flattened and broadened discharge end, while the bend itself was very sharp, the outer contour even being sharply bent to an angle of 90°. The firm Ignaz Storek of Brünn, collaborating with Professor Kaplan, executed a number of small installations, but public opinion was divided as to their efficiency. The Board of Waterfalls opened direct communication with Professor Kaplan as early as 1919, but it soon became obvious that the size of the suction pipe which would be

necessary for a single turbine of 10,000 H.P. would increase the costs so much that this solution of the problem could, for economic reasons, not be adopted.

In the meantime, the Verkstaden in Kristinehamn had resumed trials with the Kaplan turbine in 1920-21 and had now got so far, that at the end of 1921 they considered themselves in a position to be able to offer the Board of Waterfalls a Kaplan turbine with a more suitable shape of suction pipe. I will later return to the further development of this question, but will first mention a few smaller installations which have recently been completed in Sweden.

Another firm, which was able to offer an alternative tender for single runner turbines, was A. B. Finshyttan together with F. Neumeyer A.G., München. Their tender related to a rapid running turbine of Dr. Lawaczeck's design, with fast blades of very unusual shape. It would appear that the passage of water was intended to be decidedly in a centripetal direction, there was no outer band and each blade was constructed separately and fastened to a common hub by means of bolts so that the large diameter of the rotor of 6 m. would not cause any particular difficulties. The runner had been subjected to certain preliminary tests but had not yet found any practical employment.

Finally, Nydqvist & Holm A. B., of Trollhättan, together with Th. Bell & Co., of Kriens, Switzerland, had offered a fast running turbine which had been recently developed and tested by the latter firm in their own testing station. Concerning the constructive details of this turbine, no particular information was given. Both for the Bell and for the Kaplan turbine a speed of 83·3 r.p.m., corresponding to $n_s=800$ was proposed, while for the Lawaczeck turbine a speed of 62·5 revs. per min., corresponding to $n_s=600$ was proposed. Under these circumstances, the Board of Waterfalls decided in principle to go in for single runner turbines with $n_s=600$ in spite of the difficulties. The Kaplan turbine was the one concerning which most experience had been obtained, and with this turbine the best efficiency curve at varying loads could be expected. It was, however, expensive and its suction pipe would always increase the cost. Furthermore, it was a risky matter, both from the hydraulic and from the technical point of view, to decide in favour of this principle, with the great dimensions involved, as the experience gained had hitherto been based on quite small plants. Further tests were, however, to be made both at the works and at the testing station at Lilla Edet. On account of the state of constructional work alongside, a decision had to be made and the

Board of Waterfalls ordered its first Kaplan turbine of 10,000 H.P. and 62·5 r.p.m. at a head of 6·5 m., in the spring of 1922 ; a decision whereby a great impulse was given towards the development of this type of turbine. A section of the power station with the Kaplan turbine and its suction pipe will be seen in Fig. 6.

A further turbine had soon to be ordered and the other designs offered, were, in respect of their greater simplicity and cheapness, of the greatest interest. Investigations showed that the Bell turbine had been tested with a very long suction bend, a design which would have been almost impossible to use at Lilla Edet, but

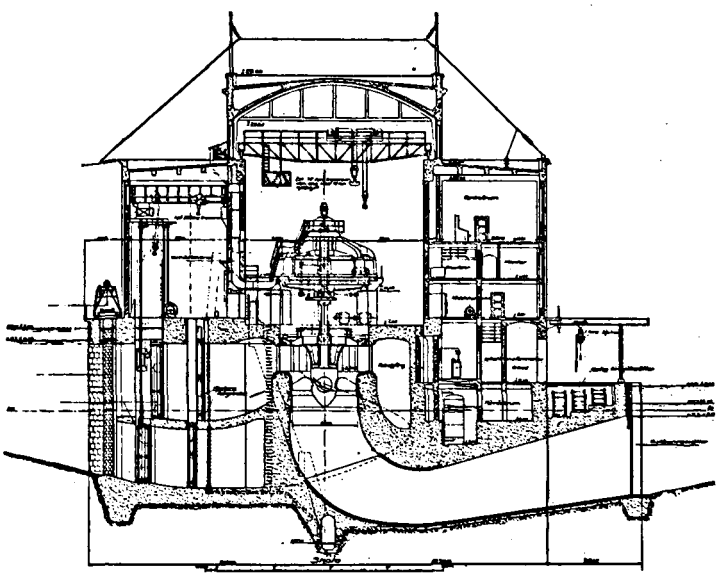

Fig. 6.
Section of the Kaplan Turbine at Lilla Edet.

it was just on this long suction bend that the good results largely depended. The type could, however, be regarded as far from ready, and for a definite decision a considerable amount of preliminary work was still necessary.

With regard to the Lawaczeck turbine it is true that the firm of Neumeyer withdrew its co-operation, but after the necessary arrangements had been made between the Board of Waterfalls, the Finshyttan Co. and Dr. Lawaczeck, a keen and extensive investigation was started with a large number of tests, partly at the laboratory of the Royal Institute of Technology with turbine runners having a

diameter of 200 mm., and also at the Finshyttan testing station with runners of 460 mm.'s diameter, and, finally, at Lilla Edet's testing station with runners of 1 m. diameter.

This work led to the ordering first, of one Lawaczeck turbine for the second aggregate at Lilla Edet, and later, after careful comparison between the new tenders for both Kaplan and Lawaczeck turbines, to an order for an additional Lawaczeck turbine for the third aggregate, with which the first stage of development was complete.

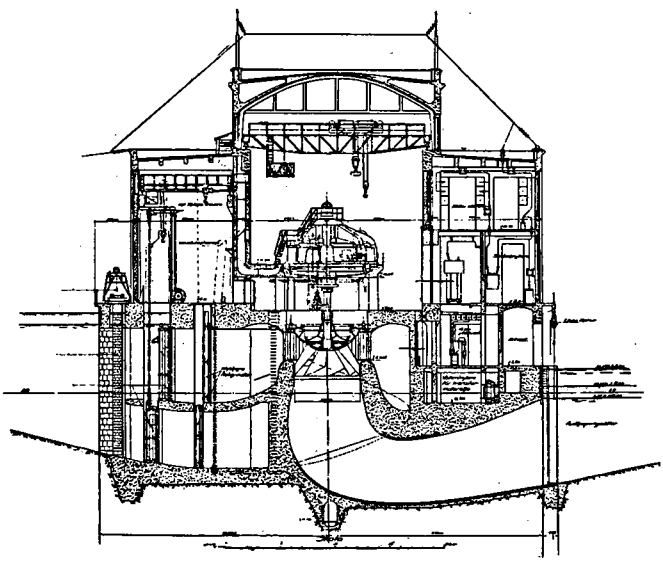

Fig. 7.
Section of one Lawaczeck Turbine at Lilla Edet.

A section of one aggregate with Lawaczeck turbine is shown on Fig. 7. The second turbine is just like the first, but it has been fitted with the same suction pipe as the Kaplan turbine, as it was desired to keep the choice of turbine open as long as possible. Tests have shown that this suction pipe had no unfavourable influence on the Lawaczeck turbine.

A couple of Lawaczeck test runners are shown in Fig. 8. The wheel will have a diameter of 6 m. and will thus be the largest turbine runner hitherto made in the world. The diameter of the Kaplan turbine will be somewhat less, about 5·8 m. Owing to

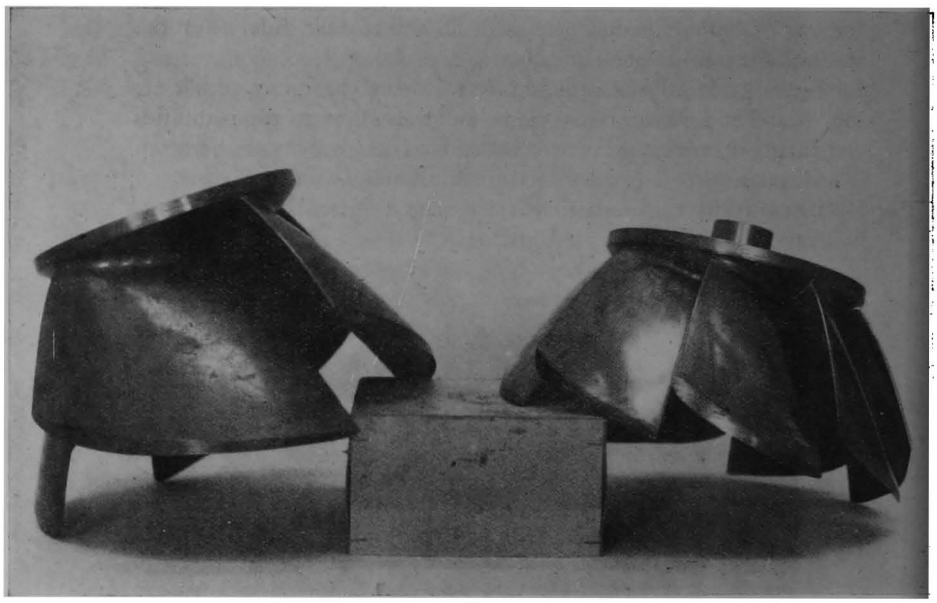

Fig. 8.
Lawaczeck Model Runners.

the fact that the Lawaczeck turbine has fixed blades, it gives an efficiency curve (Fig. 9) characterised by quite low values at a small load, efficiencies of 83, 87, 81, 73 and 65 per cent., being guaranteed at loads of 8/8, 7/8, 6/8, 5/8 and 4/8. This decrease is not of

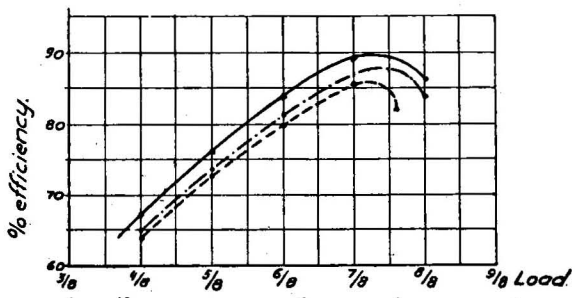

Fig. 9.
Efficiency of Lawaczeck Turbine for Lilla Edet.

— · — · — Guaranteed.
———— Calculated.
- - - - - - - - Model Wheel.

great importance as it is estimated that these turbines will always be run at approximately the most advantageous loads. For the sake of comparison, it should be mentioned that the Kaplan turbine at corresponding loads is guaranteed to have efficiencies of 84, 87, 88, 87 and 86 per cent. respectively, and thus offers great possibilities for taking up variations of load without wasting water. In addition the Kaplan turbine is calculated to be capable of an overload up to 11,200 H.P. without any great reduction of efficiency.

It is thus on the direct initiative of the Board of Waterfalls that the Lawaczeck turbine has been rapidly brought through the experimental stage to an efficient design, and the Board has thereby given a particularly powerful impulse to the development of turbine

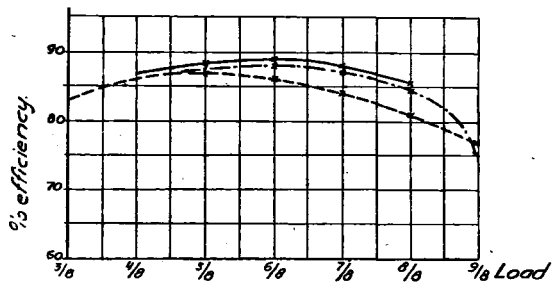

Fig. 10.
Efficiency of Kaplan Turbine for Lilla Edet.
— · — · — Guaranteed.
- ——— Calculated.
- - - - - - - - Model Wheel.

practice in Sweden and indirectly abroad. This work will be useful to the Board for its future installations and also for other electrical works, the large turbines at Lilla Edet representing, so to speak, a pioneer step, involving a certain amount of risk in spite of the extensive preliminary tests. The author considers that these risks lie principally in the danger of cavitation phenomena occurring in the blades, wherefrom corrosion might result and at certain reduction in efficiency and output. In spite of the fact that the Lawaczeck turbine has so far found little practical employment, these risks appear to be less in the case of this turbine than they are in the Kaplan turbine with the suction heights here in question.

During the last few years, Verkstaden in Kristinehamn has, however, been able to complete a few small installations of Kaplan turbines, working at a comparatively low head, which have been

proved to operate satisfactorily, and which have given good test results. These plants have been described in somewhat greater

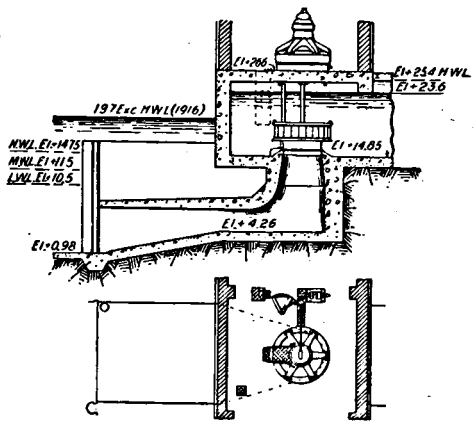

Fig. 11.
Section and plan of the power station at Strömsborg. Sweden.

detail by the writer in "Teknisk Tidskrift, Mekanik," October, 1923, and by Mr. E. Englesson in " Power," November 13th, 1923. The installation at Strömsborg in Gävle, where the turbine has been fitted with a suction pipe of the original Kaplan type—is of special

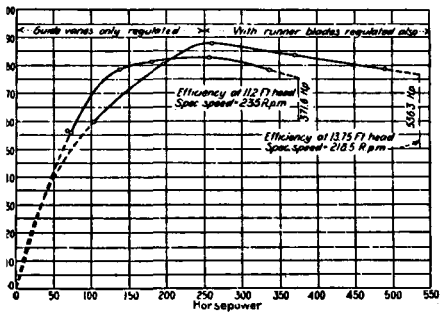

Fig. 12.
Efficiency curve obtained at the official test of Turbine, Strömsborg plant.

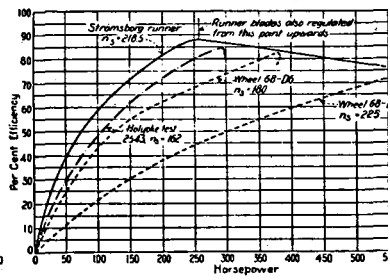

Fig. 13.
Comparison of the efficiency for Kaplan Runner with movable blades and runners with fixed blad

interest. The runner with three blades is shown in Fig. 14. The turbines are guaranteed to give 400 H.P. at a fall of 4.2 m. and 250 r.p.m. and 300 H.P. at a fall of 3.4 m. and the same number of r.p.m. In tests, it was found that the turbine was capable of a

considerable overload, so that n_s reaches very high values, *viz.*, 960 and 1,040 respectively (in the metric system), at the two heads mentioned. The results, in comparison with some American rotors with fast blades, will be seen from Fig. 12 and Fig. 13, taken from "Power."

Axial runners with fast blades of greater length than those in the Kaplan turbine, so-called propeller turbines, have of later years been built in America and in other countries. The author has designed a similar turbine, which has been tested with good results. As it is, however, the subject of an application for patent, and has hitherto not been built for practical use, a closer description may perhaps be postponed.

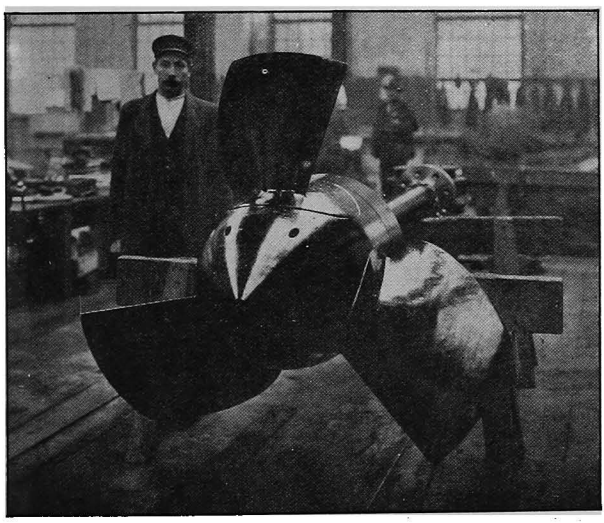

Fig. 14.

Pelton turbines are built for export by Verkstaden in Kristinehamn. Several large plants have been constructed with very satisfactory results. Thus, the latest station tested at Rio Cinca in Spain has two turbines each of 22,500 H.P. at 500 r.p.m. at a fall of 450 m. The turbines have vertical axles with one runner and three jets. The efficiency is about 85-87 per cent. on the entire range of load between 6,000 and 21,500 H.P.

With regard to automatic speed governors, it may be said that they have kept pace with the development of the turbines. A

notable advance was the centrifugal pendulum recently invented by Mr. Englesson, of Kristinehamn, known as the "evolvent pendulum." distinguished by its very sensitive action. The method, adopted for the first time at the Untra power station of driving the oil pressure pumps of large governors by electric motors instead of driving them direct from the turbine shaft, has proved to be very satisfactory and is now being generally adopted.

At a number of places, the long supply pipes for the water have necessitated surge tanks or reservoirs in order to regulate the supply. These reservoirs have in some cases been left open, in others they have been fitted with a throttled connection with the pipe line, whereby their size and cost have been reduced. The methods of calculation employed have shown satisfactory agreement with the results obtained.

As will be seen from the above, a pronounced development of the question of high speed turbine runners has lately taken place and it is now possible, for low falls, to calculate with a specific speed of 600 and somewhat more for rotors with fast blades, and with Kaplan turbines with values for n_s of up to about 1,000 instead of about 350-400, which, until recently, were usual. This development has contributed largely towards the reduction of machinery costs and will also probably decrease as a rule the cost of buildings. It will furthermore increase the possibilities of developing low head power sites.

RÉSUMÉ.

L'exploitation de la force hydraulique a depuis longtemps été un problème de la plus grande importance en Suède. Il en est résulté des travaux de recherche importants concernant les turbines hydrauliques, et en raison de la faible hauteur de chute et du débit considérable des chutes suédoises, ces travaux ont été dirigés vers le développement des types de turbines à grande vitesse spécifique.

Quand la Direction Royale des forces hydrauliques eut à construire la station hydro-électrique de Lilla Edet dans Göta älv pour une puissance correspondant à un débit de 900 m³ par seconde et une hauteur de chute variant entre 5, 5 et 7 mètres, ce projet fit l'objet d'études très détaillées concernant le type de turbine le plus favorable. Finalement la roue-Kaplan fut choisie pour l'une des trois unités de la première section et la roue-Lawazcek pour les deux autres.

Dans ce rapport on décrit les qualités caractéristiques de ces turbines ainsi que les différentes alternatives examinées en vue de la construction de Lilla Edet.

RECENT SWEDISH ARCH DAM DESIGN

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In the design of arch dams the question as to what extent stresses resulting from changes in temperature and from the shrinkage of the concrete should be taken into account, has been the subject of different opinions. Existing non-reinforced single-arch dams show considerable cracks, which evidently must be caused by stresses of this kind, as may be gathered, for instance, from an interesting investigation of arch dams in Australia.[1] Although old Swedish arch dams, as those at Gullspång and Stenkvill-Klinte, which are slightly reinforced only, have been well maintained, the Swedish arch dams of recent date have been strongly reinforced. Among these dams there are the single-arch dam at *Gideåbacka*[2] and the multiple-arch dams at *Suorva* and *Melby*[3]. The Suorva dam has been designed and constructed by *The Royal Board of Swedish Waterfalls*, the other two were designed by the *Vattenbyggnadsbyrån* (Consulting Hydraulic Engineers of Stockholm). In the following, a short account of these dams and of the principles of their design will be given.

In the calculations, attention has been paid to the horizontal arch effect as well as to the vertical cantilever effect, due to the dam's support at the bottom.

In the design of *the Gideåbacka dam* it was necessary to take into account variations of the temperature of the air from +25° to −25° C. (+77° to −13° Fahr.) and of the water from +15° to 0° C. (+59° to +32° Fahr.) Lacking an exact knowledge of the extreme temperature curves for a section through the dam, it was assumed that these be represented by straight lines (the full lines in Fig. 1). From a recent investigation of this matter it is, however, evident that the extreme temperature of the concrete follows a sharply bent curve (the dotted line in Fig. 1).[4]

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[1] Ziegler : "Über ausgeführte Gewölbe-Talsperren in New South Wales, Berechnungen, Rissbildungen, Durchbiegungsmessungen," "Beton und Eisen," 1912, numbers 1 and 2.

[2] Bo Hellström : "Valvdamm av armerad betong vid Gideåbacka" (Arch dam of reinforced concrete at Gideåbacka), "Teknisk Tidskrift," "Väg- och Vatten," 1919, number 3.

[3] Bo Hellström : "Serie-valvdamm vid Melby" (Multiple-arch dam at Melby), "Teknisk Tidskrift," Väg- och Vatten," 1923, number 2.

[4] Fr. R. Berwald and Bo Hellström : "Om temperaturvariationer och temperaturspänningar i betongkonstruktioner" (On variations of temperature and on stresses in concrete constructions, resulting from these variations), Stockholm, 1921.

In calculating the bending moments and the normal pressures, there is some uncertainty as to the modulus of elasticity of the concrete, which, as is well known, varies considerably. Different values of the bending moment and of the normal pressures, resulting from temperature and shrinkage, or from the water pressure, will be obtained, depending on whether a solid or a two-hinged arch be considered. In the first case the moments will be much bigger than in the latter. The bending moment at the abutments is particularly big in the solid arch. It was on this account that the Gideåbacka dam, on its upstream side close to the abutments, was

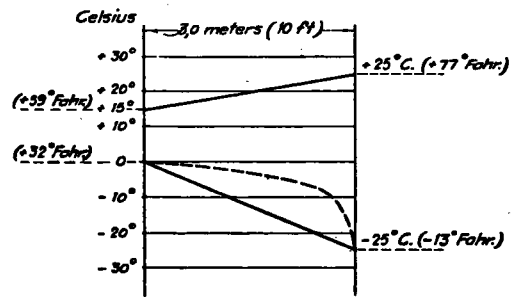


Fig. 1.

Extreme temperature curves for a section through the dam.
Courbes des températures extrêmes dans une section à travers le barrage.

provided with joints and hinges, with a view to making the dam act more as a two-hinged than as a solid arch.

The stresses resulting from the shrinkage of the concrete are equal to the stresses caused by a sinking of the temperature of 5 to 10° C. (9° to 18° Fahr.). The shrinkage stresses can be reduced by casting the concrete in separate sections, but so far this method has not been adopted in Sweden owing to the particular difficulties involved with regard to the reinforcement.

It is apparently becoming a general opinion that arch dams just as well as arch bridges should be designed according to the theory of elasticity in relation to temperature and shrinkage. In an article about the Gideåbacka dam, for instance, Noetzli states : " Very few of our California arch dams have been reinforced according to scientific methods as used, for instance, in the design of arch bridges. As a consequence many of these dams have seriously

cracked under excessive tension stresses, so that, when the arch comes under pressure, the compression forces are transmitted across a rough broken surface. In time this may lead to serious injury to the two surfaces of each crack and to gradual deterioration of the adjacent concrete. It will, therefore, be most desirable for future designers of arch dams to pay more attention, also, to the stresses resulting from temperature and shrinkage deformations."[1]

In this connection, attention is called to the fact that the reinforcing steel in a dam, provided that the centre angle and the

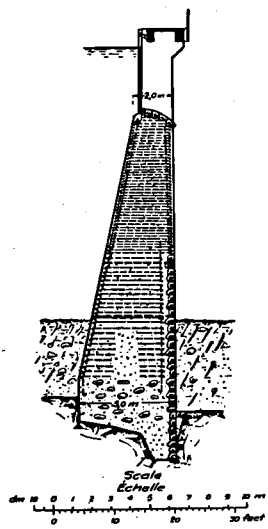


Fig. 2.

Vertical cross section through the Gideåbacka arch dam.
Coupe verticale à travers le barrage-voûte de Gideåbacka.

thickness of the arch are given, does not in the least reduce the *stresses* resulting from temperature and shrinkage. The reinforcement serves to prevent the formation of large cracks, which may threaten the stability of the dam. Should cracks occur these will be very small and evenly distributed and therefore less dangerous. The main object of the reinforcement, however, is to make it possible to reduce the thickness of the arch and thereby its rigidity, as, by making the arch less rigid, the stresses resulting from temperature and shrinkage will be reduced.

[1] F. A. Noetzli: "The Reinforced Arch Dam," *Journal of Electricity*. July 15, 1920.

In Sweden the discharge over the dam must often pass through flood openings along the crest. The water pressure against the gates is then being transmitted, through thin piers, to the arch. In cases where some of the gates are opened and some shut, the arch will be exposed to an unevenly distributed pressure, to which special attention has to be paid.

If the upstream side of the arch dam is inclined, the water pressure

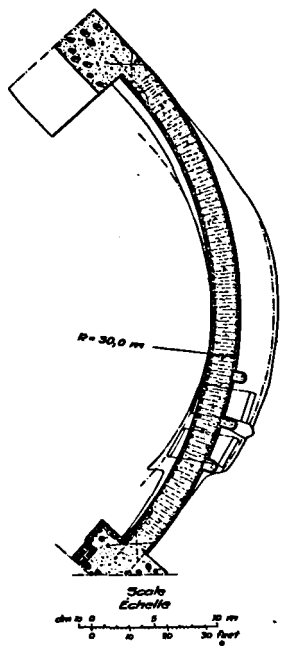
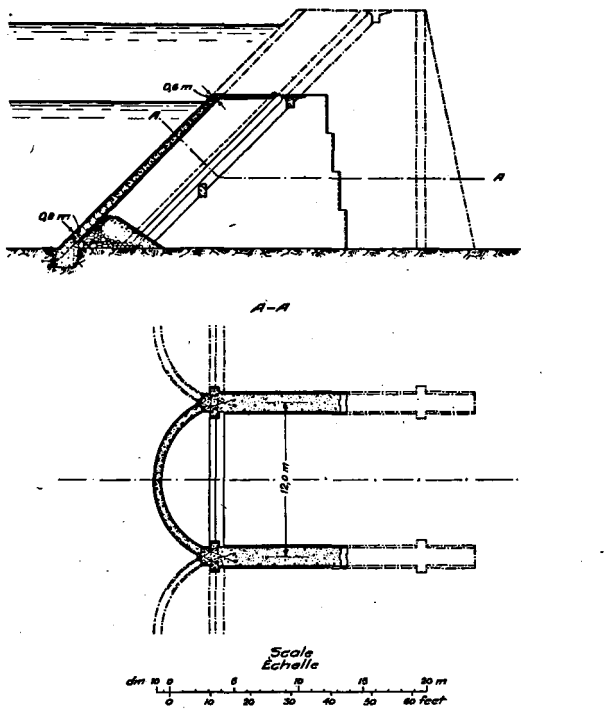


Fig. 3.
Horizontal section through the Gideåbacka arch dam.
Coupe horizontale à travers le barrage—voûte de Gideåbacka.

against the arches increases towards the abutments. Naturally, this must also be taken into account. In the design of inclined arches the weight of the structure must also be considered, as this causes considerable stresses. Owing to the transverse expansion of the concrete, attention should be paid even in vertical arch dams, to the weight, although it has but a secondary influence upon the arch stresses. In very high dams this is of special importance for the lower parts of the dam. The resulting deflection against the upstream side reduces, however, the stresses from the water pressure.

In the severe climate of northern Sweden the surface, even of

flowing water, is often frozen, and due regard must be paid to the pressure that the ice may exert against the dam. As to the magnitude of such pressure and to the means of avoiding it, the author begs to refer to the paper presented by Mr. A. Frey Samsioe entitled: "Measures taken in Sweden against ice troubles at water-power plants."[1]



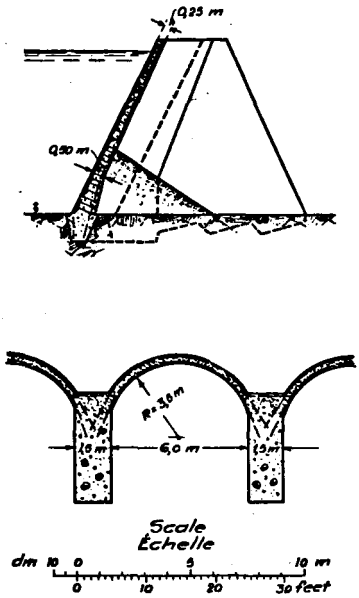
Figs. 4 and 5.
Vertical and horizontal cross sections through the Suorva multiple-arch dam.
Coupes verticales et horizontales à travers le barrage-voûte de Suorva.

As the arches are fixed in solid rock in the bottom, there will be bending stresses in a vertical direction, neutralising the arch effect at the bottom and, to some extent, even higher up in the dam. Owing to this, the dam reacts against the load by both arch and

[1] See, Transactions of W.P.C Vol. II (Water Power Production) p. 806. As may be found from that paper, an investigation of the strength and the elasticity of the ice has been made upon the initiative of the Royal Board of Swedish Waterfalls by N. Royen.

cantilever effect. In the press, several treatises will be found on this subject. Among these, the papers presented in the American Society of Civil Engineers by F. A. Noetzli and B. A. Smith should be specially mentioned.[1]

The Gideåbacka dam has a span of 40 metres (131 ft.) and a maximum height of about 26 metres (85 ft.) The radius of curvature of the upstream side changes from 30 metres (98 ft.) at the crest to 22 metres (72 ft.) at an elevation 13 metres (43 ft.) lower down.



Figs. 6 and 7.

Vertical and horizontal cross sections through the Melby multiple-arch dam.
Coupes verticales et horizontales à travers le barrage-voûte de Melby.

Below this elevation the radius is constant. A cross section and a horizontal section are shown in Figs. 2—3. In addition to flood openings at the crest, the dam has two bottom outlets, closed by stop logs, which were used during the period of construction. These outlets can be opened by pulling up or by blowing up the stop logs, in case the basin in front of the dam needs

[1] Fred A. Noetzli: Gravity and arch section in curved dams, American Society of Civil Engineers, Transaction, Vol. LXXXIV., p. 1, 1912. B. A. Smith: Arched dams, American Society of Civil Engineers, Transaction, Vol. LXXXIII., p. 2,027, 1920.

to be emptied. The thickness of the arch is 2 metres (6 ft. 7 in.) at the crest and about 5 metres (16 ft. 5 in.) at the bottom.

The concrete was made with the mixture 1 : 3 : 4, except nearest to the surface, where 1 : 2 : 2 was used. Near the upstream surface a row of vertical drain pipes have been arranged, connected at their lower ends to an outlet and at the tops left free to the air in order to avoid vacuum in the pipes.

The dam is strongly reinforced. The reinforcing steel is arranged mainly in a horizontal direction. The area of the steel amounts to at most 142 square cm. per metre of height (6·7 sq. inches per ft.) on the upstream as well as on the downstream side.

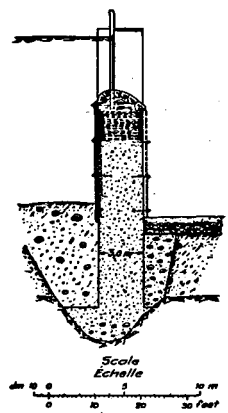


Fig. 8.
Vertical cross section through the Gullspång arch dam.
Coupe verticale à travers le barrage-voûte de Gullspång.

The Suorva dams, designed according to the multiple-arch system are erected across two branches of the Lule River in Lapland. The dams are located at about latitude 67·5° north, in a district where the winter temperature is sometimes as low as —40° to —60° C. (40° to 76° Fahr. below zero). The total lengths of the arch dams proper are 240 metres (790 ft.) and 168 metres (550 ft.) respectively. The maximum height from the bottom to the crest of the dam, in the present stage is 14 metres (46 ft.) At a future development this height will be increased by 7 metres (23 ft.) The distance between the centres of the piers is 12 metres (39 ft.) The inclination of the arches is 45° to the horizontal. Two sections of the dams are shown in Fig. 4—5. The curve of the arches—taken at right angles to the inclination—is composed of three arcs.

The thickness of the arches varies from 0·8 metres (2 ft. 7 in.) at the crest to 1·7 (5 ft. 7 in.) metres at the bottom. In order to attain sufficient rigidity in a lateral direction, the piers are provided with special reinforcement on the downstream side. On the upstream side tension members connect the piers, in order to react against the thrust from the arches during construction, and also with a view to preventing a catastrophe, should a partial break-through occur on account of some damage wilfully done to the dam.

With regard to the extreme severity of the climate in this part of the country, the arches are strongly reinforced in the direction of the generatrix as well as at right angles to that direction. The mixture of the concrete in the arches is 1 : 2·5 : 3 and in the intermediate piers about 1 : 5 : 6·5. Owing to the difficulty of supplying ordinary sand in sufficient quantities at a reasonable cost, sand obtained by crushing the rock has been used as a substitute. In the arches, however, such sand has been used to a limited extent only, about 25 to 40 per cent. of the sand in these parts being natural sand, in order to facilitate the working of the concrete. On the upstream side the arches are provided with two 10 mm. ($\frac{3}{8}$ inch) coatings (mixture 1 : 3), applied by means of cement guns.

In order to avoid excessive changes of temperature in the lowest parts of the arches, which are the most sensitive to such influence, the downstream side has been protected up to 2·5 metres (8 ft.) from the ground by a stone and earth fill, with a small open space left nearest to the arches.

The Melby dam is 78 metres (256 ft.) long and 8 metres (26 ft.) high, (see Fig. 6—7). The inclination of the arches is 2 : 1 or 63·5° to the horizontal, and the arches are strongly reinforced. There are no tension members in this dam. An intake for the penstock in the middle of the dam divides the dam into two independent parts. As a protection against great changes of temperature at the bottom, where the arches abut against rock, an earth fill has been arranged along the downstream side.

At *the Gullspång dam*, (see Fig. 8), one of the earlier arch dams in Sweden, interesting reinforcement work has recently been carried out, and it may justify a short account of this work. At the time of construction, the weather was very unfavourable and therefore some parts of the concrete in the arch did not turn out to be first class concrete. As a result, some leakage appeared in the dam, and in some parts of the concrete the cement has been gradually washed out during the last thirteen years.

Last year the work of tightening on the upstream side was carried out in the following way. A form, provided on the inside with a coat of callendrite—a kind of asphalt sheeting—was erected on the upstream side 8-12 centimetres (3 to 5 inches) from the surface of the dam. The space between this form and the dam was then filled, in water, with 1 : 1 cement mortar through pipes reaching below the level of the mortar. A considerable portion of the mortar found its way to voids and cavities in the old concrete, as could be ascertained from the fact that a far bigger amount of mortar was required than the quantity corresponding to the volume between the dam and the form and that no mortar leaked out through the form. The dam was thus made absolutely tight. It is now intended to erect a reinforced facing, 20 centimetres (8 inches) thick, covering and protecting the downstream side of the dam. In order to secure a close adherence to the old concrete, this facing is to be made in exactly the same way. The form used for the concreting will be retained as a protection against the cold.

The method of applying a coat of concrete to an old dam in the above manner has proved very successful, and the author believes that in this way many old arch dams affected with leakage and cracks may be provided not only with a suitable layer of reinforcing steel but also with a very hard and resistive facing, at quite a small expense, and without any interruption of the operation of the water power plants.

RÉSUMÉ.

Plusieurs barrages-voûtes montrent beaucoup de crevasses, sans doute causées par les efforts thermiques. Pour éviter ces crevasses on a construit les barrages arqués récents en Suède en béton fortement armé.

Dans les calculs on a considéré que le barrage supporte la poussée non seulement par la résistance des tranches arquées mais que la rigidité des éléments verticaux intervient aussi; on a observé que la loi de variation des températures dans le massif est représentée graphiquement par une ligne fortement courbée.

L'attention est appelée sur le fait que, si l'épaisseur et l'angle d'ouverture de l'arc sont fixés, l'application d'une armature ne peut pas réduire les efforts thermiques, l'armature ne servant qu'à empêcher la formation de crevasses grandes et dangereuses. Mais en employant du béton fortement armé on peut diminuer l'épaisseur de l'arc et par là les efforts thermiques.

Une description est donnée de trois barrages-voûtes suedois, ceux de Gideåbacka, Suorva et Melby.

Le vieux barrage-voûte de Gullspång a été rendu étanche par l'application d'une couche de ciment de mortier dans l'eau par une méthode spéciale.

CONSTRUCTION OF DAMS

ARTHUR POWELL DAVIS

The subject of dams is very broad, and the problems encountered in their design and construction are so complicated that such a paper as this must necessarily be confined to a limited number of generalities, in the hope of bringing out further points of interest in the discussion. It is proposed to review certain tendencies of recent practice, as compared with former practice in the design and construction of dams.

The rapid increase in the number and magnitude of such structures has developed valuable experience, and furnishes a wealth of information upon which this paper can only briefly touch; it will, therefore, be confined mainly to a summary of current practice, and especially its departure from or development of former practice.

With respect to materials of construction, dams may be divided into two principal classes, namely earthen dams and masonry dams. Intermediate types, of which the examples are much less numerous, are the rock fill dams, and the combination of earth and rock fill, through which, by insensible gradations, the earth and rock fill types are connected. Also many small dams have been built of wood, and a few of steel.

The great antiquity of irrigation is well established, and probably the first dams built by man were diversion dams to divert small streams upon their valleys for agricultural purposes. These at first were obstructions to the free flow of the water, somewhat of the type of beaver dams composed of fallen trees, brush, rock, and mud; very early also, earthen dykes were used along river banks to prevent inundation.

The earliest dams of sufficient height for storage purposes were undoubtedly of earth. Hundreds of earthen banks of great antiquity exist in India, where they form tanks for the storage of water for irrigation. Dams of wood, masonry, steel and other materials were later developments.

EARTHEN DAMS.

The type of dam most used for water storage is that constructed of earth. Storage dams of earthen type greatly exceed in number

all other types combined. The reasons for this are obviously the economy and permanency of the earthen dam.

The use of earthen dams was probably developed from the employment of dykes to prevent inundation, which were used in many parts of the world at a very early period. The design of earthen dams has been based on the application of general experience, including the use and failure of many such embankments throughout the centuries.

Recent advances in relation to earthen dams have been mainly confined to methods of construction, and adaptation of the design to such methods. The magnitude of structures of this class has, however, greatly increased.

To a great extent the design of an earthen dam must conform to the materials available for its construction. These differ widely in character from pure clay to sand and gravel, with wide variations in mixtures of such materials.

One conception of an earthen dam and probably the first employed, is a mass of materials so placed and compacted as to be as watertight as possible throughout. Where such material is not available in sufficient quantities, the watertightness has sometimes been secured by the use of a clay puddle core, supported on both sides by coarser material. Where not enough of such fine material was available for this purpose, the core was constructed of heavy masonry. This device has recently been greatly modified by using a much lighter wall of reinforced concrete. Such walls are sometimes carried only a part of the height of the dam, in order to obstruct the path of water which might percolate under the base of the dam.

It seems to have been the impression formerly that the most watertight material was pure clay puddled with water, but recent experience shows a preference for a mixture of clay, fine silt, well-graded sand and gravel, with just enough water to permit its thorough consolidation by a heavy roller.

Where only a portion of the dam is made watertight, there is a recent tendency to place this portion as near to the water slope of the dam as may be, leaving the rest of the dam as a support. It may be said that the ideal design of an earthen dam, where conditions permit, is a heavy blanket of such a mixture on the water slope, backed by coarser materials, grading very gradually from the fine silt and sand to the coarser sand, gravel and rock on the down-stream slope. The gradations should be very gradual so

that no danger of percolation of the fine materials into and through the coarse will exist.

Where ideal conditions of available material exist the tendency now seems to be to omit the masonry core unless this is required to prevent the ravages of burrowing animals.

As earthen dams far outnumber all others, it is to be expected the number of failures on such structures would exceed others, and this is true; but it is due not alone to their number, but in particular to the vulnerability of such dams, where sufficient attention has not been made to care for flood-water, and to prevent over-topping, or to prevent piping under the foundation, or along conduits, or other possible paths for percolating water. Where the dam is mostly of clay, it is necessary also to guard against sloughing. Modern experiences point strongly to the necessity of providing ample safeguards against these three menaces, and where this is done the earthen dam usually proves the most permanent form possible. In fact, it may normally be regarded as having a tendency to improve and consolidate with age.

The collection of data from the flood flow of streams under varying conditions has been widely extended of late years, and is one of the most important contributions to engineering literature, by reason of its relation to the design of storage dams and many other important functions. In the case of the earthen dam, it is especially advisable to provide a large factor of safety against over-topping, as this is one of the surest and most frequent causes of failure.

Piping is guarded against by a construction of outlet conduits or other structures, which may serve as a path for water with unyielding foundations and large and numerous cut-off collars. Where an earthen dam is founded on or near rock, it may be necessary to provide a low core wall extending some distance upward into the embankment, and if the foundation is rock of a broken and seamy character, grouting is sometimes resorted to.

Some of the more striking difficulties with earthen dams have been due to sloughing. This usually occurs when the material handled is largely of clay, which assumes a semi-liquid character when saturated with water. It is therefore an especial menace when handled by the hydraulic process. For this and other reasons it is extremely desirable to have a large admixture of sand and gravel with the clay, where economy will permit. The use of a large proportion of open material, such as sand, gravel, and rock, in the down-stream body of the dam to drain the clay blanket, is

frequently relied upon to prevent sloughing. Where the coarse material is not available, drainage pipes have been used in the lower portion of the dam.

In the case of the Belle Fourche Dam, which was built entirely of clay, chief reliance was placed upon extreme care in construction through limiting the use of water and in using a heavy traction engine for rolling, which produced satisfactory results.

Of recent years, there has been increased tendency to employ scientific processes in the experimental determination of rates of percolation through materials to be used for construction, and also, especially in the arid region, for eliminating those natural materials containing considerable proportions of soluble salts. Every dam presents its own problems, and it has been found by experience that careful and proper mixture of various quantities of earth can be made to give more satisfactory results than those usually found in nature, in regard both to percolation and stability. It has thus been demonstrated that it is practicable to construct dams of satisfactory tightness with sand, gravel, and other materials containing a very small proportion of clay.

Modern practice has virtually standardised, under ordinary conditions, the slopes of earthen dams of 3 to 1 on the water face, and 2 to 1 on the dry face, although steeper slopes have been successfully used under special conditions, especially where the down-stream portion is material coarse enough to eliminate the danger of sloughing. On the Belle Fourche Dam, composed entirely of clay, a slope was provided on the water face of 5 to 1 for a short distance at the base, then 2 to 1 to the normal water level at a full reservoir, and 1½ to 1 above the water-line. These steep slopes were adopted for reasons of economy to reduce yardage, and especially to reduce the amount of concrete paving required on the water slope. This design has been entirely successful so far as slope is concerned. The pavement was breached by waves, but this difficulty has been successfully overcome without danger to the body of the dam.

The theory that an earthen dam must be well drained to prevent sloughing was given a rather unique solution at Sherbourne Lake, in Montana, where the material readily available for construction was mainly clay. In this case a core was provided, not of masonry or puddled clay, but of screened gravel, with outlets of drain tile under the down-stream half of the dam, to furnish complete drainage to the up-stream half, and prevent saturation of the lower half. This novel device seems to work perfectly.

Earthen portions of dams are usually spread in layers of 4 to 8 inches, compacted by sprinkling and the use of heavy rollers or preferably traction engines, which concentrate the load and avoid continuous horizontal joints.

The most important recent development in methods of dam construction has been the adoption in many cases of the hydraulic method of conveyance and deposition, which has been used on works of the greatest magnitude of this character ever built, such as the Gatun Dam at Panama, and the Rimrock Dam in Washington now under construction. This method was also used in the construction of the Calaveras Dam in California, and the Necaxe Dam in Mexico. These two latter dams failed during construction, owing to the pressure of the clay interior maintained in a liquid condition by the pond on top, replenished with water by the sluicing operations. In both cases the hydrostatic pressure of the liquid clay became greater than the resistance of the dykes which had been provided, and in both cases the liquid clay forced its way out on the water slope and sloughed into the reservoir. These spectacular accidents have fixed attention upon the liquid properties of supersaturated clay, and the impossibility of its consolidation where water is continuously supplied at the top.

The uses of the hydraulic process of dam construction, and the results attainable, constitute one of the most interesting developments in the recent history of dam construction. Aside from the economy which may or may not be attached to this process, the results of its successful use are due to the skilful employment of the sorting power of water in separating heterogeneous masses of material into their constituent parts, and placing each in its proper position, and ideal results have been produced in many cases.

The largest earthen dam yet built in volume of material, though not in height, is the Gatun Dam on the Isthmus of Panama, which forms the lake constituting the summit level of the canal, and has a total height of about 106 feet, containing about 21,000,000 cubic yards of earth and rock. It has a base width up and down stream of over 2,000 feet, and thus provides slopes averaging 7 to 1 on the up-stream face, and 12 to 1 on the down-stream, the principal reason for these conservative slopes being to force a long line of travel for percolating water under the dam, where the material was considered more pervious than the hydraulic fill placed upon it. It developed under construction that with conditions presented and materials available, great difficulty would have

been encountered in building the dam by the hydraulic process on much steeper slopes than those on the upper half of the dam. This experience, together with the accidents at Necaxa and Calaveras, has emphasised the instability of undrained clay which may contain more than 50% of water, and the limitations upon this method of dam construction. The hydraulic process requires considerable skill and experience for the best results, but when successfully and skilfully employed, probably produces the most compact and watertight bank possible by any process.

A combination of methods now much employed is to place the materials of construction by means of cars or dump wagons as dykes along the upper and lower slopes of the dam, and then attack the interior slopes of these dykes with a hydraulic monitor, which washes out the fine material and carries it to the centre maintained at a lower level. The large rocks are left by the water in the dyke, the clay is washed to the centre, and the sand and gravel are deposited between these limits in graded sizes, the finest in the middle of the dam, and the coarsest near the dyke. Such methods require careful manipulation to prevent stratification and consequent zones of percolation into the centre of the dam. Such stratification as may occur is broken sometimes by boards forced into the strata and withdrawn. This is done by men wading in the pond, whose tracks in the mud also serve the same purpose. The protection of the water slope of earthen dams is sometimes secured by the deposit of coarse materials or those containing much rock upon the water slopes. Years of experience in allowing wave action upon the slope of the Conconnully Dam, formed in this manner and which has no pavement, have failed to show any notable action of the waves.

The hydraulic method is particularly valuable in cases where the quantity of clay and fine silt available for construction is very small. The water, with its sorting power, can be made to carry these to the centre, where these small quantities are placed and used to the best advantage. Here the use of other methods might necessitate the construction of a core wall. The protection of the water slope of earthen dams from the destructive action of waves is always important and often expensive, especially where rock is not at hand and cement is expensive, as at many remote localities in the West. The usual protection is a pavement of hand-laid rock, placed on a bed of gravel or broken rock. Where such rock is not available, a concrete deck is generally used, but it is noted that on the smooth facing that this affords, the waves run up the

slope much higher than on a rougher slope, thus requiring greater free board or a parapet wall. For this reason the water slope of the dam is sometimes made steeper above than below the water-line. The gravel or earthen backing behind a concrete pavement is, of course, saturated with water at and below the level of the water in the reservoir, and where high winds carry waves high up the slope, the recession of those waves leaves an unsupported hydrostatic pressure back of the pavement. Cases are known where such pressure breached the pavement, showing the back pressure to be greater than the weight of the concrete slab removed. This danger is easily obviated by making the concrete slabs of such dimensions, up and down the slope, as to possess a weight greater than any pressure that can occur back of them.

In the case of two large embankments of the Deer Flat Reservoir in Idaho, there being no rock available, and cement being costly because of transportation, an interesting experiment was tried. After finishing the embankments to the standard slopes, the tops were widened to a total of 60 to 70 feet by dumping the coarsest gravel available, which was allowed to take its own angle of repose and receive the action of the waves. These produced beaching and worked the gravel down the slope gradually, the fine silt and sand settling near the base on rather flat slopes, leaving the coarsest material on the slopes above. These banks have been in annual service about fifteen years, and the extra top width has nowhere been reduced one-half, and in some places scarcely at all. There is no prospect of extensive repairs being required for a long time to come.

The use of coarse materials for drainage purposes in the down-stream half of the earthen dam has evolved the combination of earth and rock, where an impervious bank of earth is backed by rock loosely dumped in place to form the down-stream half. This type of dam is sometimes employed where some earth is conveniently available, but not sufficient to constitute the entire structure, or the earth may be hauled from a distance in sufficient quantities where conditions permit, even though the yardage cost be high.

Where sufficient earth is not available for the making of an impervious blanket, resort is had to various other materials of construction, as lumber, masonry, or steel.

The combination of earth and rock fill requires the gradation of materials from the earth to the rock to be very gradual, so as to obviate the danger of any of the earth being washed down stream

into the interstices of the rock. The difficulty of providing gradation has in some cases led to the employment of a broad partition, to hold the earth in place during construction. The best example of this kind is the Diversion Dam at the head of the Twin Falls Canals, 90 feet high.

In early days several rock fill dams were built in the West, employing a deck of lumber on the water slope for excluding the water. These usually gave satisfaction, and recently the practice has been revived in a design for a dam of this type now under construction in Kentucky, which will be higher than any purely rock fill yet constructed, being about 270 feet high. The security of the rock fill against sloughing gives it an important advantage over the earthen dam, for dams of this great height.

In this case the water slope is made 1·2 to 1, gradually and slowly becoming steeper toward the top, where it is 1 to 1. The down-stream slope averages 1·3 to 1.

For watertightness, the up-stream slope is covered by a concrete deck laid on hand-laid stone, under the form of lumber to be left in place.

In other cases a concrete wall has been employed on the water slope, backed by a hand-laid wall of dry stone, and this in turn backed by a heavy fill of rock dumped at random. In such cases it is customary to make the water slope steep, in order to economise on concrete.

In a dam of this type built near San Diego, known as the Moreno Dam, 150 feet high, the water slope is 9 horizontal to 10 vertical for the lower 120 feet, and 1 horizontal to 2 vertical above this. The hand-packed wall is 50 feet thick at the bottom, and its up-stream face laid in mortar as rubble masonry. This dam developed bad leakage through cracks in the rubble masonry, which have been stopped by concrete facing. A rock fill dam 160 feet high on the Stanislaus River, in California, has the concrete facing reinforced. This facing has a thickness of from 36 inches at base to 9 inches at top, and is backed by a hand-laid wall of rock, in which a thickness of 2 feet next the concrete is laid in mortar. The water slope of the finished dam averages 1·1 to 1.

Near Victor, Colorado, is an example of a rock fill dam 120 feet high, which is faced with a deck of steel plates; the slope of this deck is 30° to the vertical, and the plates are riveted together through flanges along the edges, with a filler between, thus forming an expansion joint at each line of rivets.

The rock-fill type of dam has not been given due consideration until recently, but the recent successful application of this type of construction to several problems requiring very high dams, indicates its use in future to a greater extent than in the past. There are many cases where masonry dams have been constructed, or rejected after due consideration as too expensive, where a rock fill would solve the problem as well and more cheaply.

MASONRY DAMS.

The earliest masonry dams, and a large proportion of the most modern ones, depend for stability upon their weight alone. Some old Spanish and Italian dams are so heavy and the weight so disposed, as to indicate very crude conceptions of the laws of water pressure and other elements of the problem. The Gilleppe Dam in Belgium and the Vyrnwy Dam in Wales embody the idea of extreme caution and conservatism, but the weight is placed where it will secure maximum factors of safety.

All these heavy structures and many later ones seem to have been designed on assumptions of complete uplift water pressures on the entire base of the dam, or on horizontal joints, and some engineers argue that this is the true and only safe theory to employ. This assumes that there is no point of contact between the upper and lower masses forming the joint, between which the pressure is supposed to occur. Also that the water may freely enter this joint, but cannot escape on the lower side of the dam. These conditions are impossible of attainment, and could not be approximated except by special effort to do so. It is now the practice to take special precautions to prevent such uplift, by grouting the foundations, by efforts to secure the watertightness of the masonry on its water face, and by providing drainage galleries to collect and dispose of any leakage that may occur in the dam or its foundation. Notwithstanding these precautions it is customary to assume some uplift, and the addition of weight to overcome this.

The most effective means of safety against this and many other dangers, where practicable, is to give the gravity structure a curvature in plan, so that it cannot fail either by overturning or sliding, without introducing arch action, and thus transmitting the pressure to abutments. Under such conditions it cannot fail without crushing the masonry or its abutments, and this additional stability is secured without sacrificing any of its virtues due to gravity alone.

Perhaps the most notable failures of masonry dams in recent years were the Austin Dam of Texas, and another near Austin,

Pennsylvania. In both cases the foundation was upon stratified rock, with bedding planes nearly horizontal, and the failure in both cases was due to sliding on one of these natural planes below the base of the dam. The introduction of water under pressure head of the full reservoir into these horizontal joints caused sufficient uplift to overcome the sliding friction, which was probably small, owing to the presence of lubricating material like clay or talc.

In the case of the Pennsylvania dam the gorge was narrow, and security in abundance could have been obtained by curving the dam, without much additional expense. The Texas dam was much longer, so that an effective degree of curvature would have been more expensive.

Sometimes the curved form is made to economise masonry, permitting a lighter cross section than otherwise, but still retaining the theoretical gravity section, but with a smaller factor of safety in this particular.

Masonry dams arched in plan, may be divided into three classes:

1. Those depending on gravity for stability, but curved in plan to obtain greater security, against uplift or other contingencies. Examples of this kind are numerous, as the Cheesman Dam in Colorado, the Roosevelt in Arizona, the Arrowrock in Idaho, and the Don Pedro in California.

2. Those too light to depend on gravity alone, but heavier than if dependence were placed on the arch alone. Examples of this type are the Sweetwater, in California, the Shoshone and Pathfinder, in Wyoming.

3. Those depending almost wholly upon the arch form for stability. The Zola Dam, in France, and the Bear Valley, in California, were pioneers of this type, to be followed later by many others in Australia and the United States, of still bolder section, where dependence is placed upon the arch entirely. Of these, one of the boldest is one constructed in Oregon, which is one of the lightest, and is said to vary considerably from a true circle, due to defective construction, and to have had a heavy flow of water over its crest, for which it was not designed, yet it stands intact.

The effectiveness of the arch in the design of dams is inversely as the length of the radius, and in very wide canyons this radius must be so long as to make dependence upon arch action impracticable. The limit of effectiveness is usually taken as about 500 feet, though longer radii than this are sometimes employed, to increase the safety of gravity designs. Practically all dam sites are wider at

the top than at the base, and this suggests the variation of the radius, so as to employ at all elevations the shortest practicable radius. This device has been patented, and has been successfully employed on a number of high dams recently constructed. Where adapted to conditions it affords economy of yardage, and places the masonry where most effective. One of this type, 180 feet high, has been built in Switzerland, and another, 194 feet high, in South Africa.

Although light arch dams are numerous and have been much criticised, there is, as yet, no record of failure of such a dam. Many of them are striking demonstrations of the remarkable stability of the arch, and justify the expectation that the arch is to play an important part in the future of dam design.

Development in design, as illustrated by the above examples, has been accompanied by equally bold and radical development in the magnitude of structures erected. For a long time the world's record for height of dam was held by a masonry structure near Furens in France, about 172 feet in height. The Crystal Springs Dam, near San Mateo, California, about the same height, was famous as built entirely of concrete, and providing a weight to resist the upward pressure of a full head of water over the entire base.

The design and construction of the Cornell Dam, on the Croton watershed, for the New York water supply, was a long step in advance as regards magnitude and especially in respect to height, and inaugurated an era of active discussion on the design and construction of high dams that has resulted in the erection of many structures of still greater height, including both arched structures and gravity dams straight in plan.

La Grange Dam, a curved gravity structure, 100 feet high, discharging over its crest the floods of a great river, was regarded, when built, as rather bold, but still performs perfect service.

Twenty-five years later was built the Narrows Dam across the Yadkin River in North Carolina, which discharges the floods of a much larger river over its crest, which have a vertical fall of 200 feet to its toe. This great dam is nearly straight in plan. The Cheoa Dam, on the Little Tennessee, nearly as high, also discharges flood-water over its crest. It is a gravity structure, arched in plan for greater security.

An early form of diversion dam consisted of an inclined face of lumber, supported at frequent intervals by frame buttresses. A development of this in concrete has been applied to storage dams

of considerable height, and some have been built of steel. By using concrete arches instead of the deck, we have the multiple arch dam, which is one of the most important recent evolutions in dam design. Many have been built and are in successful operation in this country, one in California, recently completed, being 170 feet high. In Italy, this type is represented by several recently constructed, of considerable height, one of which recently failed, with great damage and loss of human life. The failure seems to have been due entirely to faulty construction, and should not reflected on the multiple arch type.

The Italian Government has given especial attention to multiple arch dams, and has produced several, of which one, the Zorso, is 240 feet in maximum height, and is the highest of this type yet built.

A theoretical objection sometimes raised to the multiple arch dam in cold climates, is the action of frost on the surface of thin walls, which might be considerable, where one side is exposed to the cold air, and the other confines water under high pressure. Several have been built in Northern Minnesota; and one in Sweden within the Arctic Circle. These dams should give us valuable data on this point within a few years.

Several failures of light storage dams have been recorded, sometimes accompanied by great damage to life and property, followed by a corresponding share of publicity. This has led to a growing tendency to public supervision of the design, which has generally been beneficial.

Considering the rapid development of the art in recent years, and the brief experience with some of the latest devices, we are justified in regarding the science of dam design as still in the development stage.

RÉSUMÉ.

Les barrages de détournement et de retenue ont été employés depuis une époque très éloignée. Leur utilisation s'est multipliée dans ces dernières années et leur construction est à présent une des branches importantes dans l'art du Génie Civil.

Il y a eu une évolution rapide dans les méthodes de construction des barrages de terre, dans le calcul des barrages de maçonnerie, évolution qui se poursuit encore.

Le traitement de la terre par le procédé hydraulique et l'application, dans les barrages de maçonnerie, du principe de l'arc, sont les modifications les plus intéressantes de ces dernières années.

Il faut noter tout spécialement le retour au type de gravité, dans les cas où l'emplacement y est favorable.

THE HYDRAULIC REACTION TURBINE

H. BIRCHARD TAYLOR,* M.A.S.M.E., M.S.N.A.M.E.

This paper will endeavour to set forth the outstanding features of American practice in the field of the hydraulic reaction turbine and to outline the recent progress in the development of this type of turbine in America. In treating this subject, the development of the integral parts of the turbine, such as the casing, draft tube, type of settings and the runners will be discussed as will numerous special features and turbine auxiliaries.

TURBINE ARRANGEMENT.

One of the most pronounced characteristics of American practice has been the adoption of the vertical shaft single runner type of turbine. This type has become practically standard for both high and low heads and for all except very small units. Its simplicity in design, economy of space and superior hydraulic conditions has resulted in its adoption in preference to the general practice of the preceding stage of development which featured the horizontal and multiple runner units. The only large installations in which horizontal shaft turbines have been installed within the past ten years or more have been in plants containing existing foundations for future horizontal units where the change to the vertical type would have involved unwarranted expense in alterations in the powerhouse structure. The one exception to this practice has been for turbines directly connected to pulp grinders in paper mills where the horizontal shaft arrangement is necessarily required.

It is interesting to note that even in plants containing existing settings for horizontal units, there have been a number of cases where the station substructure has been rebuilt to permit of installation of vertical shaft single runner units.

One of the most striking features resulting from the use of the vertical shaft single runner arrangement has been its effect upon the

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President —Pelton Water Wheel Company.
President —Harper & Taylor, Inc.
Vice-President—American Society of Mechanical Engineers.

powerhouse design. For example, a marked improvement has been made by incorporating the turbine as an integral part of the powerhouse structure, the metal casings of the turbines of high or medium head plants being embedded in the concrete; and the water passages in low head plants being moulded directly in the concrete. The units are closely spaced with as little distance between casings and between draft tubes as the structural strength of the intervening walls will permit; and the vertical distance from turbine to the generator is made a minimum, leaving only sufficient head room in the turbine pit for convenience of access or for removal of the bearings without the necessity of dismantling the generator. The weight of the generator is carried vertically downward through the solid concrete surrounding the turbine pit and thence to the foundation through stay vanes or the speed ring in case of concrete and plate steel casings, or a combination of stay vanes and cast steel or cast iron casings for higher head turbines. With this arrangement is sometimes incorporated a cast iron pit liner or generator supporting ring which serves to transmit the weight of the generator to the stay vanes in the same manner as the superimposed concrete supports.

The practice of surrounding the turbine casing with concrete and incorporating it as an integral part of the powerhouse structure, is directly opposed to that frequently seen in Europe, where the turbine casing is exposed on all sides except at the bottom and is set in an open chamber which is bridged over by an arch or beam construction supported at points outside of the turbine casing to carry the weight of the generator. The American type of setting ensures great rigidity of structure and freedom from vibration and at the same time secures compactness and minimum dimensions of both powerhouse and substructure. These and many other features can best be described by reference to particular installations, a number of which will be shown as typifying the present stage of development in America.

The most representative example of present practice in the field of American Hydraulic engineering is the design of the 70,000 horsepower turbines for the Station 3-C Extension of the Niagara Falls Power Company. The older portion of this station (Station 3-A) consists of thirteen 10,000 horsepower, horizontal shaft, double runner turbines, the installation of which commenced in 1907, with additional units added at intervals until 1914. In enlarging the

station in 1918 and 1919 (Station 3-B), the horizontal shaft arrangement was abandoned and three vertical shaft single runner turbines rated at 37,500 horsepower were installed. At that time these turbines were the largest in capacity in the world; and in tests of unusual accuracy they exceeded all expectations in regard to performance and efficiency. In Station 3-C, which is now nearing completion, three new 70,000 horsepower units are installed, establishing a new world's record for size and capacity. Figure 1 shows a sectional

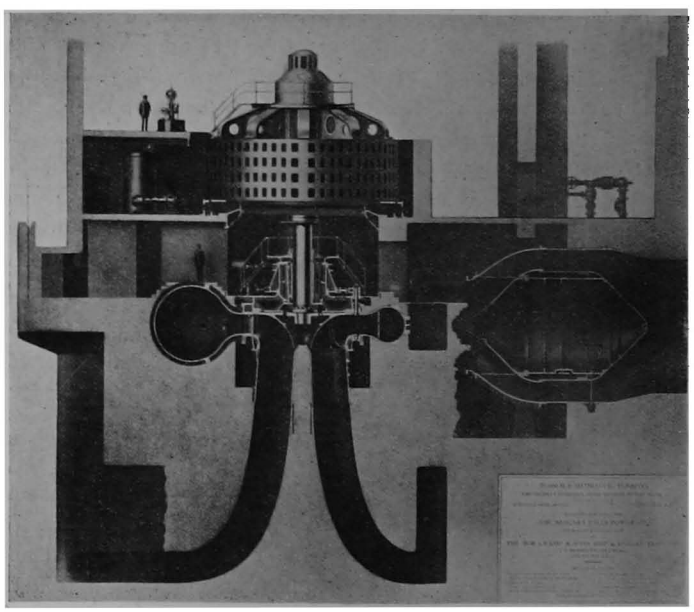


Fig. 1.

Sectional elevation of one of the 70,000 horse-power turbines of the Niagara Falls Power Company. (I. P. Morris).

arrangement of one of the two I. P. Morris turbines in this latter plant, and Figure 2 shows the unit constructed by the Allis-Chalmers Manufacturing Company. In the first two units, the casings are of the cast steel sectional type with stay vanes cast integrally, the generator being supported directly by the concrete substructure of the powerhouse without requiring a metal pit liner. In the third unit the turbine casing is of plate steel and a cast iron pit liner forms the supporting barrel for the generator carrying the weight to the

turbine speed ring and thence to the foundation. In both instances, it will be noted that the weight of the generator is carried through the turbine itself.

TURBINE CASING.

In recent years the turbine casing has been given an increasing amount of attention and material progress has been made in this portion of the design. Except for very low heads the volute or spiral casing is standard practice and even with very low heads

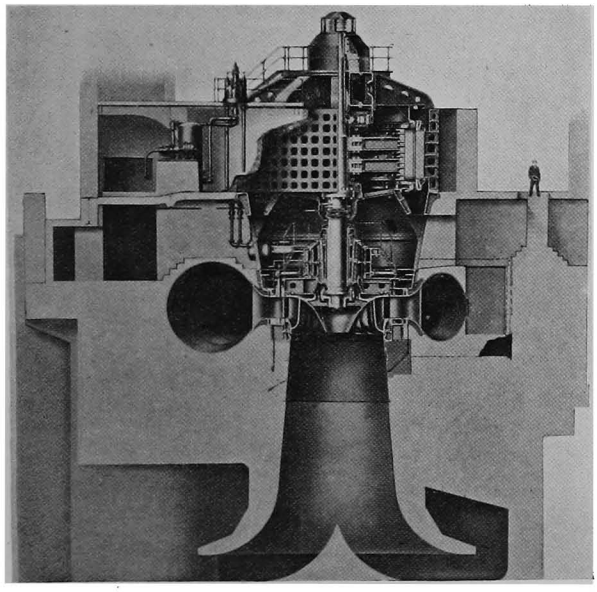


Fig. 2.

Sectional elevation of the 70,000 horse-power turbine for the Niagara Falls Power Company. (Allis-Chalmers).

various approximations to the spiral casing are used. By referring to Figure 3 the various types of casings may be noted, ranging from the open flume type for very low heads to the cast steel casing for the highest heads to which the reaction turbine is applied. The open flume type (3a) may consist merely of a rectangular water passage with the turbine placed therein. However, a modification is shown in the second arrangement (3b) where an attempt has been made to direct the water to the turbine in a more efficient manner by

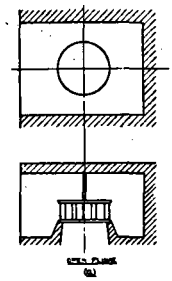


Fig. 3a.

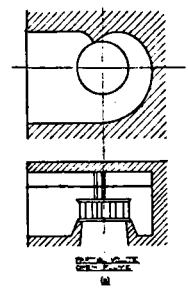


Fig. 3b.

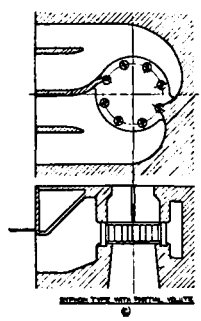


Fig. 3c.

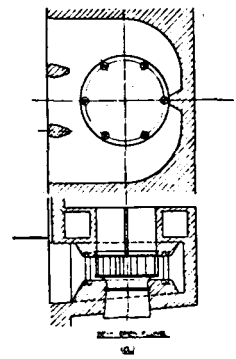


Fig. 3d.

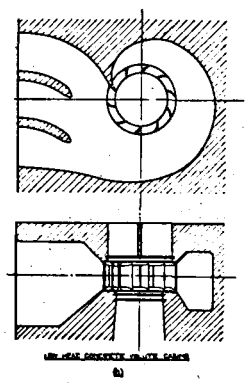


Fig. 3e.

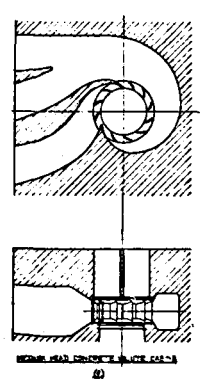


Fig. 3f.

Casing design. Figures 3a. b, c, d, e, f.

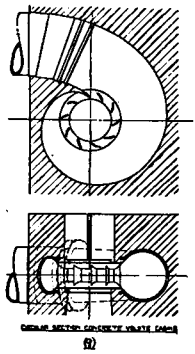


Fig. 3g.

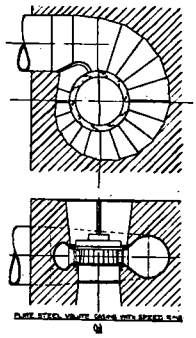


Fig. 3h.

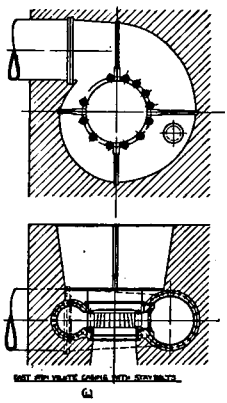


Fig. 3i.

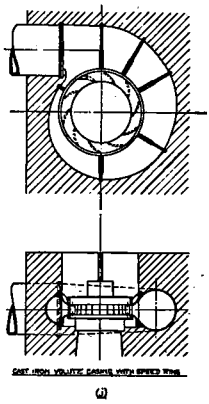


Fig. 3j.

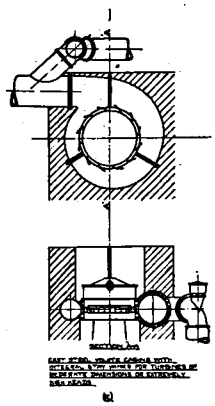


Fig. 3k.

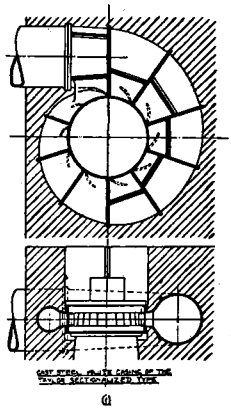


Fig. 3l.

Casing design. Figures 3g, h, i, j, k, l.

the use of a partial volute. In several instances under extremely low heads there is not sufficient vertical space below headwater to submerge the turbine properly without expensive excavation in the tail race, and for this condition a syphon setting is employed as shown in the (3c) illustration. As the head increases, the water passages may be completely enclosed and the volute type of concrete casing (3e, 3f) becomes the normal practice.

The speed ring or stay vane ring is used in connection with various types of casings to serve as a support for the generator and at the

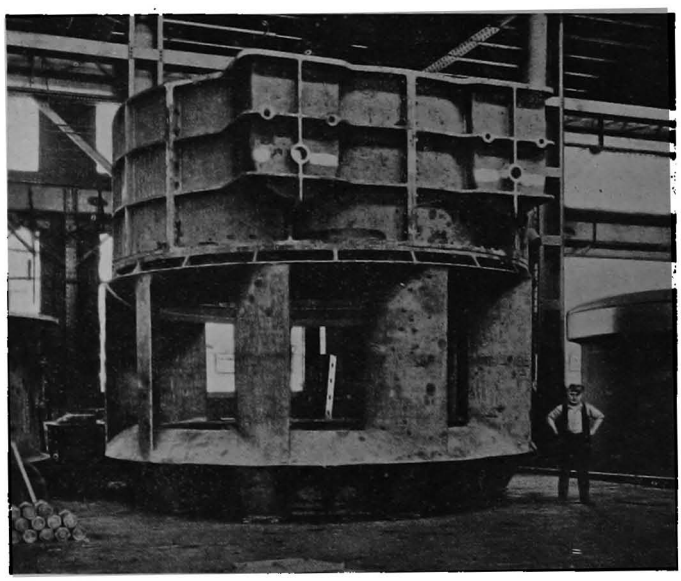


Fig. 5.

Speed ring and pit liner for 20,000 horse-power turbine for the Pennsylvania Water & Power Co. (I. P. Morris).

same time to direct the flow effectively. Figure 3 (e and f) illustrates this arrangement, and Figure 5 shows a shop assembly of the speed ring and pit liner for use in connection with the concrete casing of the 20,000 horsepower units of the Pennsylvania Water and Power Company at Holtwood, Pennsylvania.

In low head installations where concrete casings are used, the stay vanes are sometimes cast separately and set independently in the concrete rather than being formed in a continuous ring as is the usual method for higher heads. This results in considerable saving

in the metal required for the turbine with a consequent reduction in cost. In recent installations for the Manitoba Power Company, the St. Maurice Power Company, the Moreau Manufacturing Company and in the plant for Henry Ford & Son at Green Island, this construction has been used. Figure 4 shows a shop view of several of these vanes for the Moreau Manufacturing Company, the arrangement of which is shown in Figure 3 (d).

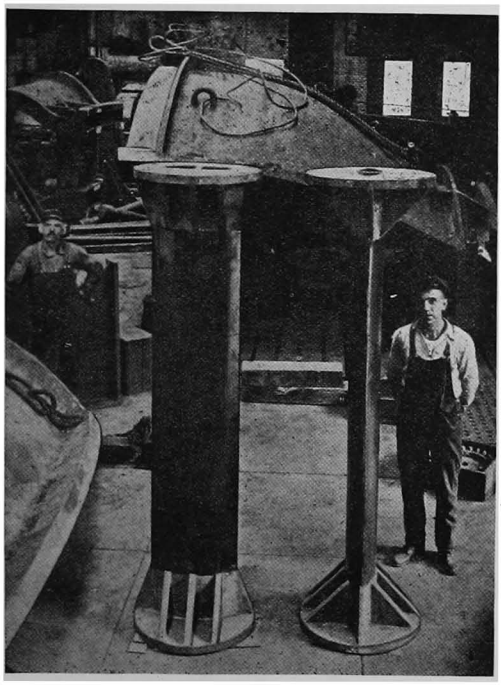


Fig. 4.
Separate stay vanes for Moreau Manufacturing Company turbines.
(I. P. Morris).

Where the head is too high for the economical use of the standard form of concrete casing, and where the plate steel type may prove expensive, an intermediate form recently developed may be used where the turbine casing is connected to a plate steel penstock. The casing has a circular section and is formed in the concrete, the reinforcing rods being made of similar shape and connected to the

speed ring directly as shown in Figure 3 (g). As the head further increases the plate steel type becomes the preferred practice. Figure 3 (h) shows such a casing used in connection with a speed ring similar to those employed with the concrete type of casing except that an additional flange is provided to which the plate steel casing is riveted.

It will be interesting to note several views of plate steel casings under construction such as the one for the 70,000 horsepower Allis-Chalmers unit for the Niagara Falls Power Company shown in

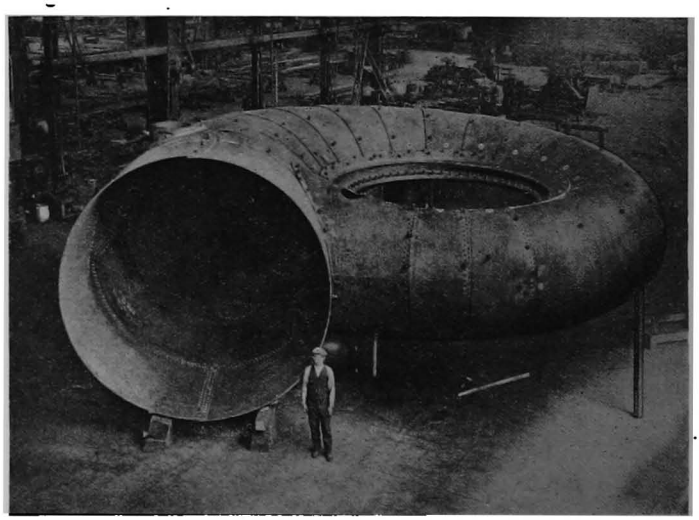


Fig. 6.

Plate steel casing for 11,000 horse-power turbine for the Clarion River Power Co. (I. P. Morris).

Figure 7, and the casing for the 11,000 horsepower I. P. Morris turbine built for the Clarion River Power Company shown in Figure 6.

The cast iron volute casing is very generally used for medium heads, and when low velocities of flow are used stay bolts may be employed to tie together the sides of the casing near the entrance to the guide vanes. Figure 3 (i) illustrates this type of construction. The cast iron casing is more generally employed, however, in connection with a speed ring as shown in Figure 3 (j). For extremely high heads, where greater strength is required, the cast steel casing is used. Figure 3 (k) shows a casing for use under very high heads

—in this case, nearly 700 feet. The stay vanes instead of being formed in a separate ring bolted to the casing, are cast integrally with the casing, thus giving it additional rigidity and simplifying the design. It will also be noted that the intake section of the casing shown is equipped with a relief valve to prevent excessive pressure rise due to the rapid closure of the guide vanes. The speed ring type of construction with cast steel casings is also employed as shown in Figure 8, a 40,000 horsepower turbine for the Skagit River Development of the City of Seattle which is to operate under a head of 375 feet. This unit is one of two built by the S. Morgan Smith Company.

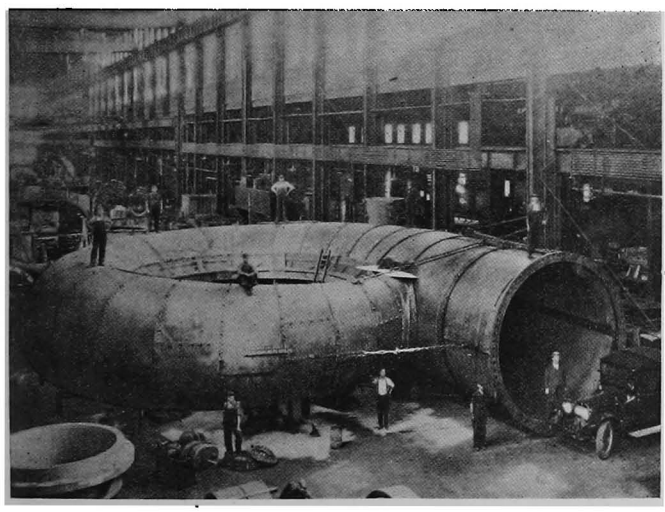


Fig. 7.
Plate steel casing for the 70,000 horse-power turbine.
(Allis-Chalmers).

In a number of large and important installations a new type of construction, developed by the author, Figure 3 (l) has been used for cast casings. This construction was employed in the 41,000 horsepower turbines for the Shawinigan Water and Power Company, the 55,000 and 58,000 horsepower turbines for the Niagara plant of the Hydro-Electric Power Commission of Ontario, and for the two 70,000 horsepower turbines of the Niagara Falls Power Company furnished by the Cramp Company. This construction involves the division of the casing into a considerable number of radial sections

separated by planes containing the turbine axis. The larger sections are further subdivided by planes which in turn divide them into two or more sections. The smaller radial sections and the inner subdivisions of the larger sections contain the stay vanes which are cast integrally with the upper and lower casing walls.

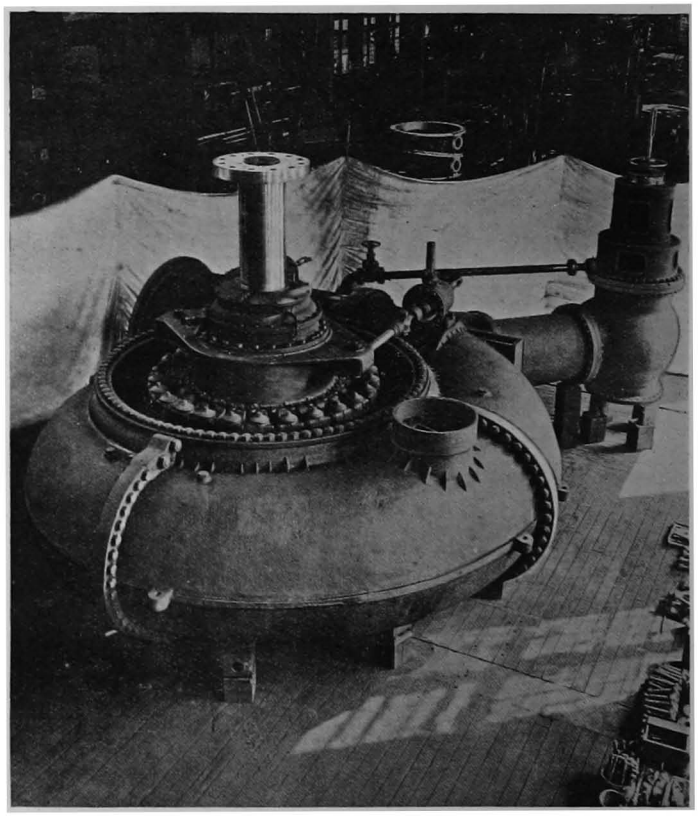


Fig. 8.

40,000 horse-power turbine for the City of Seattle. (S. Morgan Smith Co).

This construction avoids the necessity for using a separate speed ring or stay vane ring and simplifies the casing construction, and also provides a more rigid structure which is free from distortion and effectively avoids leakage at the joints. These features are clearly shown by construction views of the 70,000 horsepower casing in Figures 9 and 10.

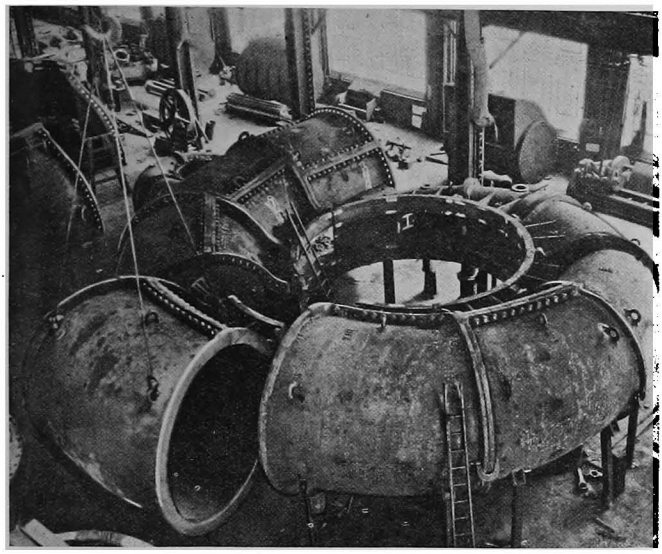


Fig. 9.
Cast steel casing for 70,000 horse-power turbine erected in the shop.
(I. P. Morris).

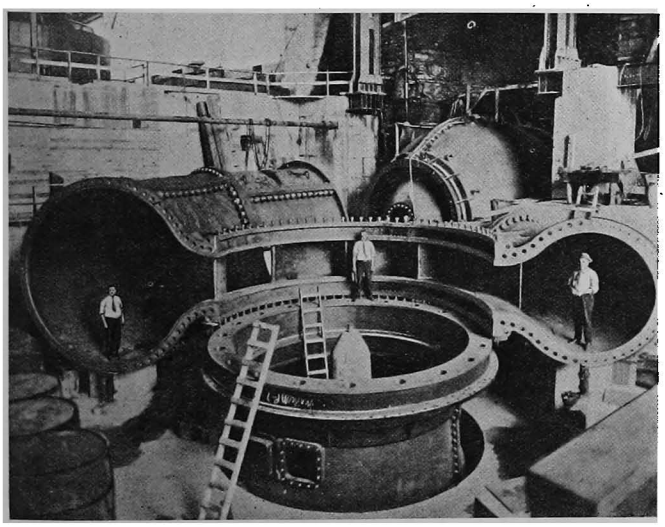


Fig. 10.
Cast steel casing for 70,000 horse-power turbine partially erected in the field. (I. P. Morris).

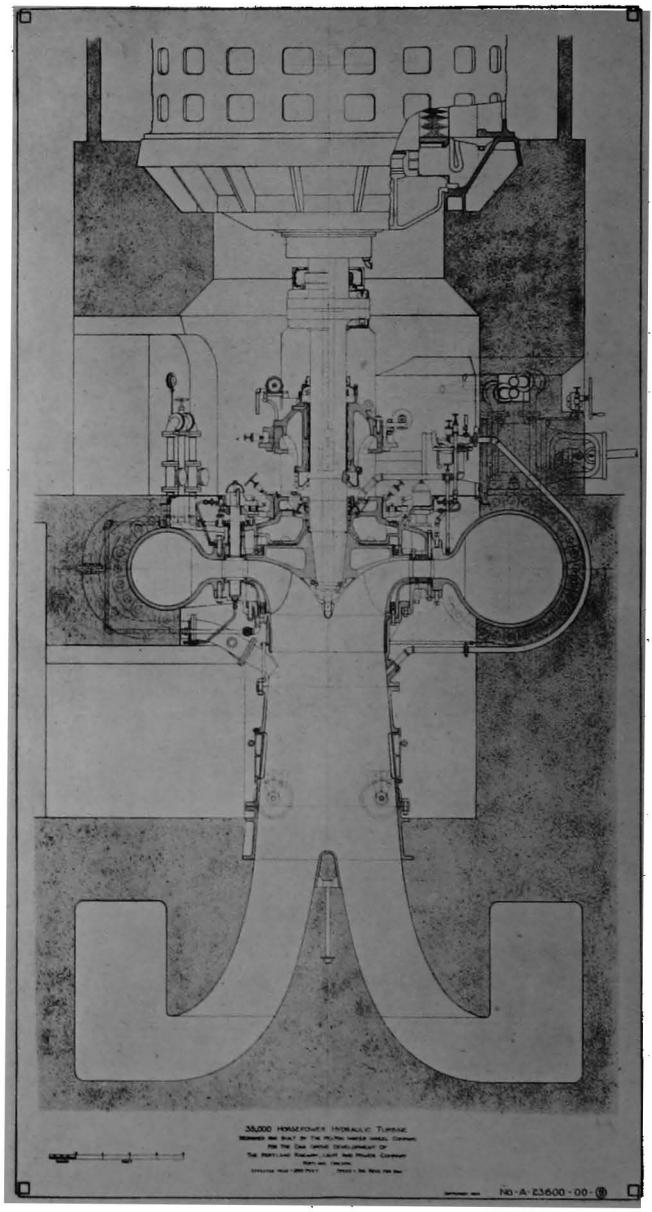


Fig. 11.
Sectional elevation of 35,000 horse-power turbine for Portland Railway Light & Power Co. (Pelton Water Wheel Company).

THE TURBINE PROPER.

The design of the turbine itself has recently undergone a number of improvements and its range of application has been extended to heads greatly in excess of those formerly considered suitable for the reaction turbine. The most recent example is the 35,000 horsepower reaction turbine now being constructed for the Oak Grove Development of the Portland Railway, Light and Power Company. This turbine is designed to operate under a normal head of 857 feet but will be subjected to pressures ranging from 850 to 930 feet. It

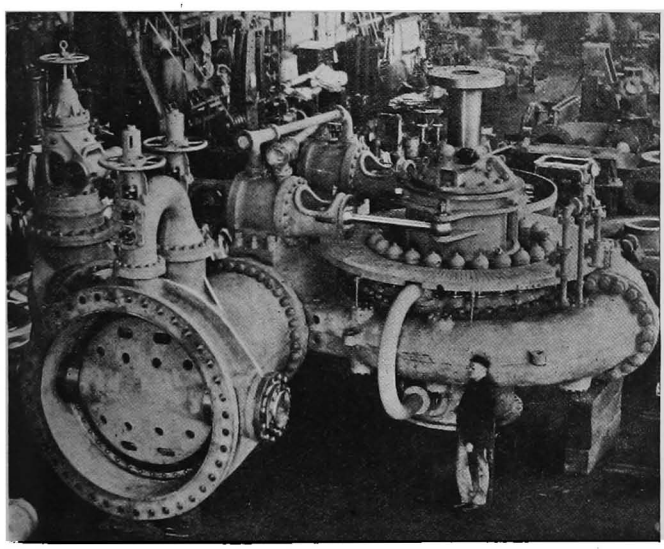


Fig. 12.
35,000 horse-power turbine for Portland Railway Light & Power Company, erected in the shop. (Pelton Water Wheel Company)

is believed that this unit is the highest head reaction turbine ever undertaken. Figure 11 shows a sectional elevation of the turbine and Figure 12 is a photograph of the complete turbine assembled in the shop of the Pelton Water Wheel Company before shipment. Two turbines of 25,000 horsepower each, in the Kern River No. 3 Plant of the Southern California Edison Company are believed to be the highest head reaction turbines now in actual service. The head under which these units operate varies from 780 to 820 feet. Figure 14 illustrates the sectional arrangement of the powerhouse

and Figure 13 is a shop view of the completed turbine assembled before shipment. These units also were designed and built by the Pelton Water Wheel Company.

In the field of low head installations the hydraulic turbine has undergone radical development as illustrated by the rapid adoption of the propeller type turbine of extremely high specific speed. The progress made in the introduction of this type of unit in actual installations in America and the improvements which have been effected in its design are particularly noteworthy. The outstanding

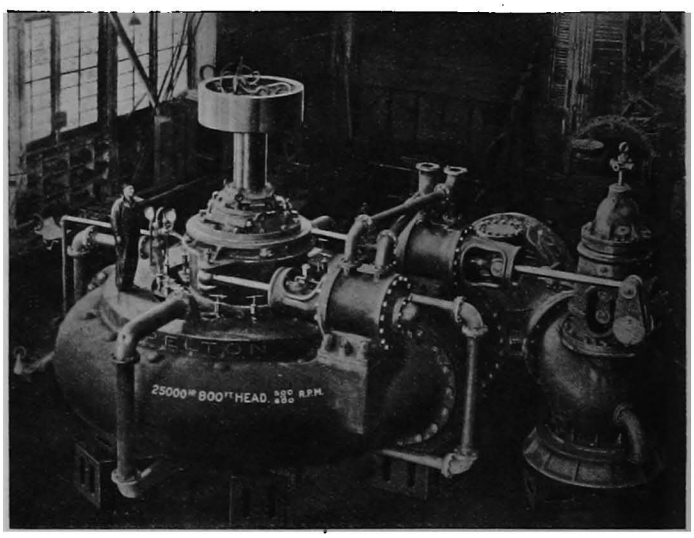


Fig. 13.

5,000 horse-power turbine for Southern California Edison Company erected in shop. (Pelton Water Wheel Co).

installation of this type of turbine is the Great Falls Plant of the Manitoba Power Company. The turbines are designed for 28,000 horsepower capacity under a head of 56 ft. and are equipped with the Moody Diagonal Propeller Type Runner of a specific speed of 154 (684 metric). These units have been in successful operation for over a year under heads varying from 18 ft., existing when construction was still in progress, to 50 ft. following the completion of the dam, and the excellence of their operation under these heads is a strong confirmation of the theoretical development and research

underlying the design of this type of turbine in America. Figure 15 shows the runner for one of these units.

Another notable installation of the propeller type turbine is represented by the Green Island Plant of Henry Ford & Son, in which the Nagler type of runner, operating under a head of 13 ft., has been installed. Figure 18 is a photograph of this runner in the shops of the Allis-Chalmers Manufacturing Company. The Nagler type of high speed propeller runner has been used in a large number

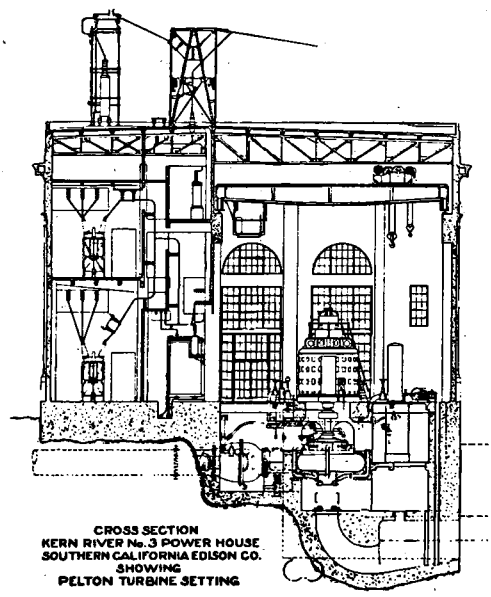


Fig. 14.

25,000 horse-power turbine for Southern California Edison Company, sectional elevation. (Pelton Water Wheel Company).

of installations starting as early as 1916. Their aggregate installed capacity is about 77,500 horsepower in a total of seventy-seven units ranging from 40 horsepower to 2,750 horsepower each. The Moody Diagonal Propeller Type runner has been used in a total of twenty units ranging from 350 horsepower to 30,000 horsepower each, and having an aggregate capacity of 200,000 horsepower.

Some of the most notable developments using the Moody propeller type turbine, which have been built by the I. P. Morris Depart-

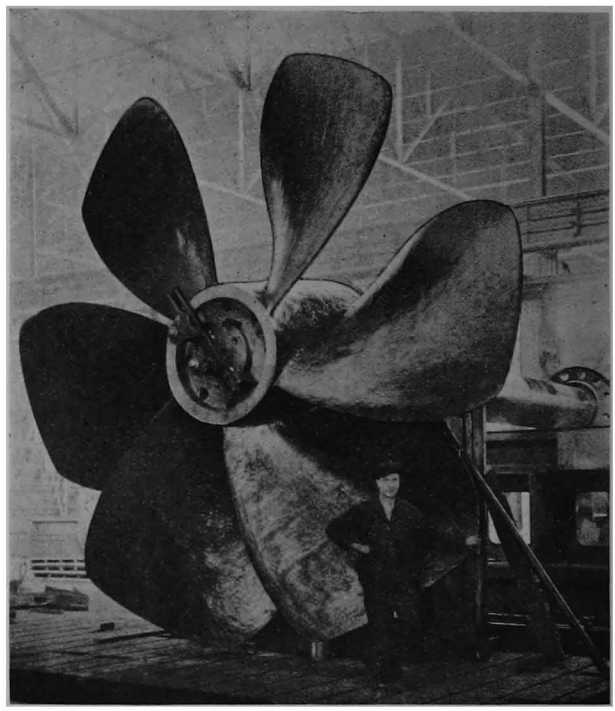


Fig. 15.

Moody high-speed diagonal flow propeller runner for 28,000 horse-power turbines of Manitoba Power Company.

ment of the Cramp Company and by their Canadian Licensees, the Dominion Engineering Works, Ltd., are listed below:

Four—1,500 horsepower turbines for the Anson Plant of the Great Northern Paper Company, operating under a head of 20 ft. Figure 22 is a photograph of the interior of the completed power house. Built by The Wm. Cramp & Sons Ship & Engine Building Co.

Four—30,000 horsepower turbines for the St. Maurice Power Co., operating under a head of 60 ft. A sectional elevation of these turbines, which are similar to the units furnished for the Manitoba Power Co., is shown in Figure 16.

Five—1,500 horsepower turbines for the Feeder Dam Development of the Moreau Manufacturing Company on the Hudson River, near Glens Falls, N.Y., which operate under 15.5 ft. head.

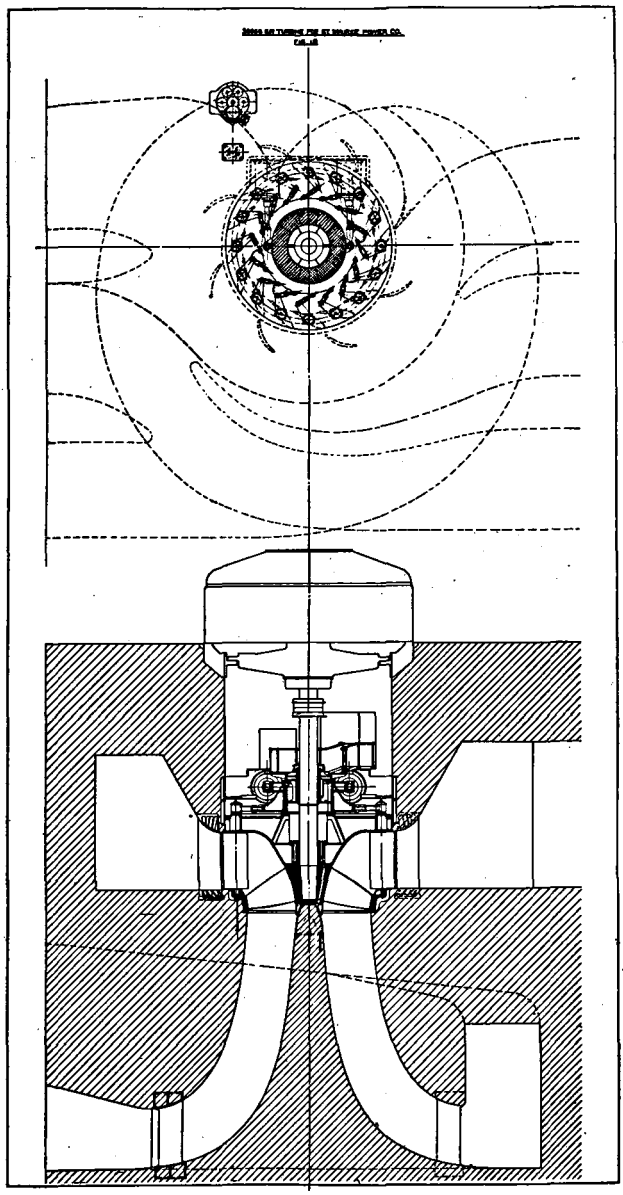


Fig. 16.

Sectional elevation and plan of 30,000 horse-power I. P. Morris turbines for the St. Maurice Power Company.

One—2,500 horsepower turbine for the Spruce Falls Company, Lt operating under 30 ft. head. This turbine was built by t Dominion Engineering Works, Ltd., of Montreal.

One—1,400 horsepower turbine for the Dryden Paper Company, operati under 29 ft. head. Also built by the Dominion Engineering Worl Ltd., of Montreal.

One—3,200 horsepower turbine for the Roanoke Rapids Power C operating under 30 ft. head. This unit is being built by the W Cramp & Sons Ship & Engine Building Company.

In the field of medium heads where the reaction turbine has be most frequently applied in the past, numerous improvements ha been effected. The most recent example of improved practice

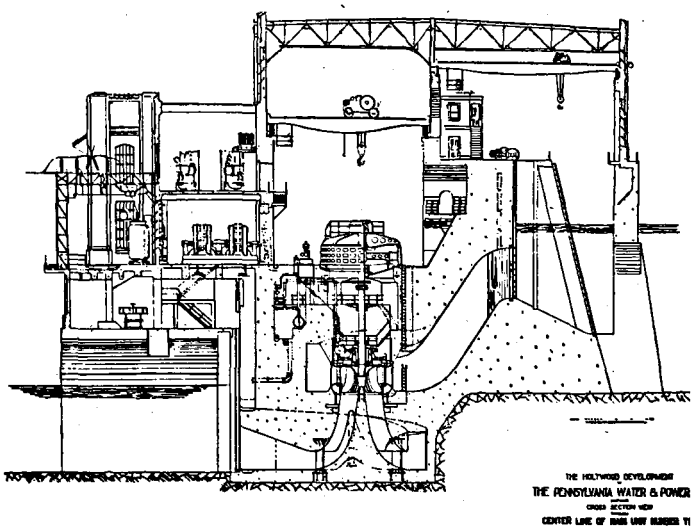


Fig. 17.

Transverse section of power-house showing 20,000 horse-power turbines : Pennsylvania Water & Power Co. (I. P. Morris)

this connection is in the 20,000 horsepower turbine recently i stalled in the Holtwood Plant of the Pennsylvania Water a Power Company, on the Susquehanna River. Incidentally, tl plant illustrates to a large extent the rapid development of tl type of turbine in America. Starting in 1907 with five units of t vertical shaft, open flume, two-runner design, in 1914 a unit larger capacity of the vertical shaft single runner type was installe and just recently the two new 20,000 horsepower turbines referr to above have been placed in operation. Each of these latter tu bines has been installed in the space originally intended for a 13,5 horsepower two-runner unit, which necessitated a considera

amount of alteration to the powerhouse substructure. These turbines are equipped with volute casings and a Moody spreading draft tube with a spiral form of discharge passage. Figure 17, a sectional view of the powerhouse, shows the arrangement of this unit.

Further details of the draft tube arrangement may be noted in illustration 23 (i). The runner for this unit is of very large size, as

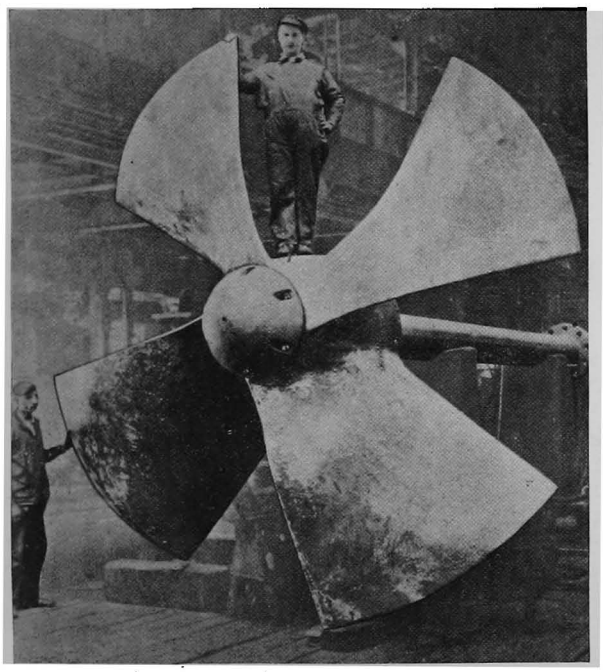


Fig. 18.
Nagler propeller type runner for 2,000 horse-power turbines for Henry Ford and Son.

may be seen from Figure 19, a photograph of this runner on the balancing stand in the shops of the builder.

In another large project which has recently been completed, are the two latest plants of the Southern Power Company, with an aggregate capacity of 170,000 horsepower. The seven turbines for these developments were built by the S. Morgan Smith Company and are of the vertical shaft, concrete casing type. Figure

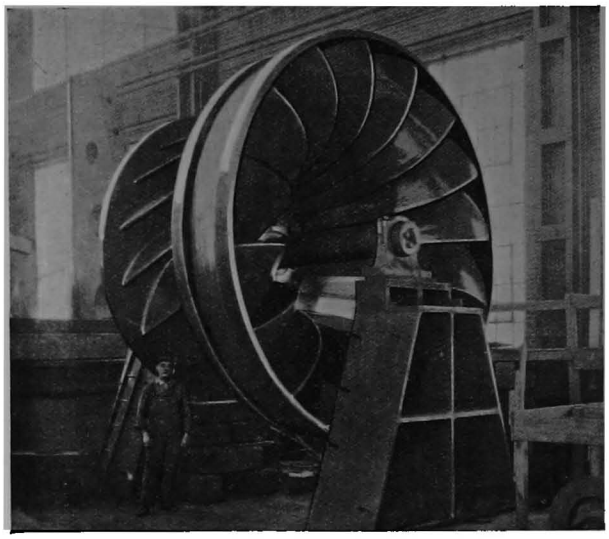


Fig. 19.
Turbine runner for 20,000 horse-power turbine for Pennsylvania Water and Power Co.

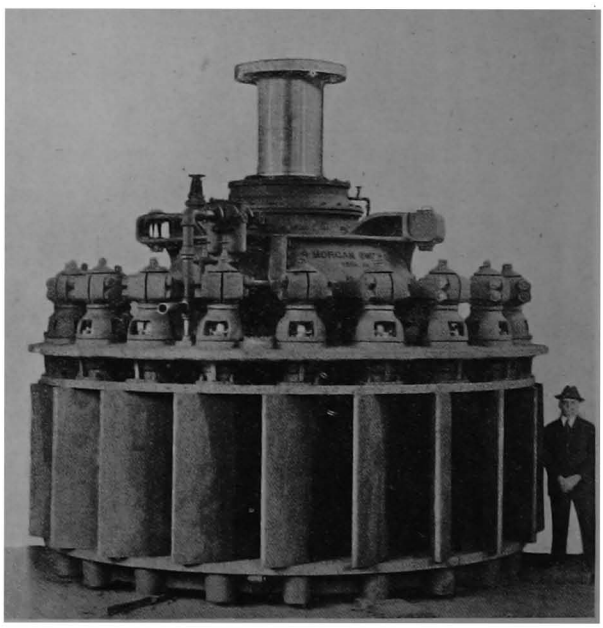


Fig. 20.
One of seven turbines for Southern Power Co., built by S. Morgan Smith Co.

20 is a photograph of the turbine erected in the shops before shipment.

The application of the Francis turbine to specific speeds approaching the propeller type turbine is shown in Figure 21, which illustrates a low head concrete casing type of turbine, and its runner of a specific speed of 110 (490 metric).

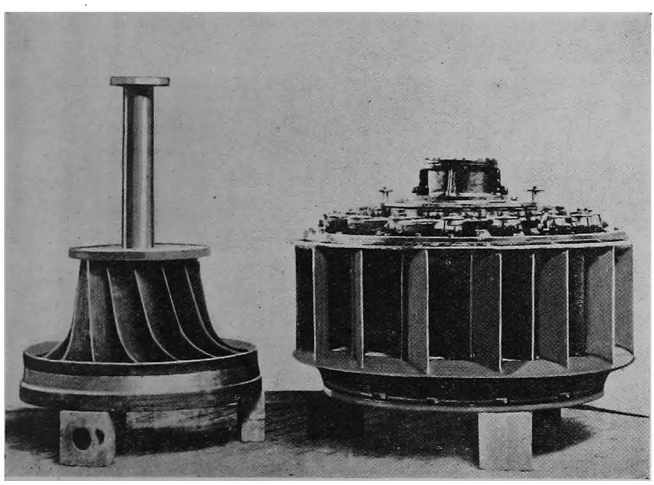


Fig. 21.

High speed Francis type turbine, built by S. Morgan Smith Co.

In the field of low and moderate heads, The James Leffel & Company, of Springfield, Ohio, has developed a series of standardized runners of the Francis type which may be economically applied to installations of small and medium size. These runners have given very good results in the Holyoke testing flume, as shown by the following data. Type " F " runner having a specific speed of 75 (334 metric), attained an efficiency of 93 per cent.; type "Z" runner, specific speed 105 (466 metric) gave an efficiency of 92.3 per cent., while recently a modification of the type "Z" runner has been developed with a specific speed of 176.5 (784 metric) and an efficiency of 89 per cent.

THE DRAFT TUBE.

Among the improvements in the various turbine elements which have been effected in recent years, perhaps none has been more pronounced than the transformation which the draft tube has undergone. The development of the draft tube is best shown by Figure 23, in which various types are illustrated. In this Figure (a) is the primitive form of draft tube, the walls being cylindrical and without any particular relation between the area of the draft tube and that of the runner discharge opening. At the time when such tubes were used their only purpose was to permit the location

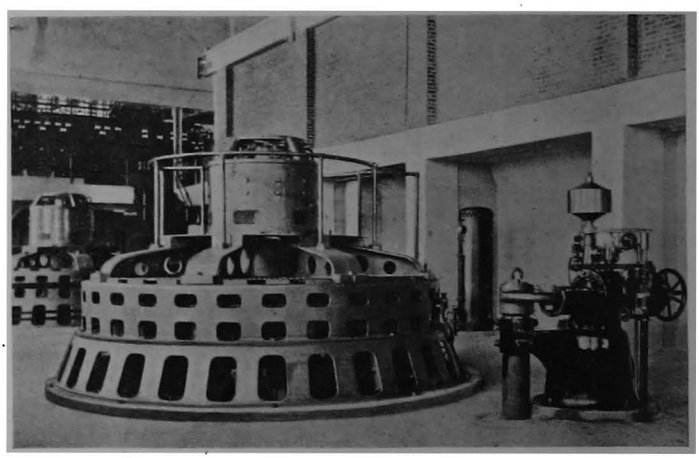


Fig. 22.

Interior view of completed power-house, Anson Plant, Great Northern Paper Company.

of the runner above the tail water surface and to conserve the static head represented by the difference in level between the runner and the surface of tail water. It is evident that such a tube did not regain any of the kinetic energy of the water leaving the runner.

The second state of development is shown as (b) differing only from (a) in having a gradually increasing area which serves the purpose of conserving the static draft head and also regains a considerable portion of the energy represented by the meridian component of flow; that is, the component parallel to the axis. In addition to this meridian component, a small portion of the tangential or whirl component of the flow was also regained, due to the

slight increase in diameter of the tube from the runner to the end of the tube. However, such a tube requires a small angle of flare in order to reconvert efficiently the kinetic energy of flow and therefore requires a great length in order to reduce the velocity to a sufficiently low value. As a result, the excavation required to accommodate such a tube was not practical except for wheels of small size, and even when space permitted its installation, it did not regain a sufficiently large portion of the velocity head of whirl to give the highest attainable results in the turbine.

From this stage draft tubes have developed to meet the requirements of the modern plant and of the vertical shaft single runner arrangement. This type of unit requires essentially the turning through 90 degrees of the discharge water from the turbine, and in order to meet this requirement, three different types have been developed. The first, Class I., the so-called elbow type draft tube; the second, Class II., the White Hydraucone; and the third, Class III., the Moody Spreading Draft Tube. Referring again to Figure 23, the first class is shown as (c) and (d) respectively, (c) being the common form designed with increasing area with the intention of regaining the kinetic energy of the water discharged from the runner. But since the actual lines of flow do not coincide with the walls of the tube as usually designed, it is ineffective as to this function. A still more serious defect is the inability of such a tube to handle the whirl or tangential component of the velocity of discharge from the runner, and therefore these tubes, even in their improved forms, are inefficient except in cases where the whirl component of flow is small.

Applying this elbow type of tube to units of high specific speed which involve a greater amount of energy in both meridian and whirl components of flow, it becomes quite apparent that such a form of tube does not regain the energy of the whirl, because the curvature of the tube is out of line with the direction of the whirling stream from the runner, which causes induced losses to be set up in the lower parts of the tube and permits the whirl to destroy the effective reconversion of the meridian component.

The real problem, therefore, in any draft tube involves not only the question of conserving the energy of whirl, but of preventing this whirl from creating induced losses. In the United States this problem has been met by the development of two types of draft tubes which have come into great prominence, namely : Class II.—the White Hydraucone illustrated by Figure 23 (e) and (f); and

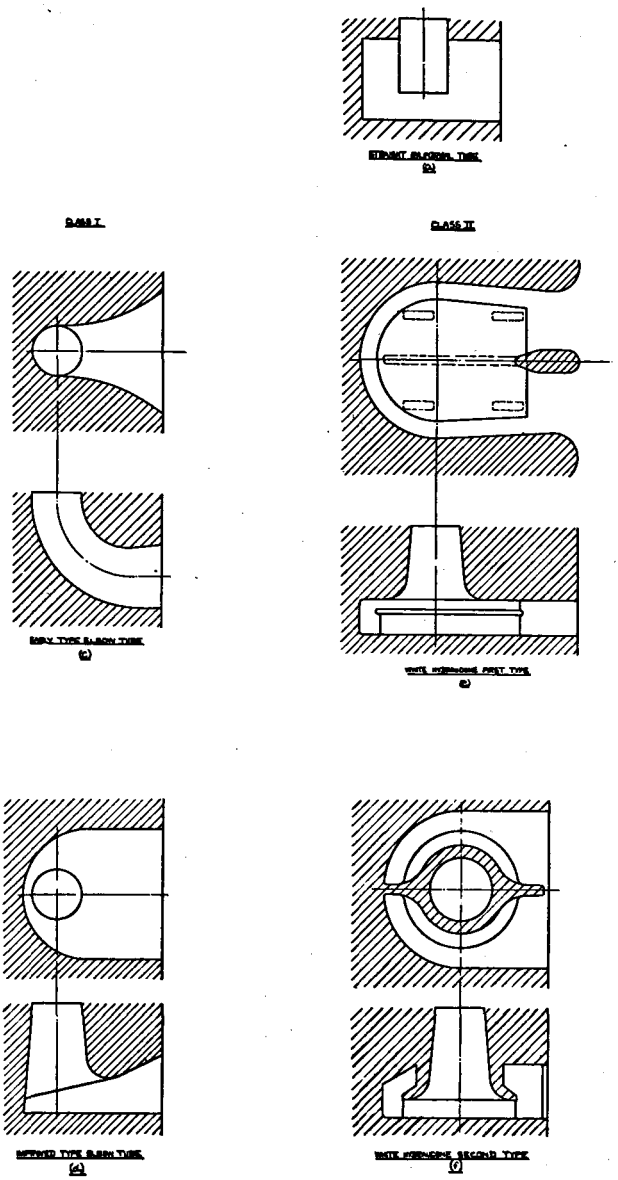


Fig. 23.

Draft tube design.

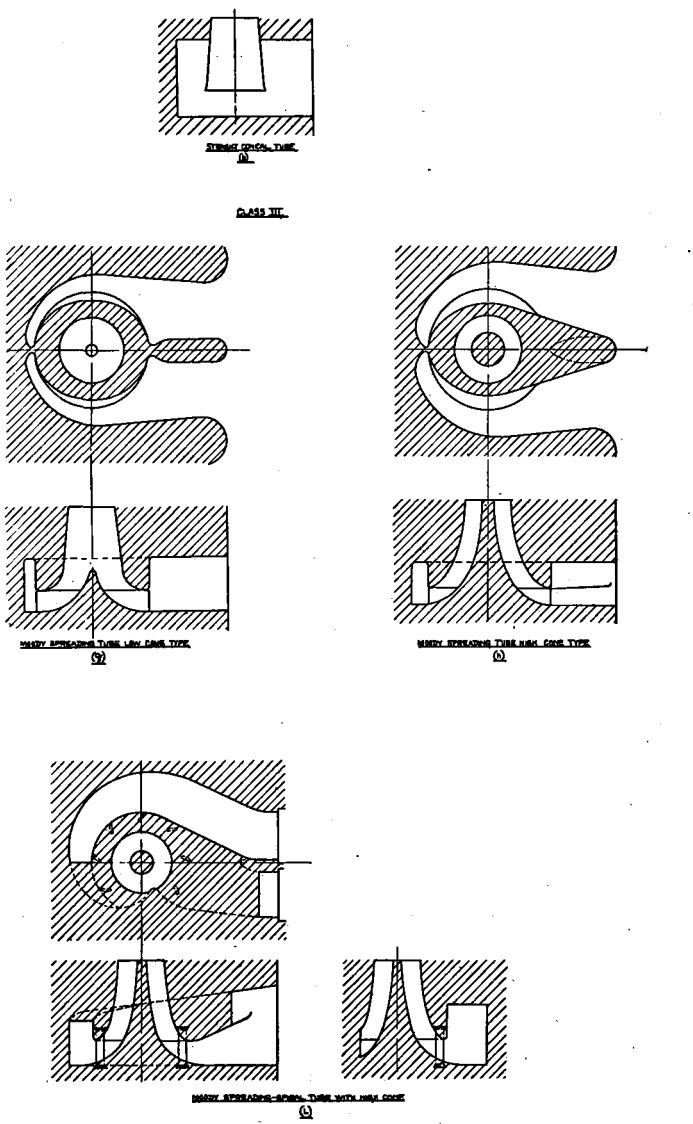


Fig. 23.
Draft tube design.

Class III.—the Moody Spreading Draft Tube, shown in Figure 23 (g), (h) and (i).

There are now in operation or under contract, turbines aggregating 1,200,000 horsepower in which the White Hydraucone has been applied, and turbines whose total capacity is 2,000,000 horsepower in which the Moody Spreading Draft Tube has been used. It is natural that the development of these two types of tube has had a marked effect on the elbow design of draft tube. One of the recently developed modifications is shown in Figure 23 (d). In this tube the induced losses due to the improper handling of the whirl have been reduced to a great extent by proper proportioning of areas so that the tube is able to regain a considerable part of the energy contained in the meridian component of flow. Such a tube, however, is still inherently unsuited for regaining the energy represented in the whirl component of the discharge from the runner.

The White Hydraucone and Spreading Tube are both concentric tubes, the areas being symmetrically disposed about the axis of the turbine. These forms of tube serve to reduce the amount of excavation. In handling the energy of whirl, the spreading tube is superior to the hydraucone, since both components of the whirling water—that is, the meridian and whirl components—are decelerated simultaneously; the first by means of gradually increasing areas and the second by the increasing distance from the axis of the turbine. Figure 23 (g) illustrates one of the earlier forms of the spreading draft tube, while Figure 23 (h) represents the tube in its complete form in which the water passage is maintained in annular form in passing from the runner into the draft tube. In both instances, after the water has passed through the spreading portion it enters the discharge passage which extends around both sides of the spreading portion and equally subdivides the flow. This form of spreading tube has been principally applied to units of low specific speed in which the form of discharge passage is relatively unimportant, since the major portion of the decelerating action takes place in the spreading or symmetrical part of the tube with the result that the velocity head of the water has been reduced to a low value before entering the discharge passage.

The tube shown in Figure 23 (i) is for use in units of high specific speed in which the whirl component has a considerable value. The initial portion is annular, followed by a spiral passage which serves more effectively to regain the energy at the discharge from the annular portion. The water passage in Figure 23 (h and i) forms

a complete annular draft tube with the passage located at a sufficient distance from the axis to avoid cavitation or the formation of a void in the flow near the axis of the turbine. By the use of this annular form of passage the water from the runner enters the draft tube without any sudden change in the shape of the section such as exists when the annular form of runner discharge space is followed by a cylindrical draft tube, that is, there is complete continuity of area transition from the runner to the draft tube. The elimination of the central region of the draft tube which is not occupied by the whirling mass of the stream, since the water there is not partaking in the general flow, has resulted in much higher efficiency and has also prevented disturbances such as vibration or water hammer originating within the draft tube, the effects of which are particularly serious in turbines having long penstocks, where the checking of the flow through the runner may cause severe surging or water hammer in the penstock.

While such disturbances have occurred in many tubes of the older forms, in recent installations where the complete annular form of draft tube has been used there has been a marked improvement in the quietness of operation of the turbine with the result that the annular tube has been found to give extremely steady conditions eliminating the objectionable effects mentioned above.

A considerable amount of experimental work directed to the problem of draft tube design has been undertaken during the past few years, and the improvement in turbine performance, as a result of the improvements in the draft tube, has represented a distinct advance in the art of turbine design.

At this point it will be interesting to show a comparison obtained from recent tests on various types of draft tubes which include several forms of the elbow tube and also the spreading type. The curves shown in Figure 24 are the results of a series of tests made in the I. P. Morris Laboratory and under the auspices of Hugh L. Cooper & Co., for the War Department of the U.S. Government in connection with the design of the Muscle Shoals hydro-electric development. The purpose of these tests was to determine the type of draft tube best suited to the conditions obtaining at this plant in which there were definite limitations as to unit spacing and the amount of excavation. The results demonstrated without question the marked superiority of the spreading type over all the other designs tested; and the designs conforming more nearly to the spreading type showing improved results over the earlier forms as

represented by the elbow type tube. It is also interesting to note that the spreading draft tube illustrated in Figure 23 has been adopted for the remaining units to be installed at Muscle Shoals. Numerous other tests have been made with the invariable result

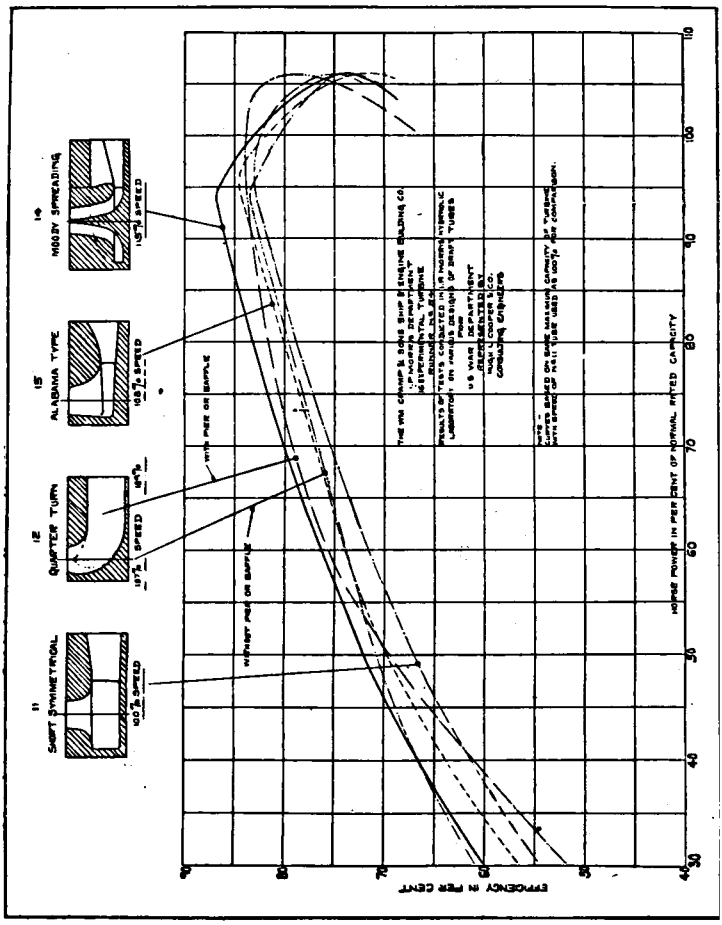


Fig. 24.

Results of comparative tests on various types of draft tube for U.S. War Department.

that the spreading type has shown a distinct superiority over all the others tested.

Passing from the hydraulic features of the draft tube to the structural features, an important improvement has been made with

the spreading type by the introduction of stay vanes at the end of the spreading portion or bell discharge, to act as columns to support the total weight of the unit and setting. This construction, developed by the author, avoids the necessity for supporting the unit by the beam or arch construction of the concrete below the turbine casing, reduces the amount of reinforcement required and simplifies the structural design.

It has also been found in practice that the use of these stay vanes permits the earlier removal of forms, thus reducing the time of construction of the concrete work. These supporting vanes have been used in several large developments, the most notable of which have been the Manitoba Power Company, the St. Maurice Power Company and the Holtwood Plant of the Pennsylvania Water and Power Company. The latter draft tube is illustrated in Figure 23 (i). In every case, the stay vanes in these installations are cast individually and set separately in the concrete.

SPECIAL FEATURES.

The development in recent years of the hydraulic turbine has been aided by the attention paid to numerous features of the turbine proper, which formerly received little consideration. In applying the hydraulic reaction turbine to higher heads, one of the greatest difficulties encountered has been the material loss in efficiency due to leakage through the runner clearances. Two methods of reducing this loss have been applied; the first the use of labyrinth seals, which have come into general practice, and the second the use of rubber seal rings, an improvement which has only recently been developed, but which has already been in successful use for a sufficient time to demonstrate without question its practicability.

It is extremely difficult for mechanical reasons to reduce the leakage beyond a certain point by reducing the width of the clearance opening when the usual metal seal rings are employed as an unduly small clearance results in serious risk of seizing due to the heat resulting from contact or due to the presence of grit or sand in the water. The labyrinth seal reduces the leakage by providing several small clearances in series, thus the head effective on each clearance is only a fraction of the total head. The 70,000 horsepower units of the Niagara Falls Power Company, shown in Figure 1, are equipped with the labyrinth type of seals.

With the rubber sealing arrangement, a stationary ring of soft rubber supported by a metal backing, surrounds the runner and

comes in close engagement with the metal surface of the runner band. By the use of this arrangement it is possible to provide a much reduced initial clearance, and the flexibility of the rubber avoids the risk of seizure. The Oak Grove unit of the Portland Railway Light and Power Company, shown in Figure 11, is equipped with rubber seal rings as a result of their successful use in other installations.

Although the clearances have been made extremely small in installations which have now been in operation for an appreciable time,

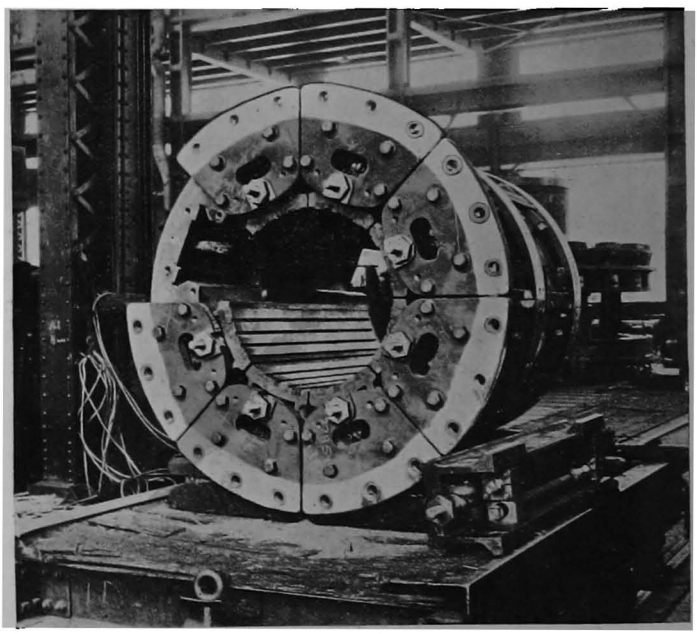


Fig. 26.

Adjustable lignum vitæ bearing for 20,000 horse-power turbines of the Pennsylvania Water & Power Co.

it has been found that the life of these seals is very much longer than that of the metal seal, even though the water contains large quantities of sand. In several instances, following the provision or rubber seal rings in old units in which considerable wear of the metal rings had taken place, increases in power and efficiency were effected even beyond the amounts which the turbines developed when new.

Another feature of the turbine which has been materially improved is the design of the main shaft bearing for many large units. American practice, particularly in low head turbines, has favored the use of lignum vitæ guide bearings. This type of bearing is valuable on account of its simplicity and decreased risk of burning out due to interrupted oil supply. The recent improvement in these bearings has been to make them of sectional construction with adjustable shoes, thus enabling the wear to be taken up without the necessity of dismantling the entire bearing and renewing it. A shop photograph of one of these adjustable bearings is shown in Figure 26. Both the 70,000 horsepower units at the Niagara Falls Power Company, and the 20,000 horsepower turbines of the Pennsylvania Water and Power Company are equipped with these adjustable bearings. It is believed that when lignum vitæ bearings are made adjustable they should be subdivided into a sufficient number of sections, such as six or eight, in order to provide effective means for compensating for wear and also to allow the wear to be taken up uniformly or non-uniformly, as the case might require.

A further improvement has recently been proposed; namely, that soft rubber be used in place of lignum vitæ in these bearings, owing to the ability, as demonstrated from its use with seal rings, of the rubber to withstand the wear resulting from sand and foreign matter in the lubricating water. Babbitted bearings with oil lubrication are also employed to a considerable extent in American practice, particularly in turbines designed for operation under high heads.

Another recent improvement has been in the design of the operating mechanism, which makes use of a double acting shearing link for connecting the turbine operating ring to the individual levers of the guide vanes. These links are so designed that they will break during either the opening or closing movement of the guide vanes so that if an obstruction should become lodged between two adjacent guide vanes, or between a guide vane and a stay vane, the link will shear and thus prevent damage to the guide vane itself. Such links also permit the use of an offset guide vane lever in place of the usual radial arrangement of lever, which by proper design permits some improvement in the governing characteristics of the unit.

Another feature which is of interest is the use of the disc type of guide vanes which serve to provide a better bond between the shank of the vane and the vane proper without obstructing the waterway.

This disc arrangement also cuts down the leakage in the clearances at the top and bottom of the guide vanes when they are in a closed position, which is of great advantage under increased heads.

GOVERNORS.

American practice employs for the most part the use of a separate governor, belt driven from the main turbine shaft. These

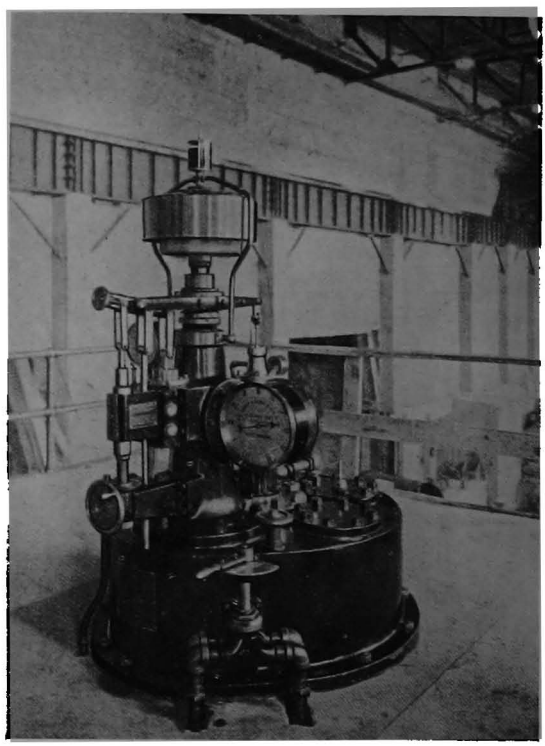


Fig. 25.
I. P. Morris double floating lever governor.

governors are designed to function in the usual manner by controlling the pressures in the operating cylinders of the turbine, and Figure 25 shows an I. P. Morris double floating lever governor, especially designed for use with units of large capacity. For smaller turbines, the Pelton governor shown in Figure 27 has come into extensive use. The S. Morgan Smith governors, shown in

Figure 30, have been used in a number of the more important turbine installations designed and built by that Company.

The use of centrifugal flyballs mounted directly on the main turbine shaft has been successfully developed by Mr. W. M. White, of the Allis-Chalmers Manufacturing Company. With this arrangement of governor, the movement of the flyballs is transmitted through a series of levers to the governor actuator in which

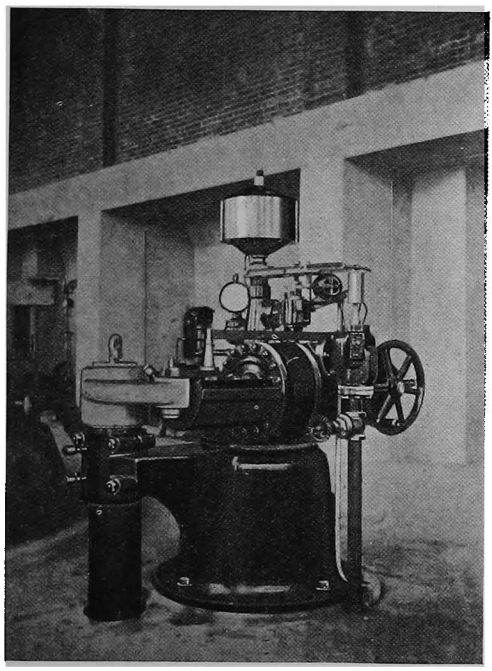


Fig. 27.
Pelton self-contained governor.

are contained the control valves. This type of governor is illustrated in Figure 28, and has been employed on a number of installations.

Another interesting method of governor drive is the use of a separate electric motor directly connected to the governor spindle and supplied with current from the main generator circuit. This type has been successfully employed by the Woodward Governor

Company and is shown in Figure 34. An interesting feature of the recent improvements in hydraulic turbine governors, has been the perfecting of the remote control for use with automatic generating stations. A number of such stations of capacities ranging up to 5,000 KW. have been in successful operation for several years. This type of plant is rapidly growing in popularity since it makes the development of small water powers an economical

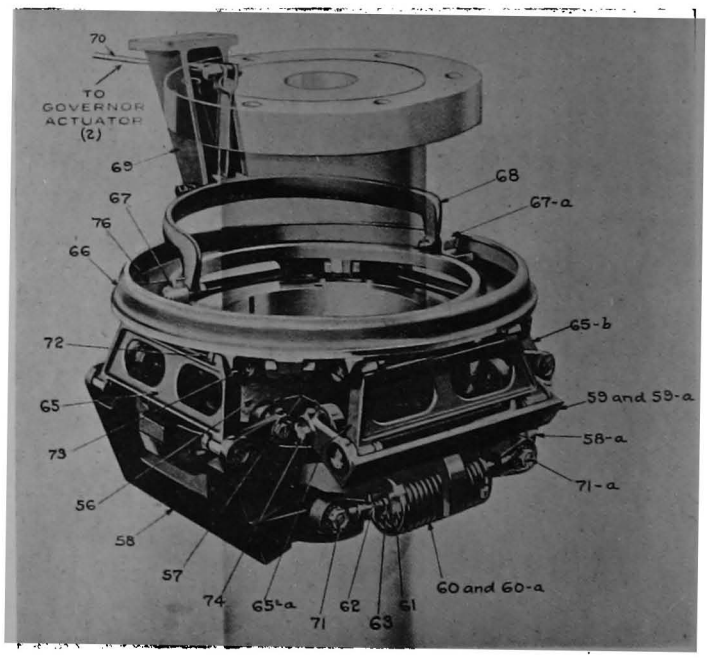


Fig. 28.
Flyballs for White integral governor.

proposition by the elimination of the attendance formerly considered necessary.

The means for supplying the pressure for the governor system is also worthy of note. In large plants where there are a number of units, a central pumping system is usually employed although individual pumps and accumulator tanks are frequently used. The Pelton Water Wheel Company have recently developed a special gear type pumping unit for oil systems which may be applied to

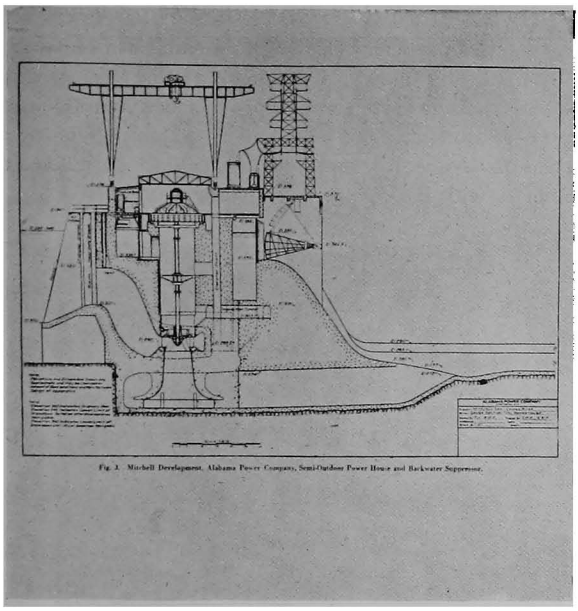


Fig. 29.
Sectional view Mitchell Dam Development, Alabama Power Co., showing Thurlow back water suppressor.

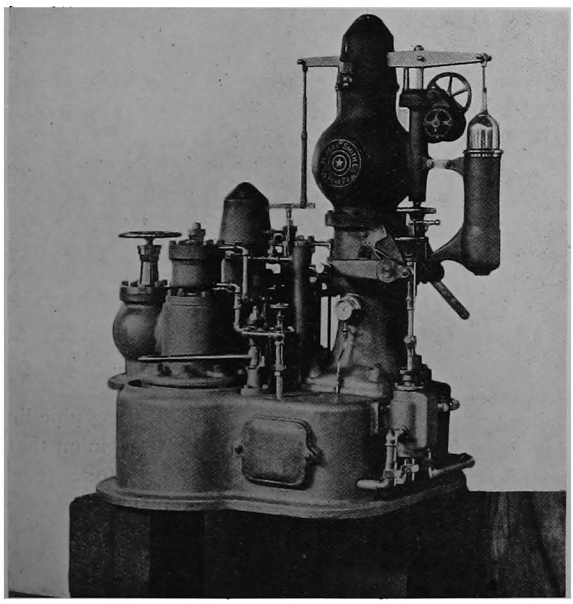


Fig. 30.
S. Morgan Smith actuator governor.

either of the two particular classes of systems. In central systems water is frequently used in place of oil as the medium for transmitting the power to the operating cylinders, and in order to prevent corrosion of pipes and valves a solution of potassium bichromate is frequently employed; and as an alternative, the use of soluble oil with the water has grown in favor.

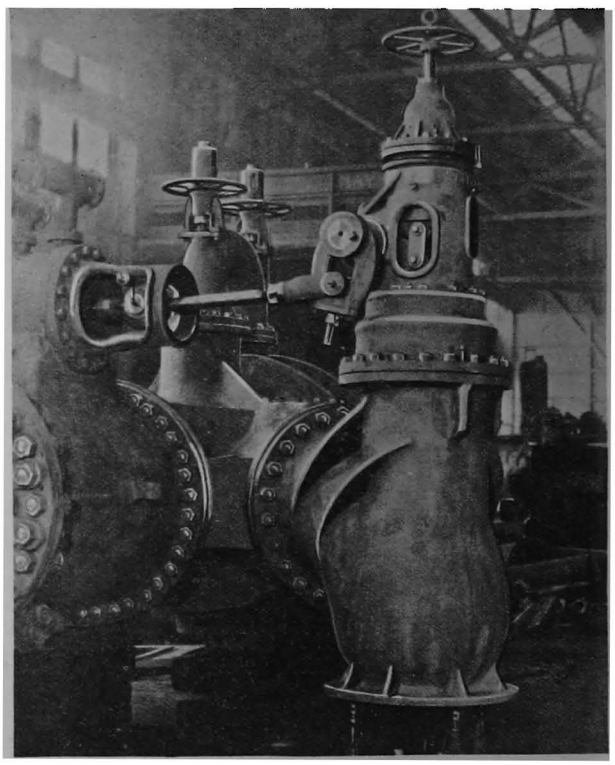


Fig. 31.
Pelton governor actuated relief valve.

OTHER AUXILIARY APPARATUS.

The subject of relief valves in connection with long pipe lines is a matter of great importance. It is the author's opinion that wherever possible some means to avoid the necessity for a relief valve should be employed. This may require the installation of a surge tank or the provision of sufficient thickness and strength of the

penstock and casing successfully to withstand the increase in pressure resulting from a rapid deceleration of flow.

It is felt that considerable increase in first cost of the installation is justified for the purpose of thus eliminating the complication and waste of water involved by the addition of relief valves. In many installations, however, having long penstocks, relief valves are necessary either to secure satisfactory speed regulation of the unit

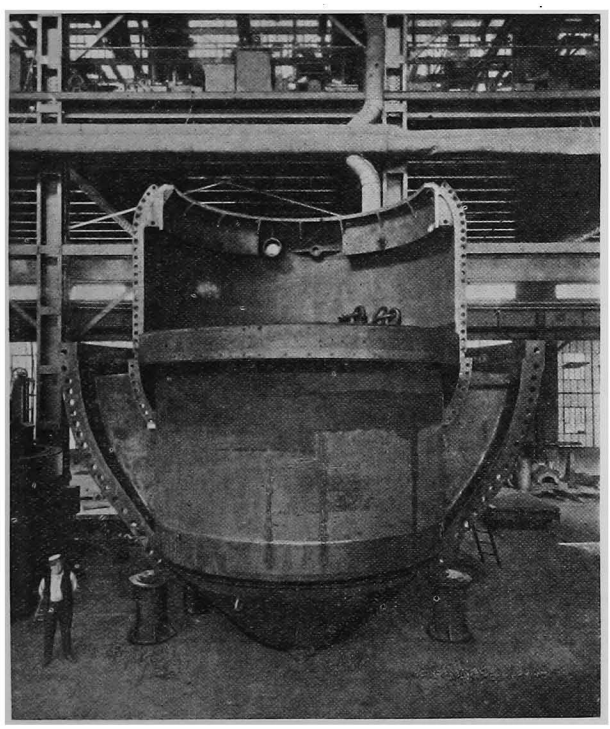


Fig. 32.
21 ft. × 14 ft. Johnson valves for 70,000 horse-power turbines for the Niagara Falls Power Company. (I. P. Morris)

or to avoid prohibitive pressure intensities in the turbine casing and penstock. In American practice, governor actuated relief valves connected mechanically or hydraulically to the turbine operating cylinder and adjusted for slow-closing operation, have been exclusively used. Such a valve built by the Pelton Water Wheel Company is shown in Figure 31.

Numerous designs of surge tanks have been proposed from time to time varying from the simple stand pipe to the differential surge tank invented by Mr .R. D. Johnson. The author desires at this time to express the view that the differential surge tank is inherently superior to the simple tank and that the invention of this differential tank has marked a notable improvement in the method of controlling pipe line surges. In the United States its merits have been duly appreciated and it is indeed surprising that this type of surge tank has not been more generally adopted elsewhere.

Fig. 33.

23 ft. 6 in. diameter butterfly valves for the Niagara Falls Power Company (Allis-Chalmers).

FLOW CONTROL.

In all hydro-electric plants some method must be used to control the flow of water entering the penstock or casing and the most usual method is the normal design of head gate. However, in recent installations where the total head at the intake to the casing is not excessive, large sized pivot or butterfly valves have been applied. Figure 33 is a shop photograph of the 23 ft. 6 in. butterfly valve which is used to cut off the flow at the entrance to the penstock for the 70,000 horsepower units installed at the Niagara

Falls Power Company. Where there is a long penstock, some means must be utilized for shutting off the water at the entrance of the turbine casing and to avoid the necessity of draining the pipe line in order to inspect the unit. Earlier practice involved the use of gate valves and butterfly valves for this purpose, but the use of the Johnson valve has become widespread, and is now considered an essential feature of design. This type of valve is operated by the internal pressure from the penstock itself and thus requires no outside supply of power for operation. The largest valves of this type which have been constructed are in use with the

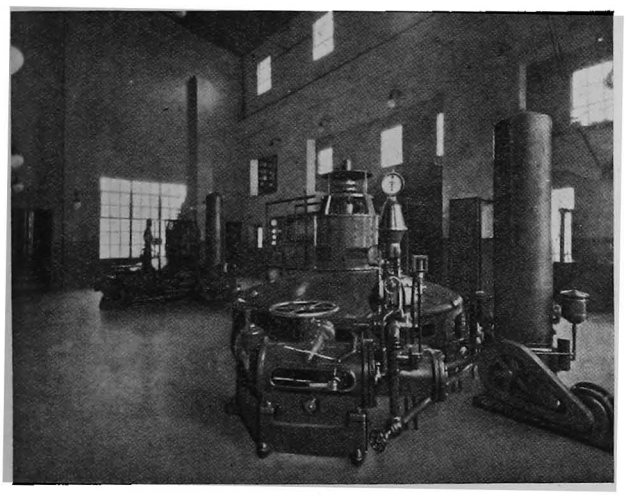


Fig. 34.
Woodward governor for automatic station.

latest Niagara units and their arrangement may be seen by referring to Figure 1. Figure 32 shows one of these large valves partially erected in the shop of the Cramp Company before shipment and serves to give an excellent idea of its massiveness.

The great difficulties experienced with gate valves in penstocks in earlier practice have resulted in their general abandonment for this use; and the use of butterfly valves has been to a great extent limited to low or moderate heads and small sizes. The Johnson valve is admirably adapted to all sizes and heads, since all its sections are of circular form, giving maximum strength and freedom from distortion with minimum amount of metal; and the

means of effecting closure through the operation of the plunger insures freedom from rapid wear and provides a tightness of closure unapproached in any other valve.

Another application of the Johnson valve has been in power plants on streams where, due to government regulation or water rights or the requirements of plants downstream, a certain definite volume of flow must be maintained at all times. In order to effect this, the Johnson valve is used in connection with the turbine governor and is operated as an approximately synchronous bypass, so that should the flow be cut off from the turbine, the valve opens a

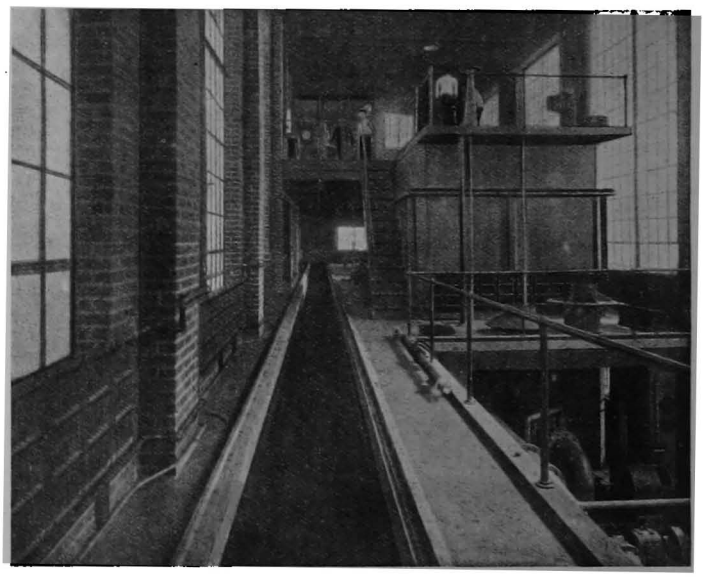


Fig. 35.
Interior view I. P. Morris Testing Laboratory.

corresponding amount and the necessary flow is thus maintained. Figure 36 shows such an installation in the Upper Falls Development of the Washington Water Power Company in Spokane, Washington.

CO-ORDINATION OF PENSTOCK AND TURBINE DESIGN.

The author wishes to mention the growing appreciation of the necessity of co-ordinating all the elements entering into the design of penstock and pipe lines with the various features of the turbine

design. In determining the strength and the factor of safety of a penstock, there must be full consideration of the effects produced by the governor action, the action of the relief valves and the closing or opening of penstock valves, before the final design is agreed upon. This calls for a careful investigation of the behaviour of all these devices in so far as their effects upon the acceleration and deceleration of the flow is concerned. It has been the unfortunate experience in the past that these features have not always been carefully considered and that the turbine design and penstock design have sometimes been worked up without regard to their inter-relation. It is essential from the standpoint of safety and uninterrupted operation that these matters be considered. There is now sufficient theory available which, coupled with actual experience, makes possible a rational treatment of the entire design.

SPECIAL DESIGNS.

One of the great difficulties encountered in the operation of low head plants has been the rise in tail water with consequent reduction of head during the flood season. In order to compensate for this, two methods are used; the first, known as the Moody ejector turbine, makes use of the ejector action caused by an annular jet of water at high velocity entering the draft tube immediately below the runner. Two units of this type, each of 12,000 horsepower capacity, are now being constructed for the Hollinger Gold Mines Limited, in Northern Canada. Figure 37 is a sectional view of one of these turbines and illustrates the arrangement of the ejector with respect to the turbine proper.

The other method employed is the Thurlow back water suppressor. By this method the turbine is set in a high concrete barrel placed upstream from the spillway section of the dam. The excess water discharged from the spillway creates a standing wave just beyond the end of the draft tube discharge passage thus reducing the tail water elevation at the point of draft tube discharge. The Mitchell Dam Development of the Alabama Power Company was the first installation to utilize this new feature, and Figure 29 shows a sectional view of the powerhouse with the discharge passage from the draft tube extending underneath the spillway.

AMERICAN METHODS OF DESIGN.

American design methods have long since outgrown the " cut and try " stage, but experimental research and careful testing of new designs by actual experiment still have a large place in

American practice. Designs are developed along proper theoretical lines and then carefully checked for performance by tests of model turbines in the laboratory or at the Holyoke flume. In recent years the leading manufacturers have built private laboratories of their own in which the experimental work is carefully tested, but the Holyoke flume still serves, in a measure, as the basis of direct comparison with the earlier stages of development. Figure 35 shows a view of the testing laboratory of the I.P. Morris Department of the William Cramp & Sons Ship and Engine Building

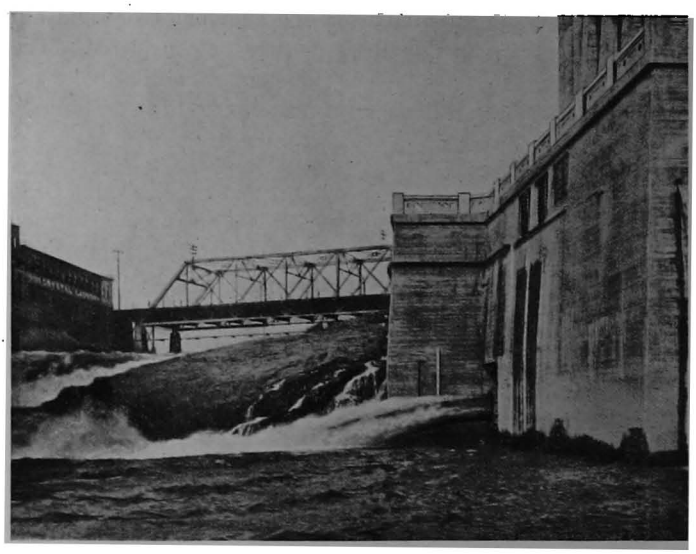


Fig. 36.
Discharge regulator in operation at Spokane Plant, Washington Water Power Company.

Company, in which the fundamental work of the development of the high speed runner, the spreading draft tube and numerous other developments has been carried on.

PERFORMANCE TESTS.

An important element in the carrying out of new designs has been the practice of making field tests on completed installations, thus giving the manufacturers frequent opportunities of checking their experimental work with the actual operation of full sized units.

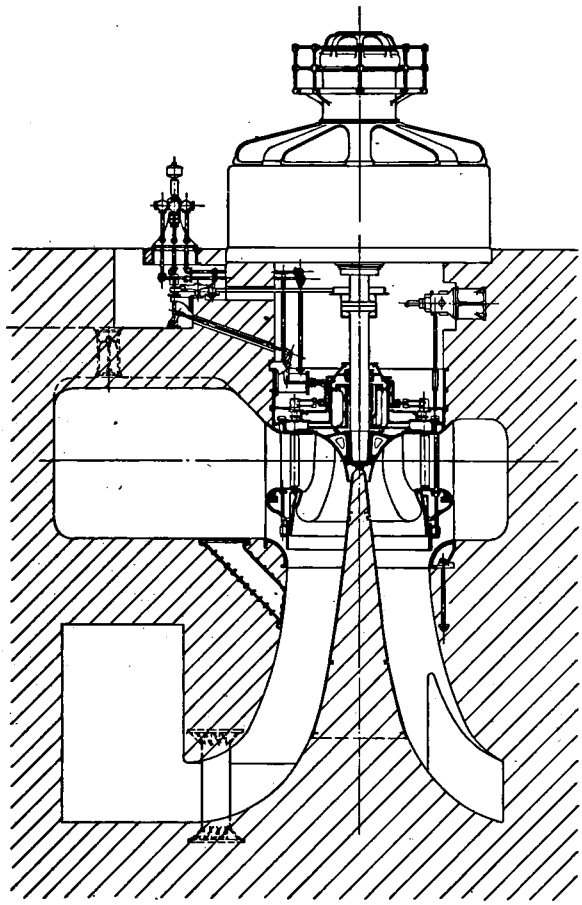


Fig. 37.

Sectional elevation of 12,000 horse-power Moody ejector turbine for Hollinger Gold Mines, Ltd.

The value of the field test is of course dependent upon its accuracy, and in recent years the development of new methods of water measurement have eliminated much of the previous uncertainties in such tests.

One of these new methods, that developed by Mr. Norman R. Gibson, of Niagara Falls, employs the principle of measuring the variation in pressure with respect to time produced by the change in momentum of the column of water in the penstock, which in turn is caused by a retardation of flow. This method of testing is readily applicable to hydro-electric developments in which there is an appreciable length of penstock. The retardation is commonly effected by closing the turbine gates in a convenient period of time ranging from a few seconds for short conduits to a minute or more for longer conduits. The variation in pressure caused by this retardation is automatically recorded with respect to time on a specially constructed Gibson apparatus and the area of the pressure-time diagrams so produced is a measure of the amount of velocity destroyed in the penstock. In this way the momentum of the penstock water column is used to indicate its velocity.

A second method still more recently developed by Prof. Charles M. Allen, of Worcester, Mass., depends upon the measurement by electrical means of the time of passage of small quantities of brine solution between two fixed points in the conduit.

By these methods the errors which were usually present in water measurements have been greatly reduced and under favourable conditions results accurate to at least one-quarter of one per cent. are possible of attainment in so far as the water measurement is concerned. It is interesting to note that these methods have developed to a point where in some instances greater precision is attainable in the water measurement than in the measurement of the electrical output of the unit.

In recent large installations, such as the 37,500 horsepower units of the Niagara Falls Power Company and the 55,000 horsepower units of the Hydro-Electric Power Commission of Ontario, results have been obtained through accurate tests in which the precision secured was unusual. In one instance in a test of the 55,000 horsepower unit, two complete sets of instruments were used and the measurements made independently of each other by using different observers stationed at different points along the penstock. The results of this test showed the two sets of measurements to be practically identical. In addition to such tests of comparative

accuracy both the Allen method and the Gibson method have been carefully checked for absolute accuracy by comparison with volumetric and other standard methods.

Figure 38 shows the efficiency curve of the Moody diagonal high speed propeller type turbine installed at the Anson Plant of the Great Northern Paper Company. In making this test, the Allen salt velocity method was applied in an open channel and the results obtained were extremely accurate. It is interesting to note at this point that a maximum efficiency of 90.9 per cent. was attained by this runner which has a specific speed of 143 (636 metric). It is

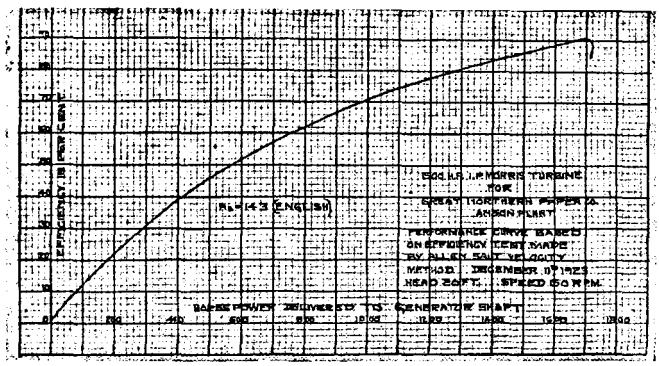


Fig. 38.

Horse-power efficiency curve based on actual tests 1,500 horse-power high speed turbine. Anson Plant, Great Northern Paper Co. (I. P. Morris).

believed that this represents the highest efficiency ever secured in an actual installation of any type of propeller turbine.

Fig. 39 is the efficiency curve of the 55,000 horsepower unit No. 5 of the Queenston Station of the Hydro-Electric Power Commission of Ontario, which was built by the I. P. Morris Department of the Cramp Company. This unit was accurately tested by means of the Gibson method and it is believed that these results represent the highest average efficiency throughout the full operating range of power ever secured in a hydraulic unit. It will be noted from the Queenston test curve that a maximum efficiency of 93.3 per cent. was attained, and that for a range of output from 45,000 to 55,000 horsepower an efficiency of 93 per cent. or over was maintained; an efficiency of 92 per cent. or over was maintained from 39,000 to

59,000 horsepower; an efficiency of 91 per cent. or over from 34,500 to 62,000 horsepower, and that from 31,500 to 63,000 horsepower, an efficiency of 90 per cent. or more was secured.

CONCLUSION.

In conclusion, the author wishes to state that the American hydraulic reaction turbine has for some years maintained an unusually high standard of performance and efficiency and that this

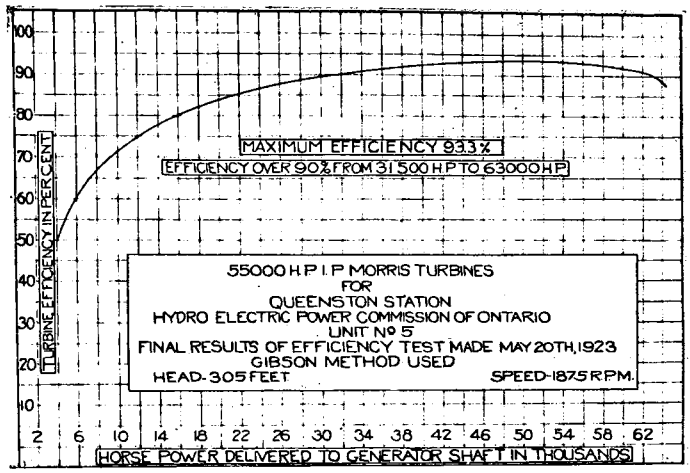


Fig. 39.

Horse-power efficiency curve from acceptance test, unit #5, Queenston Station, Hydro-Electric Power Commission of Ontario. (I. P. Morris).

is due in large degree to the hearty co-operation between the large power companies and the manufacturers, the former making it financially possible to carry on extensive experimental work, and the latter co-operating in every way to produce the finest type of hydraulic turbine possible.

RÉSUMÉ.

Les diverses et principales caractéristiques de la pratique Américaine dans le champ d'application et dans le calcul de la turbine hydraulique à réaction sont décrites dans ce rapport. On fait remarquer que le type de turbine simple à arbre vertical est standardisé d'une façon générale en Amérique et on donne une description des types préférés d'installations de turbines et du plan général des stations centrales. Les divers points intéressant la turbine font l'objet d'une discussion séparée. Un nouveau type de la chemise à cloisonnement est décrit. L'utilisation de la turbine hydraulique à réaction

sous une grande hauteur de chute se répand de plus en plus, ainsi que la développement en Amérique du type de propulseur de turbine à grande vitesse sous moyenne et basse hauteur de chute. Un nombre d'installations importantes est décrit, comprenant une turbine de 35,000 H.P., fonctionnant sous une hauteur de chute de 857 pieds (261 mètres) et une turbine à propulseur de 28,000 H.P. fonctionnant sous une hauteur de chute de 56 pieds. Les nouveaux développements des tubes d'échappement sont illustrés et discutés, et les grandes lignes de leurs avantages sont énumérées.

Ce rapport cite les nombreuses améliorations apportées à la turbine, concernant les caractéristiques mécaniques et hydrauliques comme par exemple l'utilisation des joints en labyrinthe et des garnitures en caoutchouc, des paliers ajustables bois gáiac (" lignum vitae ") et des perfectionnements apportés au mécanisme. Des types différents de régulateurs de vitesse, des applications auxilliaires, telles que valves d'échappement, valves Johnson et valves de contrôle sont illustrées.

Une description est donnée des deux méthodes les plus employées pour éviter les pertes capacité qui proviennent d'un trop fort volume d'eau du niveau aval à la suite de fortes crues.

On décrit et explique les méthodes Américaines de calcul et on attire l'attention sur la relation qui est conservée entre le développement théorique et les recherches expérimentales. L'importance des essais en supplément des travaux de laboratoire est mentionnée, et l'attention est particulièrement attirée sur les nouvelles méthodes appliquées pour mesurer les quantités d'eau.

En terminant l'auteur démontre que le très haut degrè de développement atteint en Amèrique dans le champ des turbines hydrauliques à réaction est dû à l'entente existant entre les Compagnies distributrices et les constructeurs de turbines, qui permet de mener à bien les travaux d'études et les essais.

IMPULSE WATER WHEELS

WILLIAM MONROE WHITE,
M.A.S.M.E., M.A.I.E.E.

It is, indeed, an old art with which this Paper deals. Power was developed in ancient times by the impact of flowing streams of water against flat paddles fixed around the periphery of a wheel. Such devices for driving mills were first described by the architect and engineer, Vitruvius, in 14 B.C. These mills were the forerunner of modern hydro-electric plants.

The Impulse Water Wheel was developed along the streams fed by the melting snows on the high peaks of the Sierra-Nevada Mountains, forming the western wall of the great plains of the western half of the United States of America, by men who were pioneers in the development of the mines and industries of that rich country, as well as pioneers in the art with which we here deal. These hardy, western men were driven up the canyons, along the gulches and over the mountain sides by thirst for the gold which lined the gravel beds of the streams and lay locked in the porphyry rock, cunningly tucked by nature between the granite ledges forming these mountain ranges. Power was required to pulverise the porphyry rock and release the grains of gold. A water wheel known as the " Hurdy Gurdy," driven by the impact of a jet of water against flat paddles fixed around the periphery of a disc, produced power for this purpose from the high heads easily obtained from the nearby precipitous streams.

The " Hurdy Gurdy " was a direct impact wheel, and returned only about 40 per cent. of the energy delivered to it, which was about the best that could be expected.

The efficiency of such a wheel was found to be best when the tangential velocity of the paddles was about one-half the velocity of the jet, but since the paddles were flat the water was not directed backward with reference to the rotation of the wheels, but was discharged sideways with considerable velocity and consequently considerable kinetic energy.

In that period of great development in California, between 1850 and 1880, greater and greater power was needed for driving the wheels of the growing industries, and naturally the urge was felt

for a type of wheel which would convert a larger portion of the energy of the water into useful mechanical power.

In studying the recorded history of the early development of this art, the following contributed no small part to the work of changing the impact wheel into the modern impulse wheel: Jearum Atkins, S. N. Knight, Sutter Creek, California; Nichols J. Colman, Railroad Flat, California; Jos. Muller; Professor F. G. Hassey, University of California.

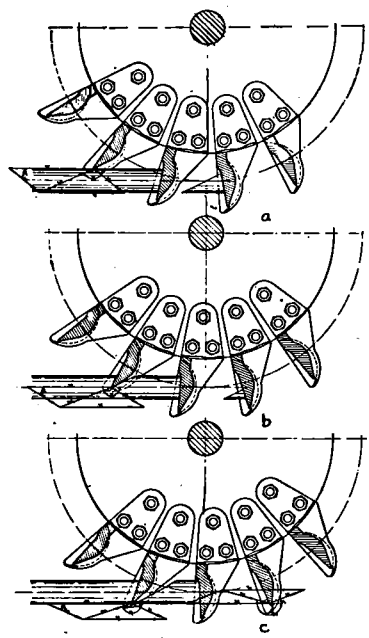


FIG. 1

Jet of water acting on an impulse wheel.

Under date of February 4, 1895, the Franklin Institute, Philadelphia, awarded the Elliott Crescent Medal to Lester A. Pelton for his invention and development of the Pelton Water Wheel. The very thorough manner in which the Committee of the Franklin Institute studied the records of the development of the art leads to the inevitable conclusion that Pelton did an original and splendid work.

The modern Impulse Water Wheel converts the water energy available as pressure into kinetic energy in a free circular jet; directs it tangentially without impact upon the buckets around the periphery of a disc mounted upon a shaft; divides and turns the jet within the wheel buckets along smooth curves, and discharges the water backwards from the moving buckets so that the water drops with least velocity.

The energy of the water is thus converted into mechanical power in giving impulse to moving parts by the force required to change the direction of the free jet.

Reference is made to Fig. 1 where a series of instantaneous theoretical conditions of operation are portrayed in order to illustrate the delivery of the water on to the buckets of the wheel.

(a) The entrance edge of one bucket is just entering the jet.
(b) The entrance edge of one bucket in mid-position of the jet.
(c) The entrance edge of one bucket has just completed its traverse through the jet.

A study of the illustrations (a), (b) and (c) will show that the angle of delivery of the jet on to the buckets at entrance is widely different from the angle at which the last particle strikes the moving bucket. The entering lip of the bucket cuts the jet into sections and these disjointed sections form the greater portion of the water flowing on to the buckets.

That part of the water last received on the bucket is at approximately nine jet diameters from the nozzle, and if the jet at that point has been distorted from its natural course or shape it will impinge upon a part of the bucket not designed for its reception with resulting shock and loss. The jet, therefore, should be maintained in approximately uniform cylindrical shape for a long distance after its discharge through the nozzle.

The traverse by the pitot tube of the jet as it issues from any of the usual types of nozzles will show transformation of pressure energy into velocity energy with very high efficiency, but this traverse does not indicate jet distortion which is one of the main causes of loss of efficiency.

The transformation of water energy available as pressure into a free jet is accomplished most effectively when the wetted perimeter is least. This condition requires the circular form of jet now in use. The simplest and most effective means for controlling the flow from the nozzle is a needle co-acting with it.

The needle centre, being circular, offers least wetted perimeter. The efficiency of a jet issuing from a well designed nozzle with needle set for discharging three-quarters capacity or better is about 98.5 per cent. The relation of the actual velocity across a diameter of a jet issuing from a circular nozzle with needle core, to the computed velocity due to the head, has been observed and is shown in Fig. 2. The transformation of the pressure energy

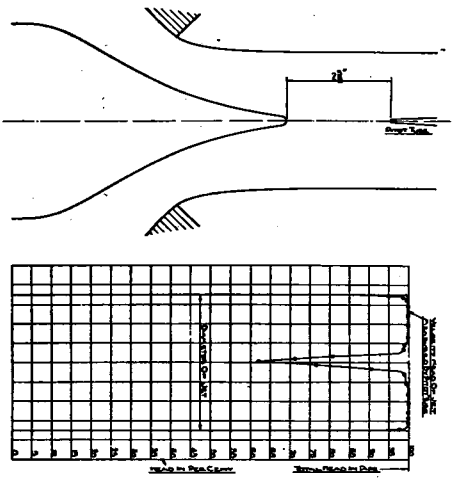


FIG. 2

Pitot tube reading across a jet plotted in percentage of total head. Upper view shows position of pitot tube with reference to nozzle and needle.

into velocity energy with high efficiency is essential, but it is even more important that the issuing jet contain no cross-currents and no whirl tendency in order that the jet will remain as nearly as possible the same uniform size until all of the water has been delivered to the buckets.

The formation of a proper jet lies not only in the form of the needle and nozzle, but in the piping system behind them. The velocity of the water in the supply pipe, the radius of curvature of the bends, the relation of the bends one to the other, the smoothness of the water passages, the operating head, all have an effect upon the form of the jet as it issues from the nozzle. The form and smoothness of the jet play a very important part in the performance of the wheel.

The adjustable needle provides a means for regulating the flow

and yet maintaining all of the jets concentric and, with fixed nozzle, directing the water tangent to one pitch diameter.

There are two important relations which govern the performance of an impulse wheel :—

(a) The ratio of the pitch diameter of the buckets to the diameter of the jet.

(b) The ratio of the width and size of the bucket to the diameter of the jet.

The pitch diameter of the buckets is the diameter of a circle concentric with the centre of their rotation and tangent to the centre of the jet.

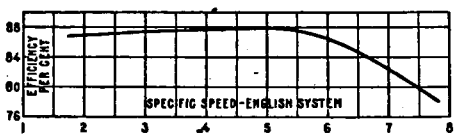


FIG. 3

Relation between efficiency and specific speed of one type of bucket.

Good efficiencies are obtainable with a pitch diameter of from eight to sixteen times the diameter of the jet and with a width of bucket, measured from one discharge edge to the other, of two and one-half to three and one-half times the diameter of the jet. The velocity of the buckets on the pitch diameter is rather definitely fixed at from 43 per cent. to 46 per cent. of the velocity of the jet. Development work is continually in progress by the larger companies, tending to decrease the ratio of the pitch diameter to the jet diameter in order to secure higher speed with equal efficiency.

It is customary to use the term specific speed to express a relation between power, revolutions, and head of a given impulse wheel. The following formulæ express this relation :—

$$n_s = n \frac{HP^{\frac{1}{2}}}{H^{\frac{5}{4}}}$$

n_s = Specific Speed.
n = Revolutions per minute.
H.P. = Horse Power.
H = Head in feet.

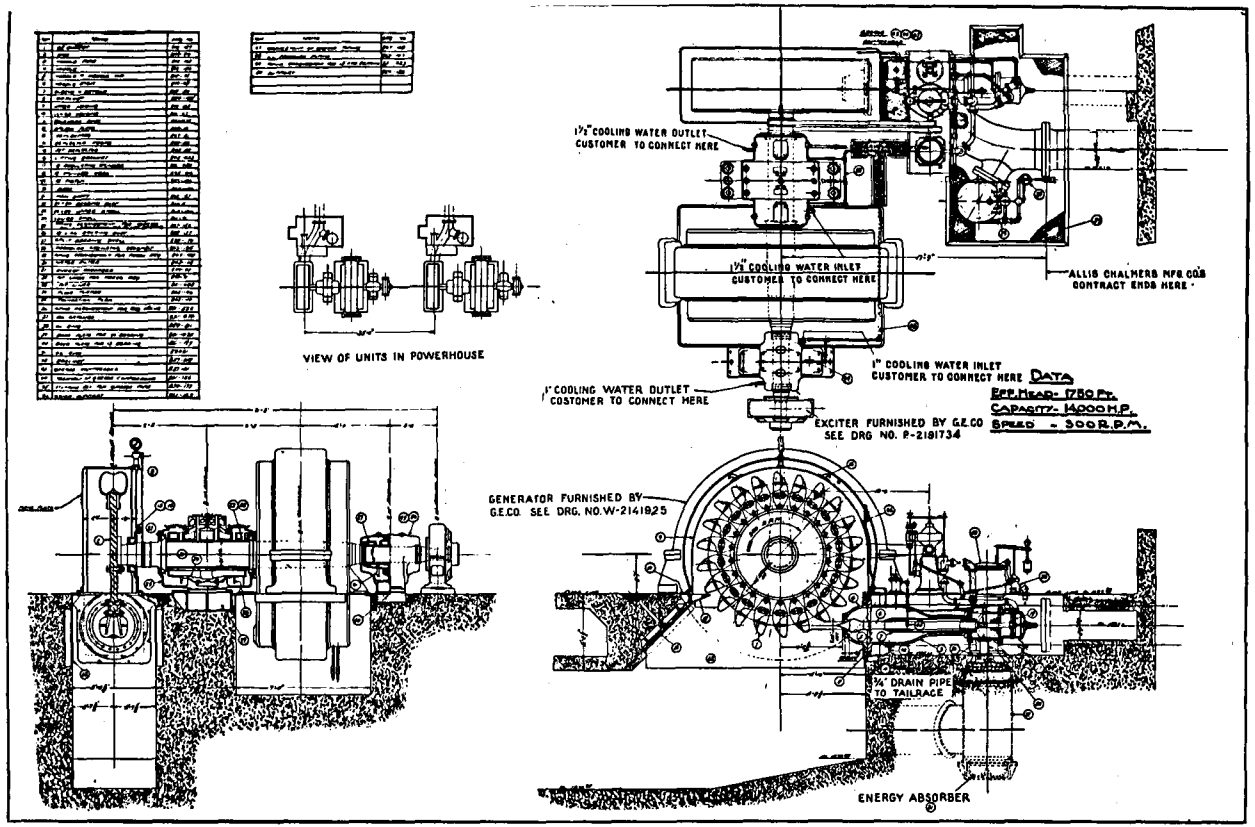


Fig. 4. Typical section of single jet, single disc, horizontal overhung impulse wheel, showing simplified arrangement of needle, buckets, governor, pressure regulator and energy absorber.

The curve shown in Fig. 3 is plotted from a series of tests made at the Hydraulic Laboratory of the Allis-Chalmers Manufacturing Company at Milwaukee, and shows, relatively, the variation in efficiency with respect to the variation of the specific speed on one type of bucket of that company. From the curve it will be noted that one type of bucket under test gave best efficiency with a specific speed of about five. Specific speed is given in English units. This specific speed corresponds to a ratio of pitch diameter to jet diameter of 10 to 1. Specific speed and the ratio of pitch diameter to jet diameter, in reality, express the same thing.

The long series of tests, on which the curve in Fig. 3 is based, clearly demonstrated the importance of proper jet formation for

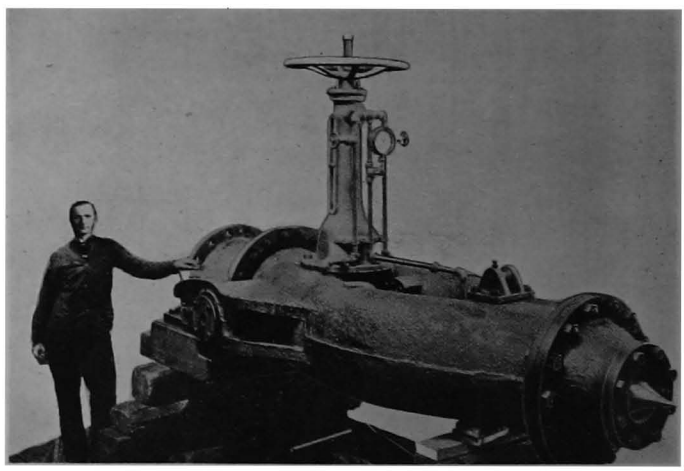


Fig. 5.
Bifurcated deflecting needle nozzle which gives excellent jet efficiency.

securing good efficiency. With certain types of nozzles high efficiencies were obtained, and with certain other types of nozzles considerably lower efficiencies were obtained. In making the nozzle comparisons all other conditions were maintained identical. The efficiency decreased as the uncompensated curvature of the supply pipe or nozzle pipe was increased. Lower velocities in the supply pipes leading to the nozzle invariably resulted in higher efficiency. In this series of tests, best efficiencies were obtained with a model of the bifurcated nozzle, illustrated in Fig. 5. The disturbances caused by the curvatures on each side of the nozzle

seemed to compensate each other at the nozzle discharge, with the result that an excellent jet was obtained.

The results, in Fig. 3, fairly represent what can be accomplished in commercial work, provided the supply pipes are of sufficient diameter, the bends in the pipe line and nozzle pipes are compensated, there are no openings or projections in the pipe line near the nozzle, and the interior surface of the pipe has sufficient smoothness to cause no distortion, so that the jet will remain

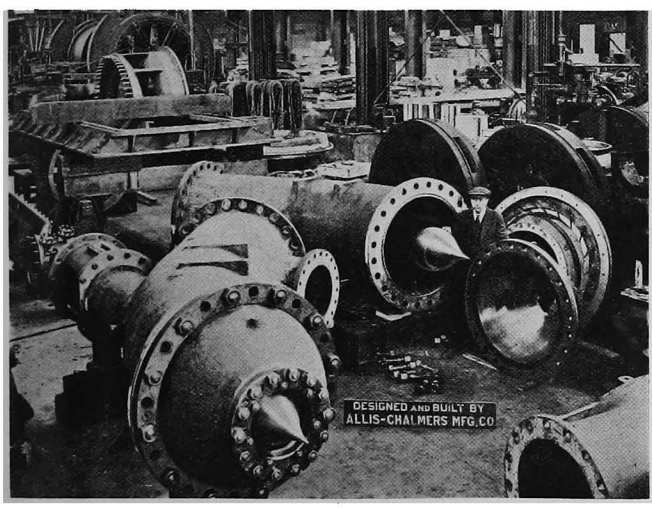


Fig. 6.
Nozzles, needles and nozzle pipes for 30,000 horse-power impulse wheels.

approximately true until all of the water has been delivered to the buckets.

The efficiency shown on the curve is the overall efficiency from computed energy in the pipe line behind the nozzle to mechanical power delivered to the prony brake, including windage of prony brake and bearing losses. Deducting the computed windage and bearing losses, the bucket efficiency was computed to be 91 per cent. The jet used was $1\frac{1}{2}$ inches in diameter and the head was 120 feet, consequently the size of the buckets and the quantity of water used was such as to differentiate these tests from the usual laboratory test and place them more in the class of commercial work.

The type of nozzle illustrated in Fig. 6 is in more general use, and it fits in well with the usual power-house layout of piping. A renewable bronze throat-ring is provided on the nozzle illustrated, to facilitate frequent and inexpensive renewals for maintaining the jet in proper form and shape. The nozzles shown are those used on the Caribou Plant of the Great Western Power Company, California.

The rotating nozzle, Fig. 7, offers possibilities for further

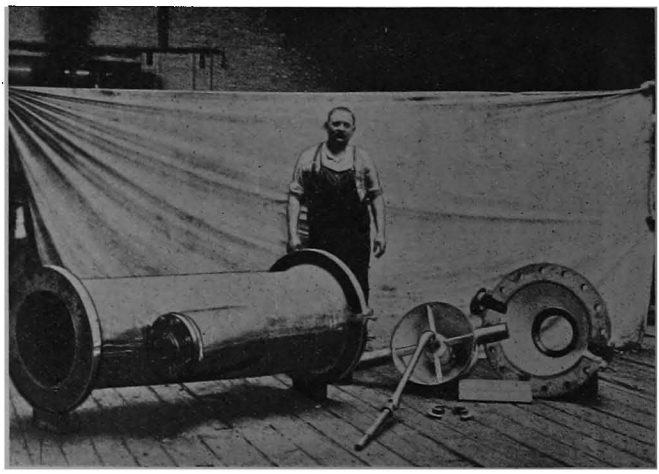


Fig. 7.
Rotating nozzle for deflecting jets from buckets.

improvement in efficiency because the needle is adjusted by means which offer less disturbances to the water in the nozzle than the stem of the usual needle.

By noting the varying entrance angles in Fig. 1 it becomes apparent that the buckets should be of the double hemispherical shape in order to turn all the jet. W. A. Doble was the first to recognise the necessity for a bucket of this general type, and invented his ellipsoidal bucket in 1899. This general type of bucket is now used by the Pelton Water Wheel Company, and is illustrated in Fig. 8, which shows a runner for a 12,000 horse-power Pelton wheel designed to operate under a head of 1,250 feet. The splitter forms a prominent part of these buckets, and the entrance of each bucket is cut away, or rather, to state the matter more correctly, the lobes or sides of the bucket have

been extended past the end of the splitter in order more completely to utilise that portion of the water which reaches the bucket last.

Fig. 9 illustrates the Allis-Chalmers Manufacturing Company type of bucket used on the 30,000 horse-power impulse wheel unit built for the Caribou Plant. It will be noted that the end of the

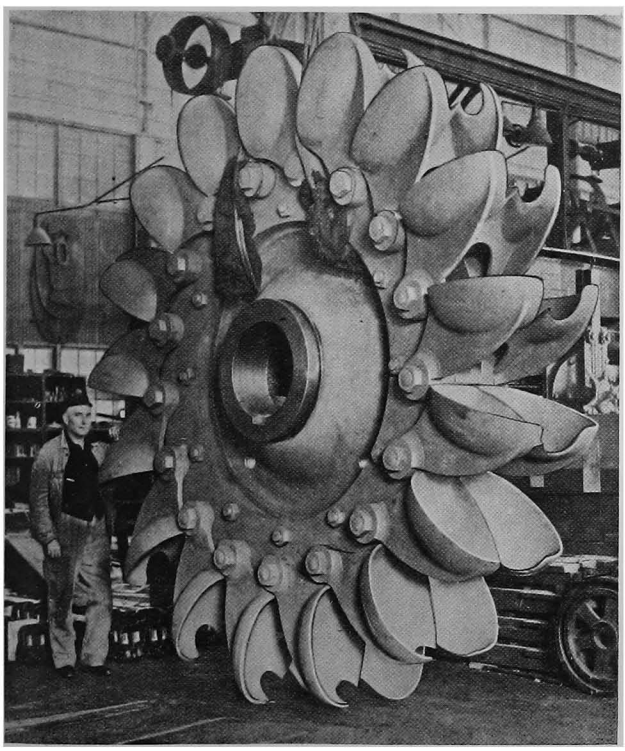


Fig. 8.
Chain type bucket wheel built by the Pelton Water Wheel Company, 12,500 horse-power, 1,250 feet head.

splitter in the Allis-Chalmers bucket is quite different from that of the Pelton bucket. Improvement in design will probably consist in harmonising the entrance portion of the two buckets. It may be that the Allis-Chalmers bucket is too flat and it may be that the Pelton bucket is too pointed. The fact remains, however,

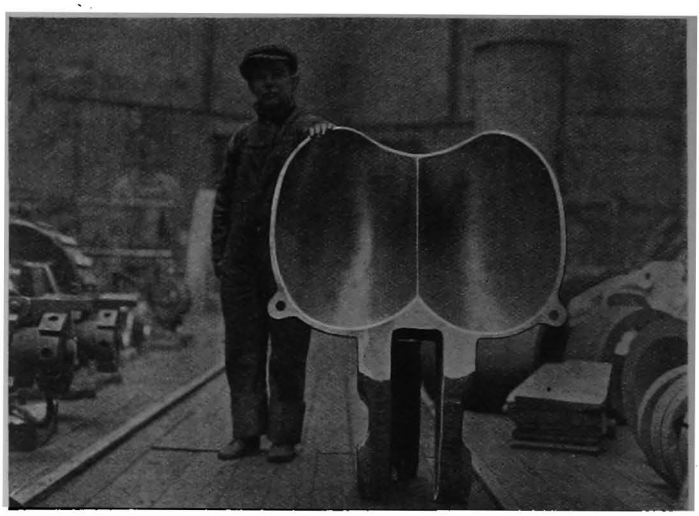


Fig. 9.
Impulse wheel bucket of Allis-Chalmers Mfg. Company.

that both types of buckets give good results under test, and each has been found to give long life in service.

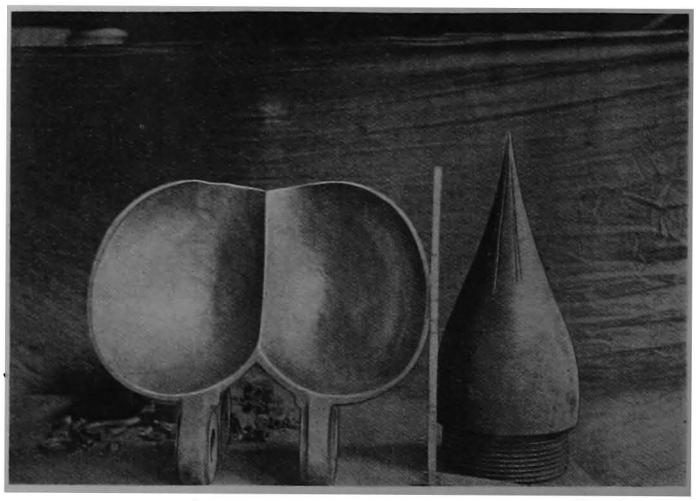


Fig. 10.
Bronze bucket and needle after five years' operation under 865 feet head. Some wear is evident on the bowls of the bucket and needle.

Fig. 10 illustrates a bronze bucket and a bronze needle which has been in service for five years at the plant of the Southern California Edison Company, operating under a head of 865 feet. The flow of the water in the bucket can be traced by noting the striated marks of wear in the bowls of the bucket.

It is common practice to use individual buckets and to bolt them separately upon the wheel disc. The Pelton Water Wheel Com-

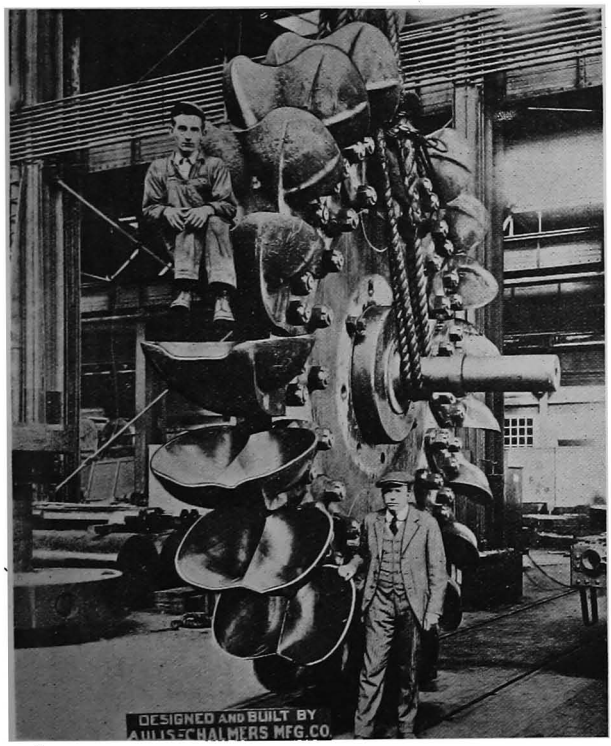


Fig. 11.
Buckets and disc for Caribou Plant 30,000 horse-power, 1,008 feet head, Great Western Power Company, weight 50,000 pounds.

pany are now using an interesting construction wherein the rear lugs of one of the buckets and the forward lugs of the next bucket are fastened to the disc with one bolt. This construction is known as the "chain type" of bucket. This design provides for

a smaller number of bolts and a larger spacing between the bolts, and therefore offers a greater resistance to the turning moment of the jet against the face of the bucket.

The Allis-Chalmers Manufacturing Company's practice, illustrated in Fig. 11, is to hold each bucket on to the disc with three bolts. This design has the advantage that a single bucket can be

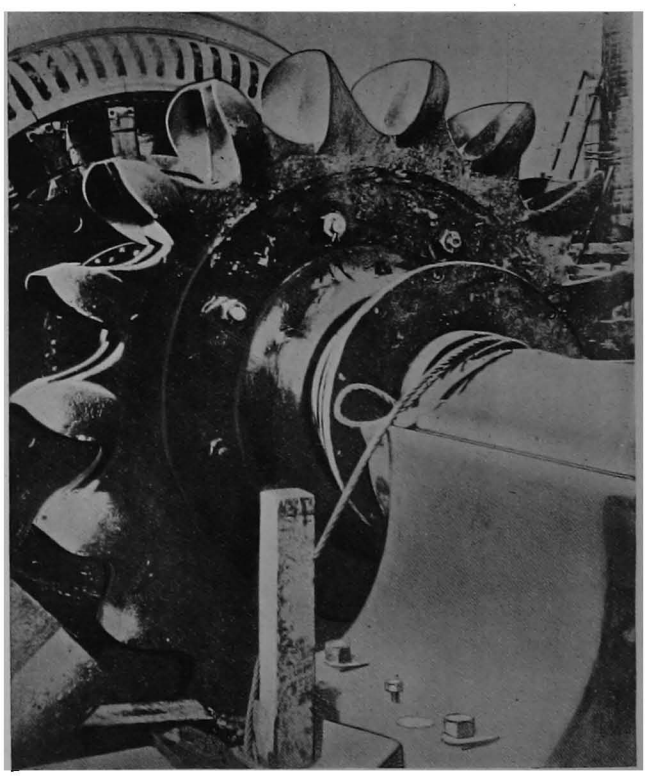


Fig. 12.
Buckets cast together on a ring and bolted to a hub for 10,500 horsepower, 1,800 feet head, units for Colorado Power Company, built by I. P. Morris Company.

replaced without disturbing any other bucket on the wheel. The disc and buckets shown are in use in the Caribou Plant.

An exception to the general American practice is that illustrated in Fig. 12 which shows all the buckets cast on one ring. Two units of this type, designed under the direction of the writer, were

built by the I. P. Morris Company and installed in the Boulder Plant of the Colorado Power Company, near Denver, Colorado, and have been in continuous operation since 1910. These units operate under a head of 1,800 feet and develop 10,500 horse-power each.

The weight of the rotating parts, the side thrust of the horizontal jets, and the size and revolutions of the shaft of large impulse wheels require bearings of large size and good design. Two bearings carry the weight of the rotor of the generator and two wheel discs and buckets, of the 23,000 horse-power impulse wheels of Big Creek No. 2 Plant of Southern California Edison Company. The total revolving weight is 225,000 pounds at a

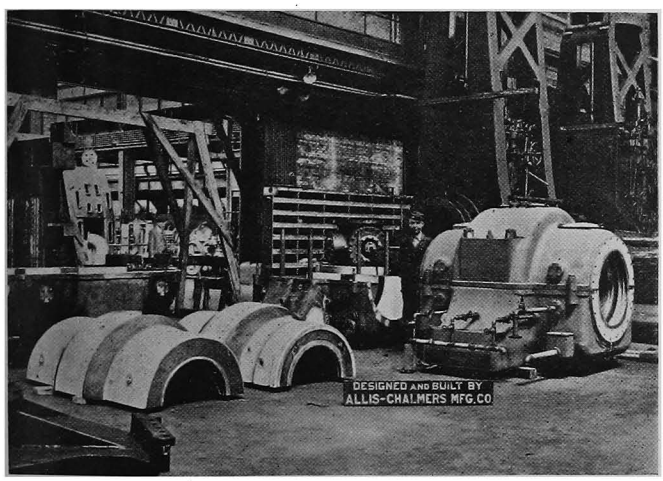


Fig. 13.
Spherical seated, ring-oiled bearing, 24¾ inches in diameter, for 30,000 horse power impulse wheel for Caribou Plant of Great Western Power Co.

speed of 375 R.P.M., and in addition, the horizontal impulse force due to the action of the jet at normal load is 40,000 pounds per nozzle. The bearing shell is 20 inches in diameter in the bore and 64 inches long. The load per square inch of projected area, p, is 104 pounds. The rubbing speed in feet per minute, v, is 1,940 feet; $pv = 202{,}000$. The above figures are on the basis of 50 cycles. This unit has been operated at 60 cycles also, and when operating at the above speed the heating factor then

becomes pv = 242,400. These bearing shells are spherical seated, hollow cast for water-cooling, and oiled by five oiling rings. Provision is made for forced lubrication from the governor oil pressure system at the time of starting.

Fig. 13 shows one of the two 24¾-inch diameter bearings supplied with each of the 30,000 horse-power impulse wheels for the Caribou Plant. The design of these bearings is similar to that above described. The rotating weight to be carried is 350,000 pounds, p = 116; v = 1,100; pv = 127,500. Both types of bearings run normally with water-cooling and with only oil rings supplying the oil.

Fig. 14 illustrates ring-oiling generator type ball and socket sup-

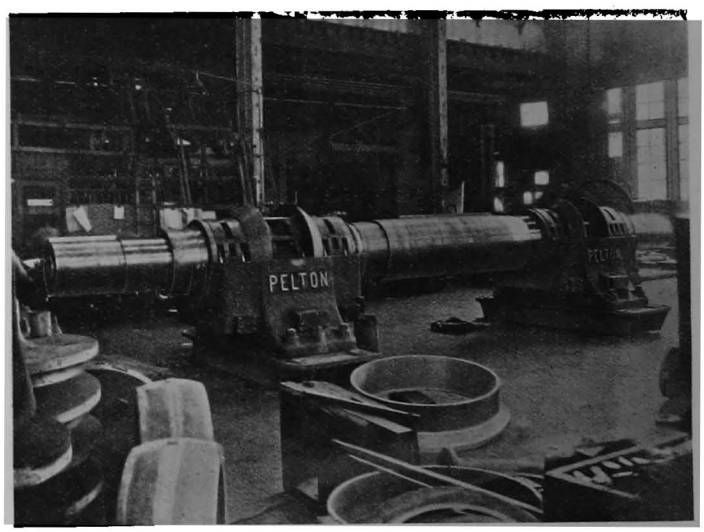


Fig. 14.
Shaft and bearing for 25,000 horse-power double overhung impulse wheel, built by Pelton Water Wheel Company.

ported bearing for a 25,000 horse-power double overhung water wheel unit. The space between the bearing is where the generator rotor is mounted and the water wheels are overhung on the ends. It is customary in the United States for the water wheel manufacturer to furnish shaft and bearings to both the water wheel and the generator.

The higher heads, under which impulse wheels are used, require

the use of long pipe lines, and the economical velocity in the pipe lines is usually so high that the flow cannot be changed suddenly without great and frequently dangerous changes of pressure. The flywheel effect of the generator and rotors of the impulse wheels is usually not large, making it necessary to adjust the water supply quickly with change of load if the speed change is to be kept small. These conditions make it a difficult problem properly to regulate the speed of these units, and it is usually done by: (a), deflecting the jet from the buckets; or (b), shutting off the jet and by passing the water through auxiliary apparatus. The former (a) is more generally used when regulating by the "water wasting" method, and the latter (b) is more generally used when regulating by the "water saving" method.

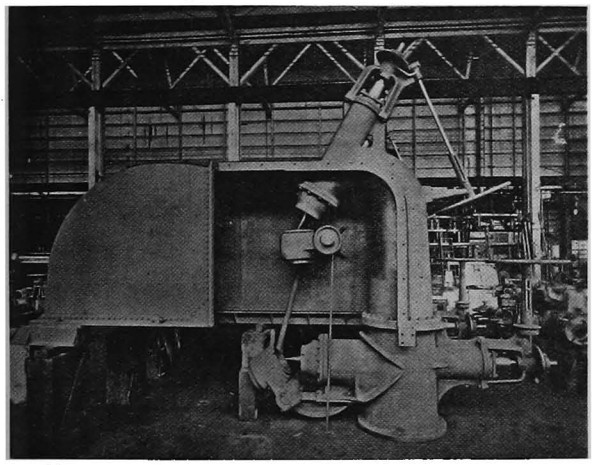


Fig. 15.
Twin nozzle, water wasting jet deflectors of the sleeve type, built by the Pelton Water Wheel Company.

The simplest method of regulating is that of deflecting the jet from the buckets and allowing it to waste. This is most easily accomplished by the use of jet deflectors. The earlier type consisted of stirrups or blades moved into the jet by the action of the governor.

Another economical and satisfactory design, in respect of cost and efficiency, is that type illustrated in Fig. 15, where the regulation is accomplished by means of cylindrical deflectors operated

by the governor. A jet deflector requires space between the nozzle and buckets for its operation, which makes a longer jet necessary, and this decreases the efficiency because of greater jet distortion. The type of unit illustrated in Fig. 15 has two rotors in adjacent casings with two manually controlled fixed jets applying to each rotor. The multiple jet unit of this type has the advantage that

Fig. 16.
Main nozzles and auxiliary nozzle used by the Pelton Water Wheel Company for water saving regulation.

when one-quarter of the total power of the wheel is required, three jets may be closed, and the remaining one operated at maximum efficiency. Any type of jet deflector breaks up the jet and usually causes pitting of the buckets.

The deflecting nozzle with needle and trunnion, invented by W. A. Doble, provides an effective means of regulation. It has

the advantage of maintaining a smooth jet, but has the disadvantage, when partially deflected, of directing the jet on to a portion of the buckets not designed for its reception. On large units the size and weight of the nozzles become unwieldly for quick governor motion. The disadvantage of weight has been overcome to some extent by balancing pistons placed underneath the nozzles. The cup leather joints between the deflecting nozzles and the piping are a source of trouble, particularly in gritty water. The deflecting nozzle is by far the preferred arrangement of the water-wasting types.

The rotating nozzle, Fig. 7, provides a means of deflecting the jet similar to the deflecting nozzle, except that the parts to be moved are much lighter and this requires less power in the governor, which tends toward better regulation.

The demand for higher plant efficiency compelled the adoption of means for regulating whereby water would be saved. This led to the application of the governor directly to the needle, and adoption of means for preventing pressure rises in the pipe line, by-passing the water shut off by motion of the needle, and then gradually closing the by-pass to save water.

For regulation by the water-saving method, the Pelton Water Wheel Company use an auxiliary nozzle, Fig. 16, operated by the motion of the main nozzle and governor through a dashpot, so adjusted that when the governor moves to shut off the water from the nozzle, the auxiliary nozzle is opened and discharges an amount equal to that shut off from the jet. The auxiliary nozzle then moves slowly to closed position and at such a rate as to prevent objectionable or dangerous increase of pressure in the pipe line. For regulation by the water-saving method, the Allis-Chalmers Manufacturing Company uses a pressure regulator, Figs. 17 and 18, connected in such manner that the motion of the governor in closing the needle operates control valves, which cause the pressure regulator to open and discharge water in proportion to that shut off from the jet, thus avoiding sudden velocity changes in the pipe line which would produce undesirable pressure changes. The valve of the pressure regulator moves slowly toward closed position by means of dashpot control of the regulating valve, and at such a rate as not to produce objectionable pressure in the pipe line. The annular opening between the pressure regulating valve and its seat provides for substantially equal increments in proportion to the motion of the valve, which

permits of more equal adjustment between the water shut off by the closing of the needle and the water by-passed. In some

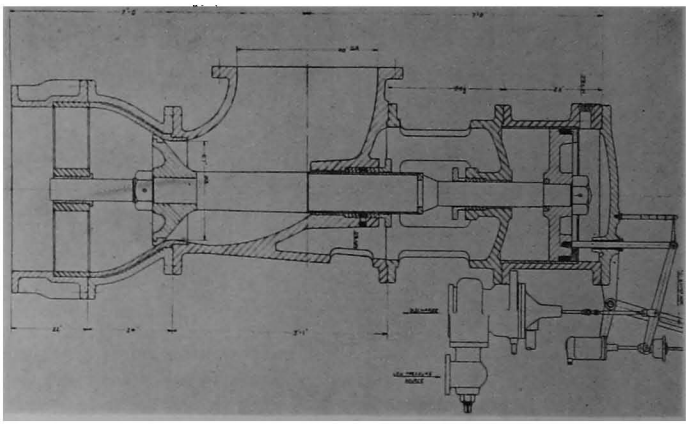


Fig. 17.
Water saving pressure regulator used by Allis-Chalmers Mfg. Co.

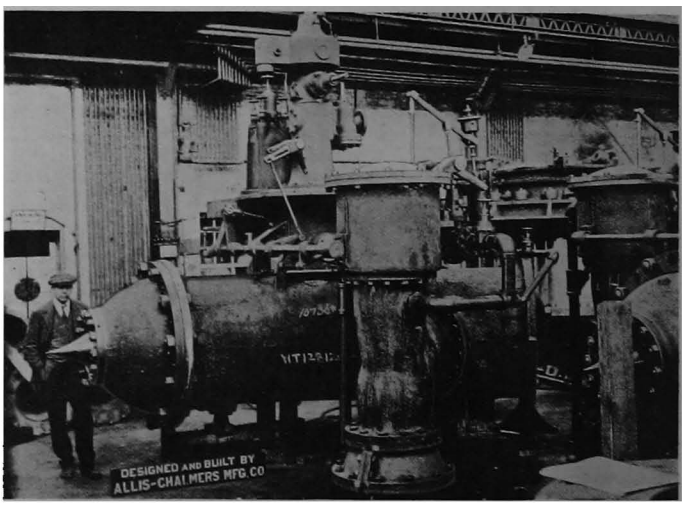


Fig. 18.
Water saving pressure regulators used on 30,000 horse-power Caribou units.

installations, independent and constant water supply is maintained against the side of the piston which tends to keep the pressure

regulator valve closed. The area of the piston and the constant pressure system are so designed that under normal conditions the valve is held closed. This provides an additional factor of safety in case of pressure rises not caused by action of the governor, which forces the pressure regulator open until pressure conditions returns to normal. The pressure regulator illustrated in Figs. 17 and 18, therefore, is capable of double function.

A short description of some of the recent impulse water wheel installations, with particular attention to the more salient details of design, will give the best idea of the present practice, and some idea of the extent of high head hydro-electric developments in the United States, most of which are in the western part of the country.

No city has had more rapid growth than Los Angeles, California, and no city has changed the character of its activities more completely than has that city. From a health restoring seaside winter resort it has become an active manufacturing city, quadrupling its size in two decades.

The city has stretched its tentacles of transmission lines into the mountains for power. One of the noted early plants to supply the city was the Kern River No. 1 Plant of the Southern California Edison Company, where there were put into operation in 1907, four 10,750 horse power, double overhung impulse wheels, operating under a head of 865 feet. Irrigation was first and still remains paramount on the Kern River, so a steady and never ceasing flow from the power house must feed the irrigation ditches. The regulation of the plant is accomplished by means of deflecting nozzles. Each unit is of the double overhung type, that is, one set of buckets on each end of the shaft, each set of buckets fed by one jet issuing from the deflecting nozzle, Fig. 5.

Each unit is equipped with one governor which operates both deflecting nozzles through levers and shafts. One of the early bronze buckets used on this plant is illustrated in Fig. 10. The needles are set by hand to discharge the required water and the deflecting nozzles are operated by the governor to regulate the load.

The impulse wheels in this plant were designed and built by the Allis-Chalmers Manufacturing Company in 1906. Recently, a new set of buckets, needles and nozzle tips were installed, after which careful efficiency tests were made by the Power Company,

whose engineers certified to an operating efficiency of over 86 per cent.

The growing industries of Los Angeles required additional power and in 1913 the network of transmission lines was extended further into the mountains and connection made with two additional plants known as Big Creek No. 1 and Big Creek No. 2, constructed on the headwaters of the San Joaquin River, which were impounded to form Lake Huntington. The impounded waters rightly belonged to the Power Company, to be used as occasion demanded, so that these two plants are regulated by the water saving method. Big Creek No. 1 Plant contains three Allis-Chalmers Manufacturing Company 23,000 horse-power impulse wheels operating under a head of 1,950 feet, at a speed of 375 R.P.M. Fig. 19 shows an interior view of the Station.

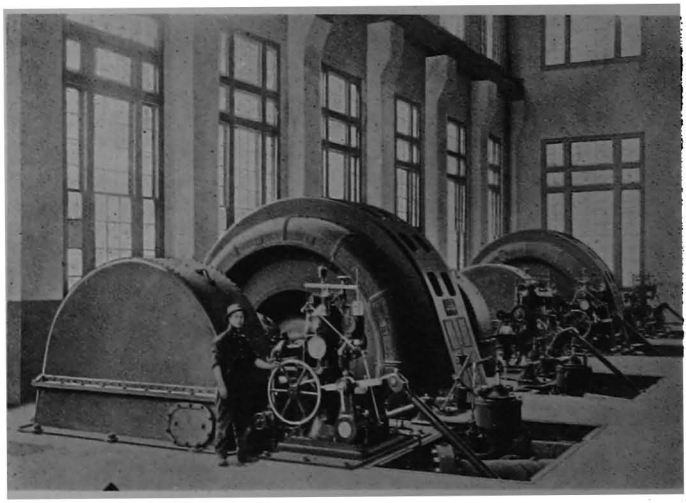


Fig. 19.

Interior of Big Creek No. 1 plant, two units of the double overhung type. 23,000 horse-power—1,950 feet head, 375 r.p.m. with governor and water saving pressure regulator on each nozzle.

Each unit is of the double overhung single nozzle per wheel type. Each needle is actuated through levers and rods by a governor mounted directly above the nozzle. Each nozzle is fitted with a pressure regulator operated by the governor. Each end of the generator, therefore, is driven by an independent water wheel,

having its own governor, pressure regulator and control mechanism, the two being connected only through the common shaft. These units have now been in operation for ten years and recent examinations show no appreciable wear upon the cast steel buckets of the units. Each nozzle is equipped with renewable bronze throat ring and each needle is fitted with a renewable steel tip. These conveniently renewable parts are changed from time to time and a good jet maintained which makes for long life of the impulse buckets. The operating head of 1,950 feet was too great to be used in the control valves of the pressure regulators, so that a supply was provided independent of the pipe line, at a pressure one-fourth of the total head. This proved not only suitable for the control valve, but afforded an additional safety in that excessive pressure in the main pipe forces the main valves of the pressure regulator open against the steady static lower pressure maintained underneath the piston actuating the main valve.

Careful efficiency tests for the acceptance of the plant were made in 1914 by Stone and Webster, the Company's Consulting Engineers, who certified to a maximum operating efficiency of 85½ per cent.

These efficiency tests were made after the nozzles had been enlarged to give 3,000 horse-power more capacity than that for which the units were designed. These wheels would have shown a higher efficiency had they been tested at capacity for which they were designed.

The Big Creek Plant No. 2, situated eight miles below No. 1 and using the water from it, operates under a head of 1,850 feet and runs at a speed of 375 revolutions. The initial installation of two units in Plant No. 2 is an exact duplicate of that in Plant No. 1. The throat rings and the nozzle tips of No. 2 Plant are slightly larger, however, on account of the lower head under which the same horse-power is required.

The City of San Francisco, lying 400 miles north of Los Angeles, is served by the Pacific Gas and Electric Company, which satisfies its power requirements principally from transmission lines strung across a hundred miles of valley land and on up into the gorges to power plants on the western slope of the Sierra-Nevada Mountains. Developments by this Company began on a small scale even prior to 1900 and larger units were added as the art of designing high head wheels developed. Additional power concerns also began to furnish power to the industries of the city.

The largest of these is the Great Western Power Company, which had built a Francis turbine plant on the Feather River, about 150 miles from San Francisco. In 1917 these lines were extended and the great Caribou Plant was built about 50 miles above their first plant, a transmission line of about 200 miles length with a tension of 220,000 volts was installed. This latest plant is located on a fork of the Feather River which still bears the mark of the early gold seekers. The station is equipped with three Allis-Chalmers Manufacturing Company double overhung impulse wheels of 30,000 horse-power rated capacity each, Fig. 20. These units have delivered 34,000 horse-power each

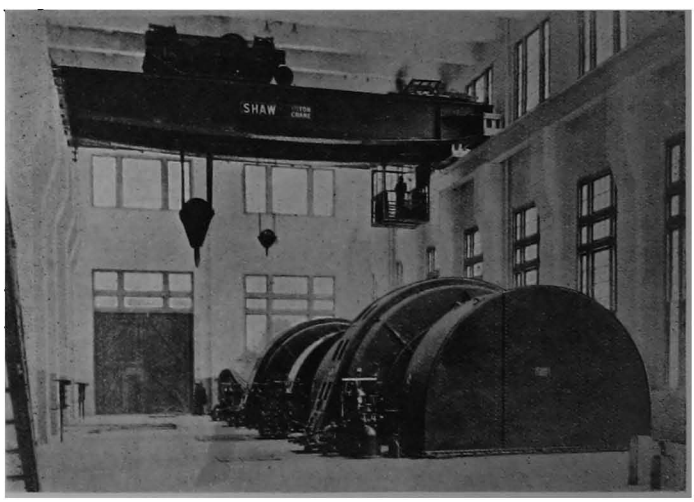


Fig. 20.
Caribou Plant of Great Western Power Company, two 30,000 horse-power 100 feet head, double overhung impulse units, two governors on each unit.

and are believed to be the largest impulse wheel units in operation in the world to-day. They are of the double overhung single nozzle per runner type equipped with water saving pressure regulators. The needle is controlled by piston mounted upon the rear end of the needle stem. The oil pressure on the two sides of the piston of the needle is controlled by an oil pressure governor mounted directly above each nozzle, making two governors per unit. The pressure regulators are controlled by an external low pressure source similar to the arrangement at Big Creek. The

pressure regulators, Fig. 18, open synchronously with the closing motion of the needle, and move toward closed position with a closing rate of about 30 seconds from wide open to full closed, thus operating on the water saving principle.

In 1912 the Pacific Gas and Electric Company started work on an extended hydro-electric development by impounding the waters of Lake Spaulding lying in the high Sierras on the border between the states of California and Nevada, with a dam 225 feet high, storing about 44,000 acre feet. A series of about five plants will use the discharge from this huge reservoir. The Drum Power House, the uppermost plant, and the only one using impulse wheels, contains four 18,000 horse-power, 360 R.P.M., impulse wheels operating at 1,375 feet head. A water wheel is mounted overhung on each end of the generator shaft and receives its power from a single jet through an "S" shaped deflecting nozzle with hand adjustable needle. One oil pressure governor per unit actuates the two deflecting nozzles of each unit simultaneously, and the discharge through the nozzle is adjusted by hand or remotely from the switchboard in accordance with the quantity of water to be delivered downstream. These units, built by the Pelton Water Wheel Company, were placed in operation late in 1913 and have given very satisfactory service. Chain buckets are used, as illustrated in Fig. 8.

Another large plant serving San Francisco has just been completed on the American River, where the Western States Power Company has put into operation two Allis-Chalmers Manufacturing Company's impulse wheels, each of 14,000 horse-power capacity under a head of 1,750 feet, Fig. 4. These are of the single overhung, single nozzle per runner type. Governing is accomplished through the water saving pressure regulators. The pipe line is 6,500 feet long. Its average velocity is 9½ feet per second; the WR. squared of the generator and wheel is 1,000,000 foot square pounds. Close regulation of this plant with water saving is a real accomplishment. The annular opening in the discharge valve of the pressure regulator gives a quantity discharge in fairly even proportion to the motion of the pressure regulator piston and affords an accurate means for compensating for quantity change by reason of the motion of the needle actuated by the governor. This plant is also equipped with the special attachment of the pressure regulator whereby the valve of the pressure regulator is held closed by pressure under a piston con-

nected to the valve stem, which pressure is fed from a constant source, in this case from a supply tank located midway up the pipe line. Any sudden excess of rise of pressure in the pipe line forces the valve of the pressure regulator open against the constant pressure underneath the piston in the control cylinder. Fig. 21 is an interior power house view of these machines in

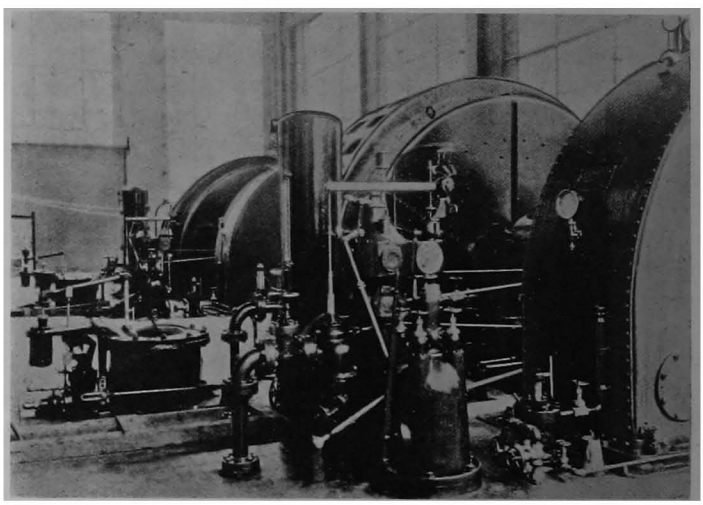


Fig. 21.
Two 14,000 horse-power, 1,750 feet head, single overhung impulse wheels.

operation and Fig. 22 is an exterior power house view with the unit on left hand side in operation and that on the right hand side by-passing full discharge through the energy absorber of the pressure regulator.

This plant, when completed, will contain two additional units, each 28,000 horse-power capacity, of the double overhung type. The wheel units are planned to be exact duplicates of the present wheel units of 14,000 horse-power capacity, allowing the same spare parts to be used for all units.

The municipality of San Francisco is now building a power plant in connection with its water supply, whereby a head of 1,250 feet is obtained by means of the Hetch Hetchy Dam. This plant will have an initial installation of three units 25,000 horse-power capacity each at 257 R.P.M. of the double overhung single nozzle per wheel type. It will be regulated by governors actuating the

needles controlling the jets impinging upon the wheel, combined with an auxiliary nozzle acting as a by-pass, having a dash pot and springs, so that the auxiliary nozzle closes slowly and automatically for saving water. A shaft and bearings for one of these units is shown in Fig. 14, assembled upon the erecting floor of the makers, the Pelton Water Wheel Company. This plant has not as yet been placed in commercial operation owing to additional work required in connection with the general scheme of the new water supply of the City of San Francisco.

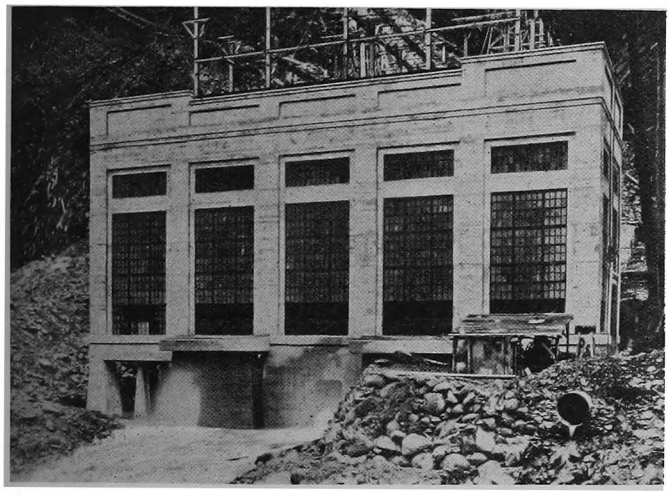


Fig. 22.
Western States Gas & Electric Company, one unit full load, other unit with regulator wide open showing effectiveness of energy absorber.

The power lines on the Pacific Coast have been so extended that power plants themselves are considered units in the operating system. Individual units in those power plants are made as large as possible, largely because of the simplification of the electrical switching.

The great plant at Kjukanfos, Norway, contains ten impulse wheel units of about 15,000 horse-power each, five units being furnished by the J. M. Voith Company, and the other five by Escher-Wyss and Company. The technical journals give the results of tests conducted in a most thorough manner at the plant

for the determination of the efficiency of these units. The water was measured by the screen method. The published results show the best efficiency of each make of wheel to be between 82 per cent. and 83 per cent. Each impulse wheel has two sets of buckets with two jets per set. The complication of piping necessary to direct the jets upon the buckets, at proper angles with relation to each other, introduces considerable curvature which undoubtedly has caused jet distortion, and this is probably responsible for the lower efficiency on this plant than was obtained, according to the technical journals, on the Escher-Wyss and Company's impulse wheels at the Adamello Plant, where there is one horizontal jet per set of buckets. The series of tests made at the Hydraulic Laboratory of the Allis-Chalmers Manufacturing Company leads to the belief that the difference in the efficiency on the two plants is due to jet distortion in the multiple jet units.

Limits of impulse wheel efficiency have not yet been reached. The writer is led to this conclusion by analogy in the case of the turbine wheel. It was thought that the efficiencies of Francis turbines were nearing the limit when they reached the neighbourhood of 92 per cent. on model sizes, such as are suited for test in the Holyoke Testing Flume, which still remains the standard of comparison in the United States.

The Allis-Chalmers Manufacturing Company has just been given a certificate of test by the Holyoke Testing Flume on a new reaction type of runner, which attains the remarkable maximum efficiency of 93.34 per cent., which is believed to be the World's record. Impulse wheel efficiencies will probably never reach this figure, but better efficiencies must be obtained than those mentioned herein.

As to the probable industrial trend in this art, it is believed that horizontal impulse wheel units will utilise more frequently a single jet per nozzle. It is believed that when the use of multiple jets is made necessary for reasons of economy, they will be more generally used upon a wheel mounted upon a vertical shaft, because greater space will be available within which the supply piping may be arranged with easy bends and compensating curves, so that jets may be obtained suitable for maximum efficiency. The vertical shaft impulse wheel is surely a logical development in view of the predominating practice of vertical shaft turbines and generators. Recent tests have demonstrated the feasibility of

avoiding serious interference from the portion of the water discharging upward from the buckets of an impulse wheel operated upon a vertical shaft.

The question is frequently asked as to just what maximum head Francis turbines can be operated under safely and as to what minimum head the impulse wheel can be used economically. High-head Francis turbines are now being constructed for operation under a working head of 850 feet of 35,000 horse power capacity. It is believed that when operating cost, interruptions to service, simplicity of operation, reliability of power supplied, are all taken into consideration, impulse wheels, even of large capacity, will not yet be crowded from their logical use under operating heads from 750 feet and up. The larger the capacity of turbine the more nearly it can be fitted to the exacting conditions of high head in respect of speed and efficiency.

In closing, the writer acknowledges his indebtedness to Mr. Ely C. Hutchinson, Vice-President of the Pelton Water Wheel Company for much of the information concerning the Pelton Water Wheel Company's practice and plants.

An art so old as this, and on which such rapid changes have come within so short a time, has not yet, in all probability, reached the perfection of attainment possible, and the vision of further accomplishment remains clear to some of us who have suffered many disappointments, but who have had many thrills of satisfaction when labouring in this worth-while art.

RÉSUMÉ.

Ce rapport donne une courte description des premiers développements des turbines à impulsion et spécifie les principes fondamentaux de leur construction. Il définit la vitesse spécifique et illustre, à l'aide de courbes, la relation des rendements des turbines à impulsion modernes par rapport aux vitesses spécifiques. Le rapport donne une analyse sur la formation convenable du jet afin d'obtenir un bon rendement et illustre par un diagramme l'arrivée de l'eau sur les godets du rotor. L'action du jet sur les godets est expliquée d'une manière simple, à l'aide de laquelle on met en évidence les points essentiels permettant d'obtenir les meilleurs résultats. Ce rapport illustre quelques grands paliers établis pour supporter les poids énormes des parties tournantes du générateur et des godets et donne les constantes d'échauffement ; il décrit également le réglage des turbines à impulsion par la méthode de perte d'eau et par celle d'économie d'eau. Une description est donnée des installations les plus importantes de turbines à impulsion sur la côte Ouest des Etats Unis et des illustrations représentent plusieurs grandes unités avec turbines à impulsion de construction récente.

WATER POWER PRODUCTION—CIVIL AND MECHANICAL ENGINEERING

DISCUSSION

Chairman: MR. S. KLOUMANN (NORWAY)

Friday, July 4th. *Morning Session*

MR. L. MANGIAGALLI *(Italy)*, in presenting his paper on *Recent Development in Dam Construction in Italy*, said that with regard to the dams constructed in Italy, one of the most important was the multiple arch dam in Sardinia, which was 79 metres high. Above it there was a reservoir of 460,000,000 cubic metres.

CAPT. H. VON HEIDENSTAM *(Sweden)*, in presenting the paper on *Recent Swedish Arch Dam Design*, by Mr. B. Hellström, said that in planning dam design, and especially arch dam design, it was most essential to take into consideration the stresses due to temperature and shrinkage deformations. In previous arch dam design, this had not been done, and the result had been that large cracks had in many cases appeared. In the theories developed by the author on temperature variations, and the stresses due to them, in arch design, he had shown the way out of this difficulty.

Dealing with the question of ice troubles (*Measures Taken in Sweden Against Ice Troubles at Water Power Plants*, by Mr. A. F. Samsioe), he said that in Sweden the conditions varied enormously.

Ice sludge was generally dealt with in Sweden by the formation of still water basins, whereby the water passed from one still water basin to another, just as it did in a series of sluices; this made it more or less impossible for ice sludge to form. The sludge had also been dealt with in some particular cases by the heating of the screens.

With regard to jamming, the remedy had been found in using the power available, either to heat the air on top of the intakes, or by heating those parts with which the water came in contact.

Another trouble which arose in connection with ice was the pressure exercised on the dams by ice in front of them.

MR. WILLIAM H. WHITE *(U.S.A.)*, in presenting his paper on *Impulse Water Wheels*, said that he believed that the impulse water wheel, or the Pelton wheel was purely American. Strange to say, this particular mechanical device was one outstanding feature which connected them with the past, back to Roman times. They had pored over their problems and developed devices which seemed extremely simple now, but which had been to them as real and apparently insurmountable as some of the problems with which they themselves were faced to-day. But they had improved the efficiency of those wheels. The modern impulse wheel converted the water energy available as pressure into kinetic energy in the form of a free jet, directed it upon buckets mounted upon the rim of a disc mounted upon a shaft, changed the direction of the jet within the buckets along smooth lines, and discharged it backward to the direction of the motion of the bucket, so that the water dropped with least velocity. The transformation of the water energy into mechanical power was thus accomplished, by giving impulse to moving parts by the force required to change the direction of the jet.

In his paper, he had shown the variation in efficiency in respect of the specific speed, or in respect of the power and speed of the wheel for the given conditions of head. He had shown the results of laboratory experiments which had cost thousands of dollars.

He thought that their engineers should not be satisfied in permitting to pass under their hands designs or machines fitted to meet a condition for the least money, but should take seriously to heart the charge which the people expected of them, and to pass to designers only that which was best. When it was considered that 1 per cent. of efficiency of one particular machine which had just been put into operation in California, meant 350 H.P., and when it was remembered that 1 H.P. did such tremendous work in California, it would be realised that a burden was laid upon the engineer to develop from such available resources every possible horse-power.

He then presented the paper on *The Hydraulic Reaction Turbine,* by Mr. H. Birchard Taylor.

The conditions in America, he said, were different from those in other countries, in that the purchasers of the machinery insisted upon having the greatest amount of energy from the water; and, because of the low relative cost of the hydraulic machinery in respect of the cost of the total development, they put into that machinery enough money to make it as good as the competing companies knew how to build. Therefore, they had been able to obtain in America remarkable efficiencies, because they were not limited in the cost of design or in the cost of experiments. He referred to the former installation at Niagara Falls consisting of three 37,500 H.P. units, where the question of the form of draft tube was one of considerable moment. Mr. Taylor had invented the type of tube they called the hydraucone—a concentric form of tube having a narrow outlet. This particular invention consisted merely in recognising the shape in the flow of water, which he thought had not been recognised or recorded before. By making the contour of the chamber of the draft tube to correspond with that shape, they had been enabled to secure higher efficiencies. He believed that by conferring together, and working together, as brother engineers, they could accomplish that real work which the people had a right to expect of them.

M. G. Darrieus *(France),** said he wished to mention two points. The first was in connection with the figures indicated by Dr. Lawaczeck for the transport of coal. In France, the cost of transport of one ton of coal for one kilometre was about two to three times the figure given by Dr. Lawaczeck, and he believed that in almost every country it would be found that the figure for transportation of coal was very much higher than that indicated in the paper. He believed that it would always be found possible to transport electric power over great distances at a lower cost than that of transporting the equivalent amount of coal over the same distances. At the present time, transmission lines were being built in France which would facilitate the transport of electric power from the central part of France to the northern part—to the coal district, in fact—at the price of about 2 to 3 centimes, all charges being included, which certainly was much lower than the transport cost of the corresponding amount of coal per kilowatt-hour.

The next point was in connection with the turbine. There were undoubtedly many points of value in the information given by Dr. Lawaczeck, but he believed he had not given the question of efficiency sufficient weight. Mr. White had shown how in the United States the question of efficiency was always considered of prime importance.

Mr. W. H. Munro *(Canada),* asked if it were not a fact that under the heading of *Water Power Production,* the mechanical engineering side had been given more exhaustive study than the civil engineering

* Translated.

construction work. Their relative costs were, roughly, 1 to 7, and yet, with the exception of the excellent papers dealing exclusively with the design of dams, there had been none under this heading, which aimed particularly at the reduction in cost of the civil engineering work.

It would appear that the mechanical engineer had outdistanced the civil engineer, in their common duty of reducing the cost and improving the quality of their respective contributions towards making cheap power available. Time and money had been spent on laboratories, on calculations, inventions, and tests, to improve the efficiency, raise the speed, and increase the reliability of operation of water turbines. Furthermore, very modest profits were the reward of the mechanical engineer.

Was not a stronger effort in the larger field of possible cost reduction a reasonable demand?

A DELEGATE, said that the proper development of water wheels could not be made without some accurate means of determining the result when the machinery was put under test. The factor usually in doubt had been up to the present time the amount of water which the turbine was using. He had used most of the standard means of measuring water, including the Weir, the Venturi meter, the Pitot tube, the current meter, and the salt solution method. All these had their limitations. The recent tremendous increase in the size of units to be tested, and the magnitude of the amount of water to be handled, and the necessity in most cases of testing the units after they had been installed, had demanded the development of some new, more accurate and less expensive method of measurement. In America, this demand had been met by the so-called salt velocity method, and the pressure time method—both as yet little known on the European Continent. Both these methods had been tested, had been calibrated, and had been thoroughly checked against volumetric measurement; and while he could not speak with authority as to the accuracy of the salt velocity method, he could say for the pressure time method that a series of tests against volumetric measurements had been made, showing a probable error for the series of something like two-tenths of 1 per cent.—an error in any one measurement or run of less than 1½ per cent. He had recently tested two plants built by different manufacturers in which the water wheels, measured from the entrance to the wheel case to the tail race had shown an efficiency in excess of 93 per cent. These units—the water wheel and the electric generator taken together—had actually put on the switchboard in electrical energy in excess of 90 per cent. of the total energy between head water and tail water.

DR. F. LAWACZECK *(Germany)*, after presenting his paper on *Large Low Head Water Power Developments*, thanked them for the kind attention they had showed to his proposals. They needed economy in the whole and not splendid efficiency in a part. It seemed to him only natural that designers who only glanced at the efficiency of their special problem could not agree with the proposal, where this efficiency was of minor importance compared to the economical improvement of the whole plant. He was glad to hear that Dr. Thoma personally seemed not to share this mere turbine designer's point of view of some German constructors, but seemed to understand what was meant by the term " economical efficiency."

DR. D. THOMA *(Germany)*, drew their attention to the fact that Dr. Lawaczeck had not said that for plants of every kind the efficiency was of minor importance. His opinion was only that for *special cases* a lower efficiency was allowable, if other advantages could be secured thereby. He did not intend to defend the views or the proposed designs of Dr. Lawaczeck—he would no doubt do that himself—but thought it should be pointed out that his views were not shared by the majority of German designers.

M. H. E. GRUNER *(Switzerland)*, said that in his country they had found out that in order to construct galleries under pressure, geological conditions had to be taken into careful account. It was the rock condition which decided the lining and the execution. If they were working in a good solid watertight rock, they could construct these galleries with a simple concrete lining. If they had a rock which was not so solid, they must put in a second lining of concrete and iron. In this connection they had found the use of the cement gun exceedingly satisfactory. The thickness of the plain concrete lining was from 20 to 40 centimetres, and the thickness of the concrete and iron was from 5 to 8 centimetres. Many injections of cement and mortar were made between the lining and the rock. They considered these injections to be of the greatest importance.

THE CHAIRMAN, suggested that one of the best results which could accrue from the Conference would be if they could secure a better understanding in the different countries of the necessity and importance of a rapid and forceful development of the water power resources of the world. He thought that in water, nature had given humanity a great and valuable source of power. Water power was a horse which would always work without any food.

When he considered the progress which had been made in the three different sections of water power production, namely, civil engineering, mechanical engineering, and electrical engineering, he thought that the greatest development in the civil engineering section was the introduction of the multiple arch dam, which dam by its relative cheapness enabled the engineers to make a very much more complete regulation of the water power; in the hydraulic section, the increase in the size and efficiency of the units, which efficiency was now brought up so near to the theoretical limit that in connection with the largeness and durability of the units, it secured the best possible economy; and in the electrical section, the introduction of the 220,000 volts transmission system, which made possible a co-operation between the countries rich in water power and those that were poor. If water power were ever to be of any real great use to humanity, it must be made as constant as possible, and in order to get constant water power all the year round, some big storages were required. They could never have had these big storages, if they had had to work with solid dams or gravity dams.

The arch dam had great advantages also in the conditions met with in the high mountains of Norway. They had had many troubles with gravity dams, because they had to build them in the winter time when there was no water, and to build big dams up in the high mountains in winter time was a very difficult task.

The turbine people had certainly done wonderfully well. They had increased the efficiency of the turbines from 75 per cent. up to 93 per cent. He quoted an example in his own experience where, by changing the buckets of water wheels, he had got an efficiency of about 89 or 90 per cent., instead of 84 per cent. That had made a difference on the two power stations in question of nearly 10 per cent., representing about 20,000 H.P.

The greatest credit was to be paid to the General Electric Company of America which had invented and put into operation a 220,000 volt transmission system. This high voltage transmission system opened up possibilities for the greatest co-operation between countries in the utilisation of water power resources.

In conclusion, he emphasised the necessity for the utilisation of the world's water power for the common benefit of all countries.

THE CHAIRMAN then closed the session.

WATER POWER PRODUCTION—
OPERATING CONDITIONS

CHAIRMAN: DR. ED. TISSOT (Switzerland)

Président de l'Association Suisse des Électriciens

ICE TROUBLES IN NORWEGIAN WATER POWER PLANTS

ARVID RUTHS
Director, A/S. Hafslund and A/S. Vamma

I. Water has its maximum density at a temperature of +4°C. (39·2°F.). In the autumn, when the water in a lake is cooled off, the water temperature at the bottom, therefore, will adjust itself to this value, the surface temperature gradually approaching 0°C. (32°F.). The water will then commence freezing at the surface, giving off its latent heat amounting to 80 calories per kilogramme of water of 0°C. (32°F.).

The cooling of the water commences at the surface level in immediate contact with the cold air, and the water thus cooled will sink to the bottom, causing the warmer bottom water to ascend to the surface, from where, after cooling it again descends. This circuit continues until all water of the basin in question has obtained a temperature of 4°C. (39·2°F.).

On continued cooling the cold water will remain in the upper strata and its temperature will decrease to 0°C. (32°F.). When its latent heat is given off, a smooth sheet of ice is formed. This ice cover, being a comparatively poor conductor of heat, will protect the water underneath against further heat losses, and the water temperature below will therefore remain considerably above 0°C. (32°F.).

Formation of ice in flowing water is governed by the same physical laws as for still water, but in addition also by the influence of the current. The surface water is also here cooled by contact with the cold air, but owing to the more or less whirling motion of the water, the cooled water particles will be carried into deeper strata, even right down to the bottom. During the time, when a certain particle of water is carried along the surface, the cooling is so intense that its conversion into ice crystals commences, but no time is left for these crystals to cohere and form an ice-layer because the whirls force them into the lower water strata.

Such ice crystals, or ice needles, are also formed in waterfalls or rapids where the water is beaten into foam. The very intimate

mingling of air and water taking place here causes formation of ice needles in large quantities. These needles have usually a length of about 20 mm. ($\frac{3}{4}$ in.) and a thickness averaging about 1 to 2 mm (·04 in. to ·08 in.) Under certain conditions, favourable to their formation, they appear in such large quantities as to fill the entire river bed from bottom to surface.

The ice needles, as mentioned, are formed in rivers where the current prevents the formation of a continuous sheet of ice, the latter acting as a heat insulating layer against the cooling effect of the air on the water. They are formed when the water temperature sinks from +0·06° to +0·05°C. (32·11° to 32·09°F.) and the formation continues as long as the temperature remains at, or below, this point. In local whirls these ice needles have a tendency to clot together and these clots will in turn mutually unite, constituting large lumps of ice needles measuring several m.^{3} in volume, and float down the river (1·0 m.^{3}=approx. 35 cub. ft.).

This formation of ice needles and their aggregates is in America and Canada termed "frazil ice," elsewhere perhaps known as "crizzle," or "young ice." The ice needles have a tendency to adhere to, and settle on, all solid objects encountered, for instance, when following the whirling motion of the water they hit the stones of the river bottom, they will immediately stick to these, forming large aggregate ice masses, bottom crizzle, or anchor ice. In the same way, when the ice needles strike other submerged bodies, as for instance structural members of iron or wood, they will cling to these, forming similar ice lumps.

The formation of ice needles—as stated—is contingent upon the water temperature being lowered to about 0·06°C. (32·11°F.) and upon the flowing water not being ice covered. Such low water temperature is again dependent upon certain atmospheric conditions, such as air temperature, wind conditions, formation of clouds, etc. With a cold north wind and clear weather, frazil ice formation has been observed in the Glommen river at a temperature of a few degrees below celsius zero (32°F.) while no such formation has been observed in cloudy weather under otherwise similar conditions. With air temperatures as low as —25° or —30°C. (—13° or —22°F.) and no wind, frazil ice will not always appear owing to the presence of a heat insulating, moisture saturated, layer of air on top of the water, which layer will prevent the cold air from cooling the surface water to the critical temperature.

This critical temperature varies, as previously mentioned, between +0·05° and +0·06°C. and the ice needles commence appearing

as soon as the water temperature has reached this point. As water crystallizes into ice at 32°F., it is, obviously, a mixture of cold and warm water particles, which causes the resulting water temperature; and when the cool water particles of 0° (32°F.) have been able to give the water a mean resultant temperature of +0·06°C. (32·11°F.), the ice crystals will be formed in the cold water particles. The lowest temperature ever recorded in flowing water in the river Glommen is +0·02°C. (32·036°F.), measured with a thermometer graduated to the scale: 1 cm.=0·1°C. (1 cm.=0·4 in.). The lower the water temperature sinks, the more intense will the ice needle formation be, and the easier the needles will cling to obstructions met on their way. Frazil ice periods may last from a few up to eight to ten days, ceasing if the water temperature for any reason rises, for instance, when cloudy weather sets in, the cold north wind ceases, surface ice is formed, etc.—in other words, when any change takes place, causing the radiation of heat from the water to the cold air to become less than the absorption from the river bed. The ice crystals melt and disappear when the water temperature has risen above the critical temperature, +0·06°C. (32·11°F.), and approaches 0·1°C. (32·18°F.).

II. Norwegian water power plants have formerly, in a large measure, had to cope with ice troubles of different kinds, so serious in certain cases as to cause complete shut-down of the plant. As the causes of these ice troubles have been more closely studied and different ways and means to obviate them have been tried we have now arrived so far—at least in connection with the larger plants—that these ice troubles no longer jeopardise operation, as in the early days of water power development.

The characteristic feature of the rivers of the south-eastern part of Norway is their long stretches (up to several hundred miles long) of swift flowing water, with plenty of rapids but no intervening lakes, followed by a stretch where one or more natural lakes are formed, whereupon the flow continues through another narrow passage with many rapids and falls.

In such a typical river of the south-eastern part of the country the ice troubles, up to the time in the autumn when the formation of surface ice commences, will be very great. Owing to the swift current and the many rapids these rivers will become ice covered rather late in the season, and their water therefore will be cooled very much. Naturally, the quiet lakes will become covered with surface ice earlier, hereby providing basins of comparatively warm water, up to 4°C. (39·4°F.). The discharge from an unregulated lake is

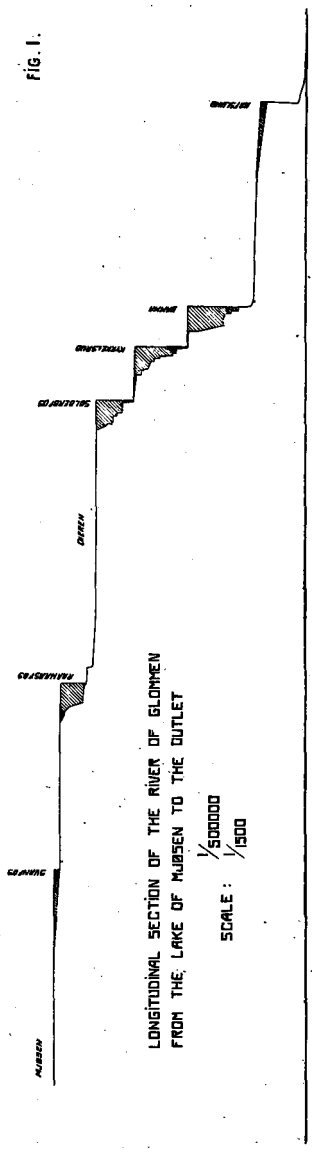
similar to that of a common weir ; it is always the surface water which is discharged and flows on down the river. This condition is not appreciably altered, even when the lakes are ice covered, although in this case the water will be cooled less in passing the lake along the surface. On its passage the water, therefore, will get its temperature lowered very much in the long river courses of swift-moving, whirling waters, whereupon it will pass the lakes as a cold surface stream and be further subjected to renewed cooling in the rapids and whirlpools farther down the river. When the frost has set in, the temperature of the water in such a river can vary from 0·1° to 1°C. (32·18° to 33·8°F.) and an intervening lake with surface discharge has no appreciable regulating influence on this temperature. Frazil ice will easily form at such a low temperature, when proper atmospheric conditions are present, *i.e.*, clear frosty weather with cold north wind. The more ice covered the river becomes during the winter, the less subject to the cooling effect of the air the water will be, with subsequent less formation of frazil ice. This statement is confirmed by the fact, that it is always the first frost period of a winter which is accompanied by the greatest ice troubles in the form of floating ice needles, and the reason for this, as stated, is that the rivers have not yet been ice covered, the cooling of the water therefore being very intense.

In rivers, therefore, where no regulation of the stream flow has been carried out and no power development exists all natural conditions favouring an excessive ice needle formation are present, the water being cooled in passing the whirlpools of the long stretches of the river and in being drawn off as surface water from the lakes.

On the other hand, the ice troubles will diminish when developments in the rivers have been carried out. The lakes will be used as reservoirs for water storage, and their water will be drawn off during the low-water period of the winter to increase the flow of the river at that time. The water is not then, however, drawn off from the surface, but through bottom outlets. Instead of cold surface water, the deep and warm water will now be discharged down the river, resulting in an increased water temperature and less tendency to ice needle formation, since the temperature no longer is so close to the critical temperature as before.

Construction of water power plants in a river will also exert a favourable influence on the ice conditions. By development of power plants, as a rule, not merely is a single fall utilised, but by damming a long stretch of the river a series of minor falls and rapids are combined into one head by means of a single dam. The

FIG. 1.


LONGITUDINAL SECTION OF THE RIVER OF GLOMMEN
FROM THE LAKE OF MJØSEN TO THE OUTLET
SCALE: 1/500000
1/500

damming has then transformed the part of river in question from a series of whirlpools and rapids into an artificial lake or forebay with comparatively quiet water, soon ice covered in the autumn. When all available falls have been developed, and the original rapids in a river have been transformed into a series of calm, ice covered basins, or lakes, from which the water, drawn from the bottom, is carried to the turbines, the cooling of the water will necessarily be considerably less than formerly in the original state of the river, the ice troubles being also correspondingly reduced. It is anticipated that this, in connection with regulation of the lakes will cause the frazil ice formation to disappear entirely.

The river Glommen has undergone a typical evolution in this respect. The upper part of this watercourse consists of two rivers, the Glommen and the Laagen. The Glommen flows through the valley of Osterdalen, where it forms no lake in a distance of more than 200 miles. The Laagen flows through another valley, Gudbrandsdalen, also without forming a single lake in a distance of about 200 miles until it runs into the large and deep lake of Mjösen, the confluence of the two rivers taking place a short distance below the lake. The river then flows into another great lake, the Oieren. The total fall of the river from Oieren to the sea is approximately 100 m. (328 feet), in a distance of 60 km. (37 miles). Of this 100 m. head, some 75m. (246 ft.) are concentrated in a distance of about 20 km. (12 miles), a stretch which, in the original state of the river, was one continuous, long rapid. Also above the Oieren there were falls and whirlpools. The natural conditions of this river, therefore, were as unfavourable as possible with regard to ice troubles. Fig. 1 shows the longitudinal section of the river from the lake of Mjösen to the outlet in the sea. As will be seen, there were here originally a large number of minor falls and rapids, where in winter the water was subjected to severe cooling. The first power plant constructed on this river—at Sarpsfossen in 1898—had therefore to contend with much ice trouble, especially heavy formation of frazil ice, at times of such magnitude as to cause complete shut-down of the plant. Gradually, however, more water power has been developed along the river, the lake of Mjösen has been dammed for storage purposes, the lake of Oieren will soon be, and in course of the next few years all the mountain lakes, which form the head waters of this river, will also be utilised for storage purposes. Practically all rapids from the lake of Mjösen to the sea will in the course of a few years entirely disappear, giving place to large water power developments. As will appear from the

sketch, the aspect of the river below Mjösen will then be totally altered, the many wild cascades and whirlpools of former days being changed into a series of well-regulated lakes and forebays, entailing cessation of the great ice troubles of the days gone by, particularly those resulting from frazil ice formation. Surface ice will now quickly cover the calm river and protect the water against excessive cooling from the air, and the tapping of lakes and forebays will no longer be effected by drawing off the cold surface water, but the warm water from lower strata.

An evolution as outlined is typical of the majority of the large Norwegian watercourses. It is the first water power developments in a river which have to fight the ice troubles. As the water power is more extensively developed these troubles will disappear.

Sudden severe frost periods will cause a large part of the river to freeze up. Large quantities of water are thus converted into surface ice, ice needles, and anchor ice, as a result of which the flow will diminish appreciably. This decrease in flow varies for different rivers, depending upon the extension of the watershed, the area of water surface, and the quantity of flow. In the Glommen, where the regulated winter flow at present is about 220 m.^{3}/sec. (7,770 cub. ft./sec.) this sudden decrease in flow, on such occasions, can amount to about 30 m.^{3}/sec. (1,060 cub. ft./sec.), or 13 per cent. measured at the last waterfall, reducing the available flow to about 190 m.^{3}/sec. (6,710 cub. ft./sec.). In the river Numedalslaagen with a regulated flow of about 35 m.^{3}/sec. (1,236 cub. ft./sec.) a drop to 25 m.^{3}/sec. (883 cub. ft./sec.) is encountered in frosty weather, in other words, 25 per cent. of the flow is retained in the river, temporarily icebound.

This phenomenon, of course, will greatly reduce the output of the power stations, unless guarded against by increasing the discharge from the storage reservoirs as soon as the frost starts. As frost periods usually last only a few days, the inconvenience caused will soon pass away, and the tapping of storage water is discontinued as soon as the frost and the ice formation has ceased. Obviously, the power plants located immediately below the storage reservoirs are most advantageously situated, because the increased water supply from the reservoirs will at once be effective upon the station output. Entirely different in this respect are those plants whose water requires several days to travel from the reservoirs to the power stations as, for instance, in the river Numedalslaagen, the storage reservoirs of which are located in the upper part of the river, in the mountains, and whose power stations are

close to the river outlet. The inconvenience mentioned can in cases of this kind be of great importance. They can be overcome, however, by running plants of this nature in parallel with power stations of the first category, which have storage reservoirs located in close proximity above, being able immediately to supply water to suit the power demand.

The same phenomenon, *viz.*, that during its passage the water is temporarily bound in the form of ice, has to be taken into consideration in manipulating the discharge from storage reservoirs. In the river Glommen, for instance, the water discharged from the reservoirs in the upper mountainous part of the watershed has to flow for a distance of several hundred miles before it reaches another lake. The water quantity passing these river stretches is sometimes small, and early in the autumn the water becomes covered by solid, thick surface ice. If the tapping of the storage is started, *i.e.*, the stream flow is augmented, some time after the layer of surface ice has been formed, the water from the storage has to pass on top of the surface ice, since the space underneath is occupied by the natural flow existing before tapping was commenced. Consequently, in long stretches of the river the water from the storage under these unfavourable conditions is converted into ice which will not melt until springtime. Operated in such a manner the benefit of storage reservoirs in the mountains is a rather illusory one.

To prevent this disadvantage, the tapping of such storage reservoirs has to be started in the autumn, before the frost commences, and it must be so continued that the flow in the river below be kept as uniform as possible. In this way the storage water will travel below the protecting ice cover which prevents it from becoming bound in the form of ice.

III. Water power developments must be planned with due regard to the ice troubles likely to arise. In Norwegian power plants it is particularly drift-ice and frazil-ice formation which cause trouble, and each of these requires special measures for its obviation.

Drift-ice appears when the surface ice of the river is broken up by a heavy storm, by variations in the water level, etc. Large and small pieces of smooth, solid ice, float down the river and are, as a rule, carried into the forebay of the plant where they will cause trouble by covering up the screens, partially or totally obstructing the water passage through these.

In designing a plant due regard, as stated, must be given to drift-ice conditions, either by adopting an arrangement that will exclude

the drift-ice from entering the forebay, or, if this is not possible, to provide such design of the forebay as will facilitate easy and quick removal of drift-ice entering.

In Figs. 2 and 3 are shown two typical examples of both arrange-

Fig. 2.
Map of River and Power Plant at Vamma.

ments. Fig. 2 is a map of the river and power plant at Vamma on the Glommen. The available head at this plant is created by damming up several minor falls, combining them into one single

head by means of a large dam structure, above which a new lake has been formed in the river, serving as forebay and storage reservoir for the plant. Early in the autumn, this basin becomes covered with surface ice clear down to the screens in front of the pipeline inlet in the dam, and this surface ice prevents drift-ice from reaching the screens. Such an ice-covered forebay will also successfully obviate frazil ice troubles, as any floating frazil ice entering the comparatively still water of the forebay will get a chance to rise and stick to the ice cover before the screens are reached. Fig. 3 shows the Kykkelsrud hydro-electric plant, also situated on the Glommen, in its present stage. Characteristic of this plant is the long headrace canal, which conveys the water from the river bed to the forebay at the power house. The water-velocity in the canal—exceeding 2 metres/sec. (6·5 ft./sec.)—is great enough to exclude formation of surface ice, and as the entire flow of the river passes through the canal, all drift-ice, frazil-ice as well as solid ice, will be carried direct into the forebay. As will appear from the sketch, an ice-sluice is provided here which, when opened, will create a surface current alongside the screens by means of which the solid drift-ice is removed with comparative ease from the forebay.

But only surface ice can be removed in this way; drifting frazil ice is not so easy to deal with. It has been mentioned that the frazil ice, at times, can fill the entire river bed from bottom to surface, and that it has a tendency to stick to all obstacles encountered. The headraces, for instance at Kykkelsrud, are, as a rule, shallower than the river bed, and the canal inlet is again wider and shallower than the canal proper. The frazil ice masses floating down the river, therefore, when entering the canal, will have their passage obstructed, as a result of which large quantities of frazil ice will accumulate at the canal intake. The ice masses at this point may become so heavy as to menace the operation of the plant. It has happened at Kykkelsrud, that an ice-barrier has been built up in front of the canal intake from bottom to surface, about 20 metres (65 ft.) wide. By careful use of dynamite such ice masses can be blasted to pieces and the current will then carry them through the canal down to the screens.

Plants of the Vamma type, Fig. 2, without headrace canal, are therefore far more advantageous with regard to ice troubles than those with headraces, as per Fig. 3.

At plants of the latter type, having no large ice-covered forebay as protection against ice troubles, it has been sought to remedy this disadvantage by placing, in the autumn, a coarse network of

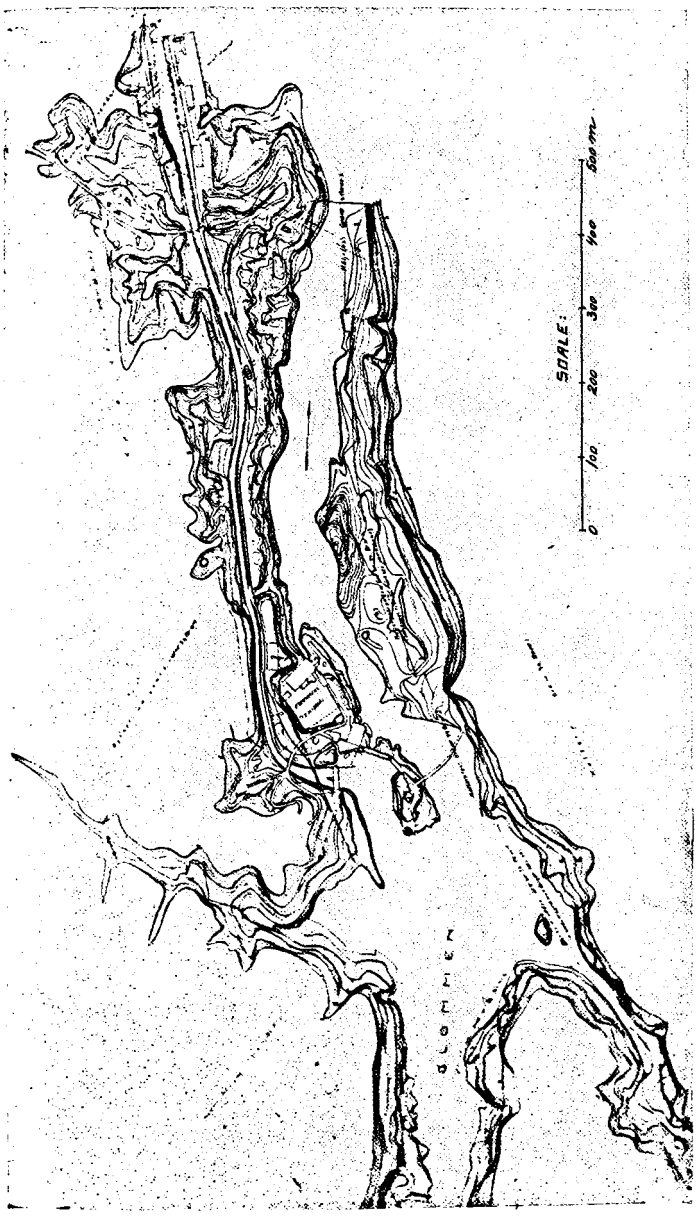


Fig. 3. Map of River and Power Plant at Kykkelsrud.

timber, in the canal and river above, which by its quietening and damping action on the water will facilitate the formation of a protecting sheet of surface ice.

IV. All ice troubles concentrate at the screens. When the ice needles, uniformly distributed in the water, come floating and strike the iron bars of the screens they will stick to these, immediately followed in succession by others, so that the bars soon become covered with an ice layer, rapidly increasing in thickness, until the screens are choked up entirely. The ice appears to be growing, as it were, on the bars. The large lumps of ice needles, measuring several cubic metres, drifting with the current and capable of floating in all levels are with great force thrust against the screens and by the water-pressure the large spongy lumps of ice needles are soon compressed into a solid ice mass, impermeable to water. In this way, the entire surface of the screens can be covered with a layer of ice up to 1 metre (3·28 ft.) thick, as a result of which the water supply to the turbines will be stopped entirely. The screens will be subjected to the full, one-sided water pressure, causing heavy strains on the screens and their supporting members. One case is recorded where the support gave way and the screens collapsed.

In the course of time several means have been tried to keep the screens free of frazil ice. To start with, hand scrapers were resorted to for this purpose. As many men as could conveniently find place on the stand above the screens, were mobilised at times of frazil ice formation, trying with scrapers of different lengths to keep the screens free. As a rule, though, these endeavours were entirely in vain ; the screens clogged up in spite of this, and the output was reduced accordingly. Mechanical scrapers of various designs have also been tried. These were placed in front of the screens, and consisted mainly of a frame structure, to which were fastened suitably spaced horizontal beams provided with teeth meshing with the openings between the screen bars. The frame, driven by a motor, was arranged to slide up and down the screen, and by this motion of the teeth between the bars the screens were to be kept free of frazil ice. But even these mechanical scrapers have proved unsuccessful, the ice formation being occasionally so heavy that they stopped entirely.

One method is to remove the screens when the ice troubles start and replace them by a coarse rack of wooden planks. This arrangement allows the frazil ice to pass through the turbines as comparatively loose masses, from which no damage will result. But smaller or larger pieces of solid ice following the current and

passing through the racks may involve a certain danger to the turbines. Of course, such racks are also apt to be clogged up with ice, and their use is therefore rather delusive.

Proper depth location of the screens must embody complete submersion during winter. The temperature of the screen bar will then be the same as that of the water, even when the temperature of the latter falls below the critical point. Consequently, when frazil ice formation commences, the bars will possess the same low temperature and the ice needles will stick to the bars.

If, by any means, the temperature of the bars could successfully be raised above the critical temperature to between +0·06° and +0·1°C. (32·11° and 32·18°F.), the ice needles would no longer adhere to the bars and the worst troubles from frazil ice would be overcome.

Heating the bars by steam has been tried. The bars were then made hollow, with pipes conveying steam inserted into them. This method, however, has not proved satisfactory; it is elaborate, the bars must be thicker than usual, entailing a loss in net area of the screens; the steam pipes become leaky, whereby the heating of the bars ceases and the freezing-up commences. This steam heating is also very uneconomical as far as the thermal efficiency is concerned, and can be considered only for plants producing steam for other purposes also.

At the Borregaard power plant on the Glommen some screens are heated in this way and the steam consumption amounts to 13 kg. (29 lbs.) of steam per hour per square metre (10·8 sq. ft.) net screen area (minimum water area).

The best remedy hitherto devised for protection of the screens against frazil ice is electric heating of the bars. By this method, either single bars, or groups of bars, are connected in series. The current then passes through all the series connected bars, or groups of bars, and heats them.

For common screens with a water velocity from 0·4 to 0·7 m./sec. (1·3 to 2·3 ft./sec.) and a bar section of about 400 to 700 mm.^{2} (0·6 to 1·0 sq. inches), sufficient heating of the bars will be obtained with 250 to 300 amperes per bar, A.C. 50 cycles.

Fig. 4 shows diagrammatically a section of the electrically heated screens at the Kykkelsrud plant. This section comprises three fields, one field for each turbine developing 6,000 H.P. at a water consumption of 35 m.^{3}/sec. (1,236 cu. ft./sec.). Each field, as

appears from the sketch, consists of four screens in series, and the three fields in question are Delta connected with a secondary bus-bar system at a voltage of 220 volts.

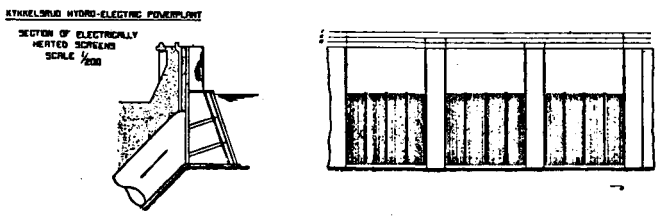


Fig 4.

Fig. 5 shows a detail drawing of the screens. As will be seen, the length of the screen bars in this case is 8650 mm. (28 ft. 4 in.) and each screen contains fifty-six bars of 70×10 mm. ($2\frac{3}{4}$ in. $\times$ $\frac{3}{8}$in.) section, parallel-connected in groups, comprising four bars each. This connection is made by a suitable piece of channel steel, welded to the ends of the bars. The bars are fastened to a frame of oak planks, which again is bolted to a steel frame resting against the supporting structures of the dam. Oak has been used for insulation.

The calculation of the power consumption is based on the ohmic resistance of the screens. Assuming the specific resistance of steel to be 0·1, the theoretical resistance of a field comprising four bars, as in Figs. 4 and 5, is:

$$R_1 = \frac{0{\cdot}1 \times 8{\cdot}65}{700} \times \frac{1}{4} \times \frac{56}{4} \times 4 = 0{\cdot}0173 \text{ Ohm.}$$

The actual resistance, however, is considerably greater owing to the additional resistance of the welded bar connections, the cables, etc., and has been measured for the field in question at Kykkelsrud as:

$$R_2 = 0{\cdot}15 \text{ Ohm} = K R_1 = 8{\cdot}7 R_1$$

The screens at Kykkelsrud, illustrated in Fig. 4, work with a power factor $(\cos \phi) = 0{\cdot}76$.

With above values of the coefficient K and the power factor it is an easy matter to compute the power, voltage, and transformer capacity required to obtain a current of 250 to 300 amperes through the screen bars.

The table below contains particulars and readings from various electrically heated screens, the values given for power consumption, etc., being those found adequate to prevent the ice needles from adhering to the bars.

Particulars of electrically heated screens.	Hafslund, I.	Hafslund, II.	Kykkelsrud.	Övre Lerfoss.		Nedre Lerfoss.	
				Old Plant.	New Plant.	Old Plant.	New Plant.
Number of bars connected in parallel	4	4	4	1	1	1	1
Power factor (measured at the primary side of the transformer)	0·73	0·72	0·76	—	—	—	—
Power factor (measured at the secondary side of the transformers)	—	—	—	0·88—0·87	0·85—0·86	0·85	0·86
The coefficient K	8·4	8·1	8·7	6·66	5·45	5·2	5·27
Current per bar, in amperes ...	270	274	275	280	240	178	290
Sectional area of bar, in mm.^{2} ...	10 × 70	10 × 70	10 × 70	6 × 65	6 × 65	6 × 65	6 × 65
Current density per bar, in amp./mm.^{2}	0·39	0·39	0·39	0·72	0·615	0·455	0·75
Frequency (at the test)	50	50	50	48	48	48	48
Voltage between outer phases, in volts	225	225	215	156	158	164	162
Method of bar field connection	Y	Y	Δ	Δ	Δ	Δ	Y
Free opening between bars, mm.	32	32	28	46	36	25	32
Water velocity through screen, metres/sec. ...	0·6	0·49	0·65	0·65	0·79	0·514	0·78
Energy consumed per m.^{3} flow of water, kW. ...	5	5·7	5·2	6·9	4·8	3·5	4·8
Energy consumed per m.^{2} effective screen area, kW.	3·1	2·8	3·3	4·5	3·8	1·82	3·76
Length of bar per m.^{3} water consumption in m. ..	52	64	54	56·5	60	86·5	45
Energy consumption per linear metre bar length, kW.	0·095	0·09	0·094	0·12	0·081	0·041	0·106
Energy consumption per m.^{2} of bar surface, kW.	0·6	0·56	0·58	0·85	0·566	0·29	0·75

As will be seen in the table, the power consumption of these screens averages 5 to 6 kW. per $m.^3$ (35 cu. ft.) of water passing through the screens per second.

The use of electrically heated screens prevents the ice needles from adhering to the bars, facilitating the frazil ice passing through. However, large quantities of solid ice blocks may be floating on the water finally settling at the screens. These ice blocks must be removed by the watchmen as quickly as possible. Manual assistance cannot, therefore, be entirely dispensed with by the use of electrically heated screens, but while formerly—with unheated screens—a gang of fifty to sixty men, working with scrapers on the screens, failed to maintain the operations of the plant, it is possible, with heated screens, to keep the same plant going during the worst periods of frazil ice formation by the aid of a few men only, for removal of drifting ice blocks.

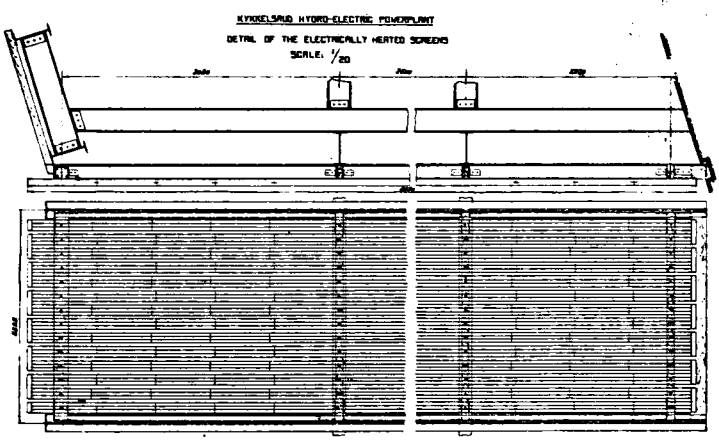


Fig. 5.

Plants having uncovered pipelines between the dam and the turbines, are in frosty weather troubled with interior icing of the pipes, the inside of these being covered with a compact layer of solid ice up to 30 cm. (12 in.) thick in certain cases. This ice crust is formed at the same time as the frazil ice, *i.e.*, when the water temperature is below +0·06°C. (32·11°F.) and the air temperature less than about −10°C. (+14°F.). As, with increasing water and air temperatures, the formation of frazil ice ceases, the ice cover will loosen from the inside of the pipe and hard, solid pieces of ice

will be carried down to the turbines where they may cause damage and interruption of the service. This trouble can be overcome by protecting the pipeline against the influence of the cold air, either by imbedding it in concrete, or by covering it with some heat-insulating material; for instance, by so casing it in that an air space is left between the protecting cover and the pipes.

Ice sluices and various other discharge openings are liable to clog up with ice, and must be kept open by steadily cutting the ice away. Such icing is prevented by inserting electrical heating elements in the adjacent masonry, such elements to be of about 1,000 watts capacity, spaced about 1½ to 2 metres (5 to 6½ ft.) apart. In this way, the masonry is heated sufficiently to exclude the possibility of ice growth, facilitating clean discharge passages during the most severe frosts.

The same preventive, *i.e.*, imbedded heat elements, can also be used as a guard against roller dams freezing up to the side walls at both ends of the roller. Equal results are also obtained by provision of suitably located, electrically heated steel bars. The latter method is employed at the Vamma power plant to protect the roller dam against freezing.

In connection with fermette-weirs a certain condition may arise, worthy of attention. When the river above the weir freezes up, the ice cover will extend right down to the fermettes and freeze on to these. If now the water level above the weir varies and, consequently, the surface ice moves up and down with the fluctuating level it may happen, providing sufficiently strong and thick ice, that the fermettes are lifted over the sill of the weir and are carried away, great quantities of water being then suddenly discharged. To avoid this calamity, it must be strictly observed at all levels of the water to keep an open belt in the ice, about 1 metre (3·28 ft.) wide, in front of such weirs.

RÉSUMÉ.

Ce rapport donne une brève description des ennuis causés par la glace contre lesquels ont eu à lutter les installations norvégiennes de force hydraulique.

La section I traite de la formation de la glace en général et l'on y montre comment, dans l' eau courante, la formation de la glace provoque l'apparition de ce que l'on appelle des aiguilles de glace.

Dans la section II est décrite une rivière type de la région sud-est de la Norvège; l'on y montre comment, dans cette rivière, se rencontrent ces conditions qui favorisent la formation d'aiguilles de glace et de glace solide, sources d'ennuis dans les deux cas pour les installations de force hydraulique. On y montre également, toutefois, comment dans les dernières constructions

de travaux pour la régularisation de courant et l'installations de nouvelles usines de force ces inconvénients causés par la glace seront considérablement réduits.

Dans la section III l'on démontre comment une installation de force devrait être comprise de manière à réduire autant que possible les inconvénients causés par la glace.

La section IV traite des ennuis occasionnés aux grilles, aux vannes etc., et des différentes méthodes qui ont été tentées pour obvier à ces ennuis, le chauffage é ectrique des grilles y étant décrit en détail.

ELIMINATION DES APPORTS PIERREUX DANS LES CANAUX INDUSTRIELS

CORNELIO ARELLANO
Ingénieur des Ponts et Chaussées.

Dans tous les canaux dérivés de rivières charriant de grands apports pierreux (limons, sables, graviers et pierres de plus grandes dimensions), il est très important d'éviter leur entrée dans le canal, car si on ne fait pas de nettoyages coûteux, la capacité de transport est, dans quelques cas, réduite jusqu'à s'annuller ou à peu près, et s'il s'agit de canaux industriels il faut éviter l'arrivée de ces apports dans les turbines car ils y produisent de profondes érosions qui diminuent le rendement.

L'ingénieur soussigné travaille depuis plus de vingt cinq ans aux rivières de grands apports et il a réalisé plusieurs aménagements en y essayant différentes solutions avec des améliorations successives jusqu'à celle qui a été adoptée dernièrement à la chute de Anzánigo, sur la rivière de Gállego, province de Huesca (Espagne), inaugurée au mois de Février 1923.

Cette installation compte donc près d'une année de fonctionnement et comme pendant ce temps on a constaté l'absolue efficacité de la solution adoptée, nous osons la soumettre à la considération de MM. les Congressistes.

La solution généralement adoptée pour éliminer ces apports consiste à placer les vannes de chasse dans le barrage lui-même, près des vannes de prise, mais nous ne les avons adoptées qu'une seule fois, car nous considérons que leurs avantages sont très limités et nous jugeons qu'elles ont quelques inconvénients parcequ'elles peuvent faciliter l'entrée des matériaux flottants, dont nous parlerons dans une autre Communication. Nous ne signalons pas ces avantages et inconvénients pour ne pas trop allonger ce rapport.

SOLUTION ADOPTÉE À ANZANIGO.

On a exécuté plusieurs travaux pour éliminer les apports d'origine pierreuse ; ces travaux sont :

1°.—Prise d'eau.

2°.—Différentes purges le long du canal.

3°.—Deux réservoirs de décantation.

1°.—*Prise d'eau.* Nous avons toujours prévu des vannes de faible hauteur, pour faciliter leur inspection, mais par contre nous leur avons donné beaucoup de largeur de façon à réaliser une grande section de passage.

Le barrage de " Anzánigo " a 4 mètres de hauteur, le débit dérivé est de 12.000 litres par seconde et quoique le canal ait un tirant d'eau

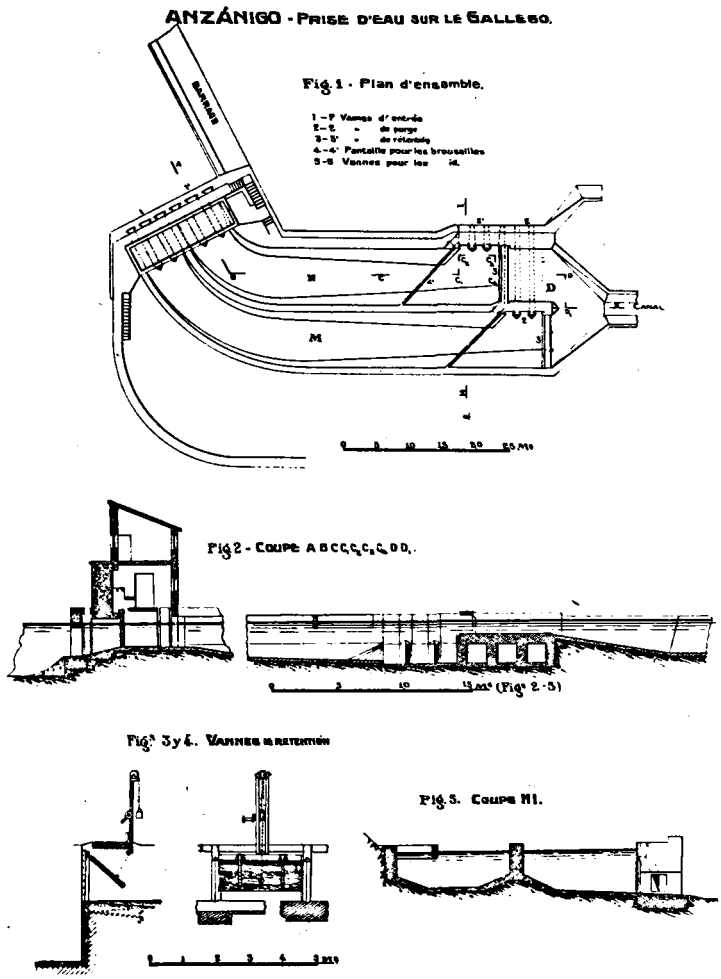


Planche 1 : Anzánigo—Prise d'eau sur le Gallego. Figs. 1-2-3-4 et 5.

de 2,50 mètres, nous avons placé six vannes de prise, ayant chacune 1, 60 mètre de largeur et 1, 70 mètre de hauteur, depuis le radier jusqu' au niveau du couronnement du barrage. Il en résulte une section mouillée de 16,320 mètres carrés.

Comme on le voit dans la figure 1, on a construit une double prise. L'eau entre par les six vannes 1—1' dans deux grands réservoirs de décantation M et N séparés par un mur longitudinal : à chaque réservoir correspondent trois vannes et de celles-ci l'eau passe à l'origine du canal par un évasement en élévation et plan D—D'.

Chaque réservoir possède à son extrémité aval trois vannes de chasse 2—2' qui déversent dans la rivière : l'eau sort directement du réservoir N, et de M par des canaux situés sous le radier dans la partie qui unit le réservoir N à l'origine du canal.

En rapportant les cotes des points à un plan de comparaison situé à 10,00 mètres en dessous du couronnement du barrage, la cote des vannes de prise est de 8,30 mètres : en partant de celle-ci avec une pente uniforme, on arrive aux vannes de chasse à une cote de 6, 70 mètres, et en continuant à descendre jusqu' à déboucher dans la rivière on atteint la cote de 6,50 mètres.

A l'extrémité des réservoirs, à côté des derniers orifices de chasse il y a un seuil de 1,80 mètre de hauteur (figures 2 et 3) devant lequel s'arrêteront les galets de toutes formes et les sables. La partie supérieure de ce seuil est à la cote 8,50 et comme il n'y a pas de perte de charge sensible à la prise à cause de ses grandes dimensions, le tirant d'eau sur les seuils est de 1,50 mètre. La largeur libre dans chacune de ces entrées est de 7,00 mètres, de façon à ce qu'entre les deux il y ait une section mouillée de 22,50 mètres carrés.

A la partie supérieure des seuils il y a trois vannes de retenue (à chacune des entrées) de 2,50 mètres de largeur, séparées par des piliers en béton armé de 0,25 d'épaisseur (figures 3 et 4).

Ces vannes sont mobiles autour d'axes horizontaux placés à la partie supérieure des cadres, elles s'ouvrent vers l'aval poussées par le courant ou actionnées par des câbles qui s'enroulent à des treuils installés sur des passerelles et se ferment en position verticale, retenues par des cornières fixées aux cadres quand le courant d'eau change de direction.

Chaque vanne a un câble attaché lequel, après être enroulé plusieurs fois sur le treuil remonte à une poulie et porte à l'autre bout un léger contrepoids qui permet de maintenir le câble tendu.

En marche normale l'eau entre par les six vannes de prise et arrive à l'entrée du canal en passant par les deux réservoirs et par les six

vannes de retenue qui seront ouvertes horizontalement, suspendues à des étriers installés sur les passerelles.

La section mouillée des deux réservoirs est très grande (d'environ 44 mètres carrés à l'extrémité) et le débit étant de 12.000 litres/sec. l'eau circulera à u e vitesse inférieure à 0,30 mètre par seconde, ce qui permettra aux sables et aux graviers fins de se déposer sans qu' aucun de ces apports ne franchisse les seuils.

Quand une crue survient il entre beaucoup d'apports, mais dans ce cas et toujours quand on dispose d'eau en abondance on nettoie l'embouchure et les réservoirs de la façon suivante.

Supposons que l'on veuille nettoyer le réservoir N, c'est à dire le plus proche de la rivière.

1°. On décroche les trois vannes de retenue du réservoir N en enlevant les clavettes qui les maintiennent aux passerelles et comme les contrepoids sont légers, les vannes s'introduiront dans l'eau suspendues par leurs axes de giration et elles ne se placeront pas verticalement car elles seront poussées par le courant.

2°. On ouvre complètement les trois vannes de chasse du réservoir N dans lequel se produit de suite une descente de niveau et un contre courant, du canal vers le réservoir, et les vannes de retenue se ferment immediatement poussées par l'eau.
Le réservoir N sera ainsi isolé du canal et les 12,000 litres/sec. entreront par les vannes correspondantes dans le réservoir M dont la section est amplement suffisante pour cela, en particulier si le niveau de la rivière dans la retenue est plus haut que le couronnement du barrage, époque à laquelle on fera principalement ces opérations.

3°. Les vannes de chasse du réservoir N, étant complètement ouvertes, on ouvrira de même celles de prise de celui-ci jusqu'à ce que le niveau soit aussi haut que possible sans que les vannes de retenue arrivent à s'ouvrir car il en sortira ainsi le maximum de débit par les orifices de chasse. Il y aura de cette façon un très grand tirage à l'embouchure ce qui nettoiera celle-ci, et les apports qu'il y aura devant la prise entreront et, sans s'arrêter dans le réservoir, retourneront à la rivière par les orifices de chasse.

4°. On baissera les vannes de prise du réservoir N et quand son niveau descendra, jusqu'à ce qu'il se vide si l'on veut, on verra s'il se n ttoie, dans le cas où il resterait encore des graviers ou pierres de plus grandes dimensions, on relèvera les vannes. On a donné au mur de séparation et aux murs latéraux une pente de

2 de base pour 1 de hauteur (fig. 5) depuis le radier jusqu'à 1,70 mètre sous la surface de l'eau, de façon à ce que, lorsque le niveau descend, la section se retrécisse et la vitesse de l'eau augmente, ce qui facilitera le nettoyage. Si lorsqu'on laisse à sec le réservoir on y voit des pierres de grandes dimensions qui n'auraient pas pu être emportées par l'eau, on les enlèvera à la main et on les transportera en dehors des vannes de chasse.

5°. Une fois le réservoir N nettoyé, on ouvrira ses vannes de prise et, après quelques minutes, lorsque l'eau ne sera plus trouble, on fermera les orifices de chasse. Lorsque le niveau dans le réservoir aura atteint la même valeur que celle dans le canal, les vannes de retenue s'ouvriront automatiquement poussées par le courant et avec les treuils on les relèvera jusqu'à leur position normale hors de l'eau.

On nettoiera de la même façon le réservoir M et son embouchure et comme cette opération peut se faire fréquemment, même avec un débit réduit, en profitant des heures de diminution de charge de la centrale et en utilisant une partie de la retenue du barrage, on maintient toujours les réservoirs et leurs embouchures complètement propres, sans qu'il arrive au canal ni graviers ni sables. Ces nettoyages peuvent être faits, comme on le voit, sans interrompre la marche de la centrale même si elle travaille à pleine charge.

PURGES LE LONG DU CANAL.

Quoique par la disposition adoptée à la prise nous supposions comme il est arrivé, qu'il n'entrerait pas de matériaux pierreux du barrage, il fallait espérer que dans les parties de canal découvert les orages devaient produire des charriages assez importants de terres et graviers et pour les éliminer on a construit six purges distribuées dans les 10.900 mètres de canal et, en outre, des réservoirs de décantation.

Les six vannes de chasse sont installées dans six ouvrages construits pour les passages des ravins.

Les radier des purges sont 0,40 mètre plus bas que celui du cana et il existe sur ce radier des seuils de forme incurvée en plan pour guider les apports vers les vannes.

RESERVOIRS DE DECANTATION.

Un de ces réservoirs de décantation est situé au kilomètre 9, à l'entrée d'un siphon qui permet de franchir un profond ravin (Figures 6, 7 et 8).

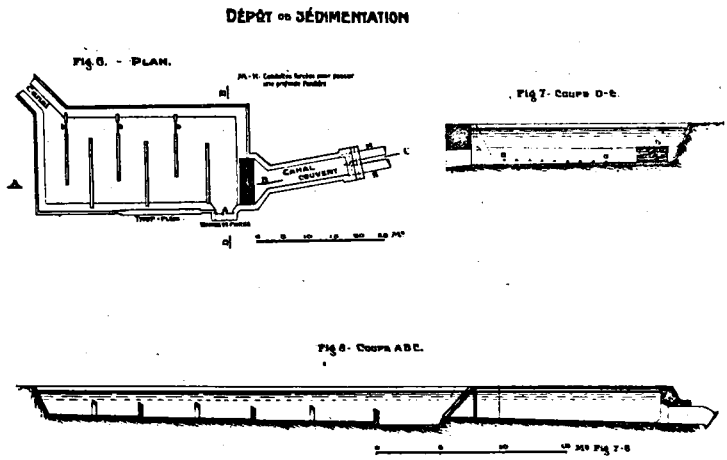


Planche 2 : Dépôt de sédimentation. Figs. 6-7 et 8.

Il est de forme rectangulaire en plan (fig. 6) de 40, 80×20,00 mètres et l'eau entre par un des sommets du rectangle et sort par le sommet opposé, passant dans le siphon par une grille à intervalles larges.

Comme on le voit dans les plans, on a construit plusieurs épis de faible hauteur qui sont noyés en marche normale et qui, dès qu' on ouvre les orifices de chasse installés près de la grille, quand la charge de la centrale le permet, découvrent leurs couronnements et comme l'eau circulera par tous les canaux en zig-zag avec une grande vitesse (par le fait que le radier a une pente de 1 mètre depuis l'entrée dans le réservoir jusqu' aux orifices de chasse) elle entraine les sables et limons déposés à l'abri des épis.

Les batardeaux *b—b* indiqués dans les épis d'un côté sont destinés à être enlevés lorsqu' on voudra produire des charriages dans le canal et les orifices en triangle *a—a*, qui traversent les épis à leur partie inférieure, servent au passage de l'eau pour que celle-ci remue les sables en facilitant ainsi le nettoyage.

Le second réservoir de décantation est celui de l'extrémité duquel partent les conduites forcées (figure 9). La vue en plan est celle indiquée dans les dessins et il possède aussi des épis qui forment des canaux de façon à ce que l'eau parcoure toute la surface dès qu'on ouvre les orifices de chasse et les batardeaux pour le charriage dans le canal.

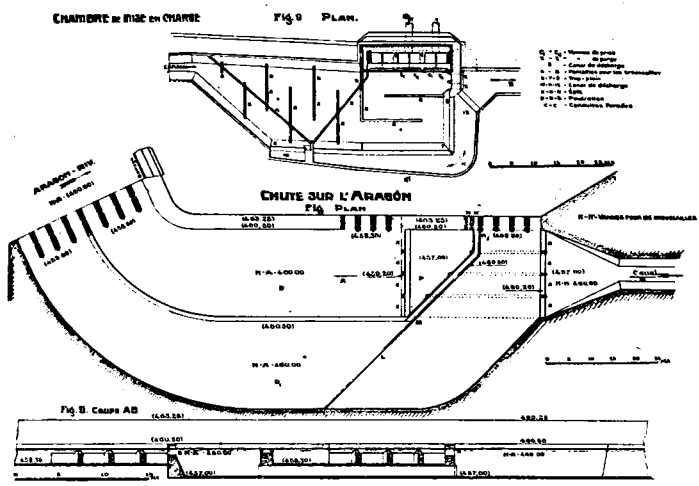


Planche 3: Chambre de mise en charge. Chute sur l'Aragón. Figs 9-10 et 11.

Il a été amenagé dans le réservoir un large déversoir et des dispositifs spéciaux, pour l'élimination des branchages, dont nous parlerons dans une autre Communication.

Pendant les onze mois d'exploitation de ces ouvrages on a fait beaucoup de fois ce nettoyage et on calcule qu'il a été écoulé par les 4 réservoirs plus de 30.000 mètres cubes de sable.

Une disposition analogue peut être employée lorsqu'on dérive un débit important avec un barrage de faible hauteur.

Les figures 10 et 11 représentent une prise que nous avons projetée pour dériver 20,000 litres/sec. de la rivière Aragón dans la Province de Zaragoza (Espagne), avec un barrage de 1,20 mètre de hauteur au dessus du niveau d'étiage ou de 1,70 mètre au dessu du lit de la rivière.

L'eau du réservoir D passe dans le canal, par une conduite forcée sous les orifices de chasse et de retenue du réservoir D_1. L est un écran superficiel permettant de dériver les branchages du réservoir D_1, lesquels passeront avec l'eau par un canal ouvert dans l'épaisseur du mur $M—N_1$ de séparation des deux réservoirs: il existe en N^1 une vanne de surface pour les déverser dans la rivière quand il y aura lieu. Le petit mur à gauche de ce canal sert d'écran

pour les branchages du réservoir D qui pourront se déverser dans la rivière par la vanne de surface N.

En donnant à ce canal la profondeur et la largeur suffisantes, il peut servir également comme déversoir de surface des deux réservoirs dans le cas où l'on ne peut pas aménager un déversoir direct dans la rivière, car le niveau des crues sous le barrage est de beaucoup supérieur à celui de l'eau à l'origine du canal. La vanne N^1 empêcherait l'entrée de l'eau lors des crues.

RÉSUMÉ.

The author explains the layout of a water supply system in Spain, and sets forth the conclusions arrived at, which are as follows :—

1. How to lay out water collectors to prevent matter (stones, etc.) from reaching the channel entrance.
2. Method of making the water supply remove by its own stream all matter washed down at places where the open channel system is made use of.
3. The arrangements made for both sedimentation and reservoirs and the method of cleaning them by water flow.

He also explains the operation of a double water collector ; water entering into two independent sedimentation reservoirs, and flowing out to the river through two large separate channels.

How cleaning operations for conduits and reservoirs may be carried out without cutting off the supply, is shown in the paper.

ELIMINATION DES DÉBRIS ET BROUSSAILLES DANS LES CANAUX INDUSTRIELS

CORNELIO ARELLANO
Ingénieur des Ponts et Chaussées.

On connaît l'importance du nettoyage des grilles dans les canaux des chutes d'eau. L'ingénieur soussigné a étudié tout spécialement cette question, car il a dirigé l'exploitation de plusieurs entreprises hydro-électriques et, pour la dernière chute, qu'il a construit et inauguré en Février 1923, il a adopté une solution dont on a déjà pu apprécier les grands avantages pendant onze mois d'exploitation.

La disposition générale embrasse les points suivants :

1°. Empêcher, autant que possible, l'entrée des broussailles et des débris dans le canal d'amenée.

2°. Enlever les débris qui entrent à travers la prise d'eau, et ceux qui tombent dans les parties découvertes du canal, avant leur arrivée aux grilles.

3°. Nettoyage automatique des grilles.

DISPOSITION DE LA PRISE D'EAU.

Pour empêcher l'entrée des broussailles dans le canal, on place généralement un grillage, mais nous n'avons employé ce système qu'une seule fois, parce que nous avons observé qu'il présente plusieurs inconvénients.

Le système que nous adoptons toujours consiste à disposer les ouvertures dans un mur sans aucune saillie, perpendiculaire à la ligne de barrage, et à faire les trous d'accès rectangulaires en plaçant les linteaux à 0,500 mètre ou plus au dessous du niveau de la partie supérieure du barrage. De cette façon, quand les crues de la rivière sautent par dessus le barrage, la direction du courant suit la ligne du mur où sont placés les trous, et comme les broussailles flottent très au-dessus de ceux-ci, elles sont emportées en aval sans entrer dans le canal. Dans la chute d'Anzánigo à laquelle nous faisons allusion, nous avons placé les linteaux à 0,500 m. au-dessous du couronnement du barrage.

ÉCRANS SUPERFICIELS.

Malgré cette disposition, on a dû supposer que certains débris flottants entrent dans le canal, et pour les enlever, ainsi que les débris provenant des parties découvertes du canal, etc., on a installé plusieurs écrans superficiels analogues à ceux dont nous parlerons pour le réservoir de charge.

Ces écrans forment un angle de 45 degrés avec le courant, et pénètrent dans l'eau 0,400 mètre en régime normal, et à leur extrémité en aval, il y a dans le revêtement du canal une petite vanne superficielle qui se lève quand on voit circuler beaucoup de débris.

NETTOYAGE AUTOMATIQUE DES GRILLES.

Le réservoir d'extrémité, avec les entrées dans les conduites de charge, est représenté dans les figures 1 à 4.

On a installé deux unités de 3,000 H.P. avec un débit de 6,000 litres par seconde pour chacune d'elles, et l'on a réservé la place nécessaire pour une autre unité identique.

La forme du réservoir avec les épis submergés, obéit à la nécessité de faire le nettoyage automatique des pierres entraînées par le courant dont nous avons parlé dans une communication précédente.

Pour les matériaux flottants, on a mis deux écrans, 4 et 5, en ciment armé, de 1,000 mètre de hauteur, qui pénètrent dans l'eau à 0,500 m. quand le niveau arrive au trop-plein. Le premier de ces écrans fait dériver les broussailles vers le trop-plein, dans lequel il y a une petite vanne, et le deuxième les emporte vers un canal 0—0—0 qui court par derrière les grilles, isolé des chambres d'eau, et qui va se déverser en dehors du réservoir, après les vannes de décharge. Dans la première partie de ce canal 0—0—0, il y a aussi une vanne superficielle qui s'ouvre quand l'eau entraîne beaucoup de broussailles.

Les deux unités installées ont des conduites forcées indépendantes de 1,800 mètre de diamètre et l'eau y entre, avec une profondeur de 3,000 mètres par une avenue de 4,800 de largeur, divisee en deux par un guide vertical qui est commun aux deux vannes jumelles, *Ci—Cd*, d'une largeur égale à la moitié de la largeur totale. La grille, inclinée à 45 degrés, est située après ces deux vannes, et sous celle-ci il y a une chambre en forme d'entonnoir pour raccorder, sans angles ni grands changements de direction, la section rectangulaire de la grille avec la section circulaire du tuyau.

Depuis le guide vertical commun aux deux vannes jumelles, jusqu'à la *surface de la grille*, il y a une cloison en ciment armé qui divise en deux l'entrée générale, mais seulement jusqu'à la grille,

car après celle-ci la chambre en forme d'entonnoir mentionée plus haut n'est plus divisée. Cette cloison dépasse de 0,500 mètre le niveau de l'eau en régime normal, et les grilles ne sont qu'à 0,600

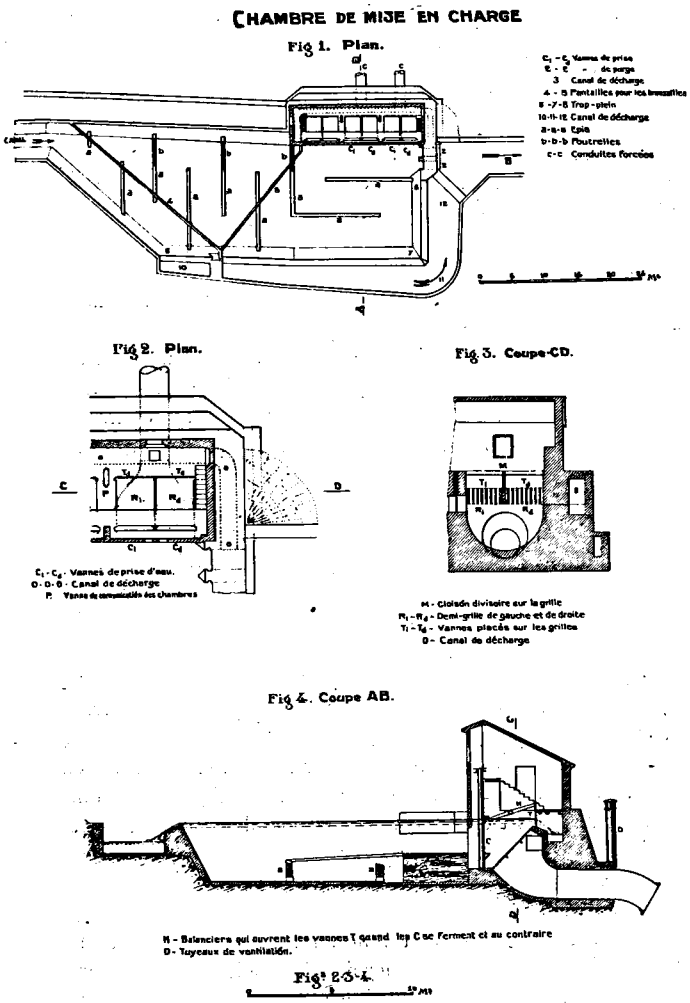


Planche 1 : Chambre de mise en charge.—Figs. 1-2-3 et 4.

mètre sous ce même niveau. Ce 0,600 mètre se ferme avec deux vannes *Ti* et *Td*, chacune d'elles dans une des deux parties de l'avenue.

Ces vannes ouvertes, l'eau coule dans le canal 0—0—0, qui, comme nous l'avons dit plus haut, se déverse hors du dépôt.

Soient, comme l'indiquent les figures, *Ci* la vanne de la demi-entrée de gauche, *Ri* la demi-grille correspondente et *Ti* la vanne du même côté située sur la grille, et supposons les mêmes lettres avec le subindice *d* pour celles de droite.

En ordre de travail, les deux vannes d'admission *Ci* et *Cd* seront ouvertes et les *Ti* et *Td* seront fermées ; mais supposons que *Ci* se ferme et que simultanément *Ti* s'ouvre, du même côté. La turbine correspondante continuera à marcher, même si elle marche à pleine charge, parce qu'il entrera une quantité plus que suffisante d'eau par *Cd* (auquel on a, précisément dans ce but, donné de larges proportions) et si le niveau du dépôt est le niveau normal, la vanne *Ti*, qui sera levée comme on l'a vu, déversera dans le canal 0—0—0 une quantité d'eau importante.

Cette eau viendra de la chambre en forme d'entonnoir située sous la grille, l'eau passera à travers cette grille de bas en haut dans le sens contraire du sens normal, et les broussailles retenues par la grille s'en détacheront et tomberont dans la rivière par la vanne *Ti* et par le canal 0—0—0.

Supposons donc que la vanne *Ci* soit mise en mouvement par un moteur électrique auquel on envoie le courant de l'usine même : que les vannes *Ci* et *Ti* du même côté soient en relation, de manière que, au moyen des balanciers *N*, figure 4, quand on ferme la *Ci* on ouvre la *Ti* et vice-versa : et que avèc le mouvement de *Ci*, quand la vanne arrive aux deux extrémités supérieure et inférieure, de la course, le courant électrique s'interrompt et le circuit s'ouvre : nous aurons ainsi une disposition grâce à laquelle on pourra faire le nettoyage automatique de l'usine même, en actionnant un commutateur qui donnera le courant pour faire monter ou descendre la vanne. Ce procédé a été employé à Anzánigo, et comme on y répète très souvent cette opération dès qu'il y a un excédent d'eau, en ajoutant de l'eau du réservoir si cet excédent n'est pas assez grand, on parvient toujours à maintenir les grilles parfaitement propres.

Pour démontrer l'excellent fonctionnement de ce système, nous dirons qu'au mois de Juillet dernier, à la suite de grands orages, la rivière charria une telle quantité de broussailles que plusieurs usines durent s'arrêter ; qu'en Novembre la rivière grossit beaucoup et que dans une autre usine dont nous dirigeons aussi l'exploitation, il fut nécessaire de mettre dix hommes auprès des grilles : dont le nettoyage demanda trois jours, et l'on fut obligé de réduire le service

à un tiers du service normal, parce qu'il ne passait pas une quantité d'eau suffisante par les grilles. Malgré cette abondance de broussailles on n'a jamais eu besoin, ni alors ni en aucune autre occasion, de faire le moindre nettoyage à la main à Anzánigo, dont l'usine a marché au maximum de rendement, pour suppléer à l'arrêt de l'autre usine.

Nous avons établi trois autres projets semblables au précédent pour autant de chutes d'eau dont une est déjà construite.

CHUTE DE LA RIVIÈRE IRATI.

L'Irati est une rivière de Navarre (Espagne) par laquelle on transporte, en les faisant flotter, les produits de l'exploitation des grands bois de hêtres et de sapins, depuis les branches jusqu'aux grands troncs de 3,000 mètres de longueur sur 1,000 mètre de diamètre.

On ne peut pas mettre de grilles aux entrées des canaux, parce qu'elles s'obstrueraient complètement pendant les grandes crues; dans notre projet, nous les avons établies dans le canal, près de la prise d'eau, de la façon qu'indiquent les figures 5, 6, 7 et 8.

C'est une grille submergée R, légèrement inclinée relativement à la ligne d'horizon, qui traverse le canal et qui est divisée en deux, *Ri* et *Rd* par une cloison en ciment armé Q-S, appuyée sur la grille même et qui dépasse le niveau de l'eau ; *Ci Cd* sont deux vannes dont les supports sont sur un mur sur lequel s'appuient les grilles, qui en ordre de travail doivent être ouvertes, et *Ti Td* sont deux autres vannes qui ont aussi leurs supports sur les grilles et qui en ordre de travail doivent être fermées.

F-G-H-J-M-N est une voûte plane submergée, formant un petit canal qui traverse le grand canal : les murs H-J et J-G ou N-P dépassent le niveau de l'eau, et en F-G il n'y a pas de mur, ce qui donne une sortie sur la rivière dans le sens indiqué par la flèche.

En ordre de travail les vannes *Ti Td* ferment tout passage, et comme toute l'eau circule à travers les grilles dans la direction des flèches a, b, c, d, sous la voûte plane, les broussailles et les morceaux de bois de toutes grandeurs y sont retenus.

Pour nettoyer une des demi-grilles, *Rd* par exemple, il n'y a qu'à fermer la vanne *Cd* et ouvrir la *Td*, et quand l'eau de celle-ci se déverse dans le petit canal transversal, il en sort en même temps toute la broussaille, le bois, etc., suivant la direction de la flèche X, vers la rivière. Si le garde chargé de cette opération voyait que par sa grandeur démesurée un morceau de bois ne pourrait pas passer, il l'aiderait à passer avec une perche.

CHUTE DE KIRATI

Fig. 5. Coupe

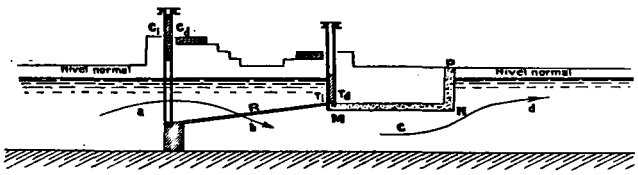


Fig. 7. Plan.

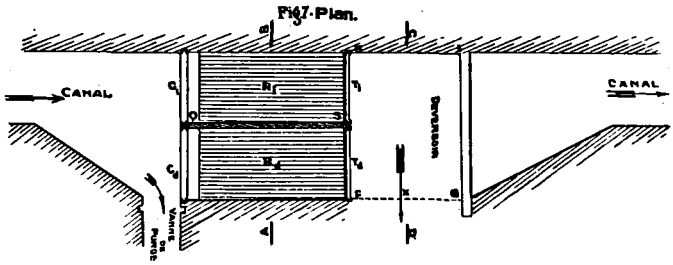


Fig. 6. Coupe AB.

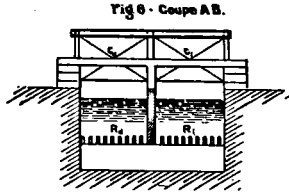
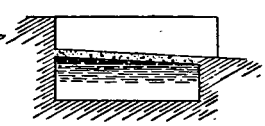


Fig. 8. Coupe CD



CHUTE DE CARCAVILLA

Fig. 9. Plan.

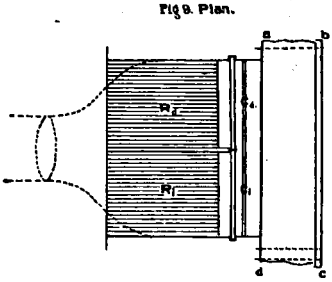


Fig. 10. Coupe.

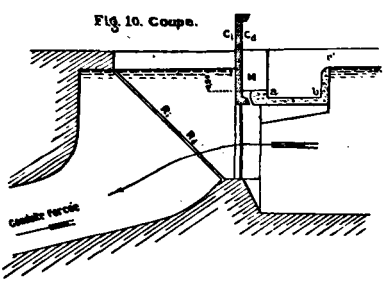
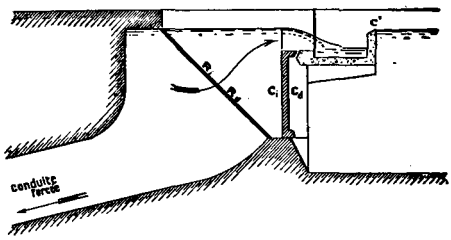


Planche 2 : Chute de l'Irati.—Chute de Carcavilla.—Figs. 5-6-7-8-9 et 10.

CHUTE DE CARCAVILLA.

Cette chute est située, comme celle d'Anzánigo, sur la rivière de Gâllego, et elle a été construite il y a vingt ans : nous nous occupons de la modifier en ce moment.

Fig. 11. Coupe



CHUTE DE CASA-BLANCA

Fig. 12. Plan. (sans les tabliers C_1C_2-C_4)

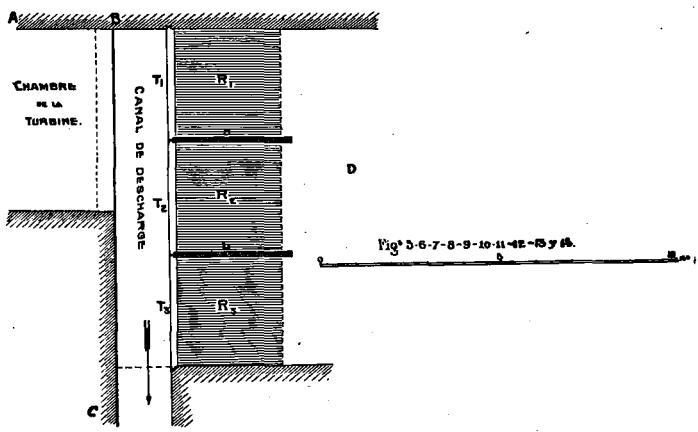


Fig. 13 Coupe.

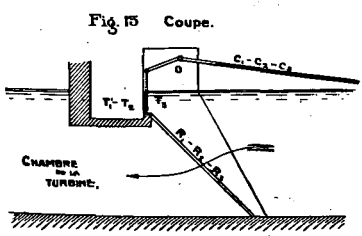


Fig. 14. Coupe

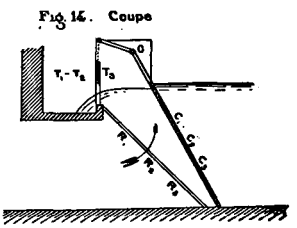


Planche 3 : Chute de Carcavilla.—Chute de Casa Blanca.—Figs. 11-12-13 et 14.

Le dépôt d'extrémité était très petit, et pour avoir l'amplitude suffisante dans le trop plein, nous avons mis un canal de ciment armé devant les vannes qui donnent accès aux sept unités installées.

Ce canal a, b, c, d., (figures 9-10 et 11) sert par le côté *c'* de trop plein, et par le côté *M*, il remplace le canal qui à Anzánigo, est situé derrière les grilles, le nettoyage automatique de ces grilles devenant ainsi beaucoup plus simple.

Les vannes d'entrée *Ci* et *Cd* sont placées à 0,600 m. au-dessous du niveau normal de l'eau, et entre elles et le canal on a établi une fermeture hermétique M, aussi bien quand elle est en bas (figure 11) que quand elle est levée (figure 10). En ordre de travail, *Ci* et *Cd* seront levées (figure 10) et l'eau entrera sous le canal *a. b.* ; et même si le niveau atteint *c'*, l'eau ne s'écoulera pas, parce que la fermeture M l'en empêchera.

Quand on voudra nettoyer une demi-grille, *Rd*, par exemple, on n'aura qu'à baisser la vanne *Cd* (figure 11), et comme l'eau qui coulera dans le canal par suite du dénivellement de 0,600 mètre viendra de la chambre commune située sous la grille, elle suivra la direction des flèches et emportera les broussailles.

CHUTE DE CASA BLANCA.

Cette chute est depuis longtemps en exploitation. Son débit est de 10,000 litres et sa chute de 6,000 mètres : c'est une dérivation du canal Impérial d'Aragon (Zaragoza—Espagne), et on va y faire des changements le mois prochain.

Il y avait autrefois plusieurs turbines dans l'édifice A.B.C., et elles recevaient l'eau d'un grand dépôt D., mais maintenant il n'y en a plus qu'une, à chambre ouverte, les vannes d'admission étant à l'entrée du dépôt.

La grille actuelle est insuffisante et nous avons l'intention de l'agrandir en établissant en même temps le nettoyage automatique dans la forme qu'indique les figures 12-13 et 14. Nous y mettrons une grande grille, divisée en trois, R1, R2, R3, par les cloisons *a b* en ciment armé qui, comme dans les autres cas, s'appuient sur la grille et dépassent le niveau de l'eau. Sur le haut des grilles, on met les vannes T1, T2, T3, et dans les avenues formées par les cloisons, il y a des tabliers C1-C2-C3 pivotant autour des axes *O*, qui, en descendant, ferment le passage de l'eau du dépôt. Ces tabliers C1-C2-C3 sont très simples parce qu'ils doivent toujours avoir de l'eau sur leurs deux côtés, avec une très petite différence de pression, et ils sont en relation avec les vannes T1-T2-T3 de sorte que, lorsque C1-C2-C3 s'ouvrent, T1-T2-T3 se ferment et vice-versa.

La position normale sera d'avoir les vannes C1-C2-C3 levées et les vannes T1-T2 T3 fermées (figure 13), et quand on veut nettoyer une des trois grilles, R1, par exemple, on baisse C1, T1 se levant en même temps automatiquement (figure 14) ; et comme l'eau qui se déverse par elle coule sous la grille, celle-ci se nettoie.

Les dispositions précédentes sont étudiées pour des prises d'eau de réservoirs à niveau constant. Nous avons aussi étudié d'autres dispositions pour le nettoyage automatique des grilles dans les prises des grands réservoirs dont le niveau est très variable, mais nous ne pouvons pas les décrire parce que leur description dépasserait les limites assignées aux communications.

RÉSUMÉ.

The paper explains a method carried out in Spain and the conclusions arrived at, which are as follows :

1. Arrangement of sluices to prevent rubbish from settling in the channel.
2. Process by which rubbish flowing down from the river, or washed down at places where the channel is unprotected, will be carried away by the rush of water in the channel.
3. Automatic cleaning of the grating.

This automatic cleaning of the grating is brought about by the water flow in the channel which is made to flow in an opposite direction to its usual course. The rubbish is thus loosened and carried down the river by water through a channel placed behind the gates or just before the sluices.

A grating can be cleaned even when the system is working at full power without any appreciable loss of level.

MEASURES TAKEN IN SWEDEN AGAINST ICE TROUBLES AT WATER POWER PLANTS

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Ice is a source of trouble to many hydro-electric plants all over the world. The extent to which disturbances may be expected varies with the hydrological conditions in the river on which the power station is situated and with the severity of the winter season.

Sweden extends a fairly long distance in the direction north to south, and the climate varies with the latitude from the almost arctic conditions in the northern part to fairly mild in the south. Some experience of the difficulties due to ice and how they can be overcome, has therefore been gained at the Swedish water power plants, which range from north of the arctic circle to a latitude of 56° north. The worst trouble, however, is not caused by the ice in the extreme north, as here the occurrence of ice sludge is less frequent and the other menaces of the ice are so evident that adequate measures are generally taken to meet them. In the middle and southern parts, however, such measures are sometimes considered too expensive and are therefore omitted, with the result that serious troubles occur when occasionally the winter cold gets severe.

ICE JAM AND ICE SLUDGE.

Rapids above the power plant are always a source of trouble. In these, anchor ice is likely to form on the boulders in the river bottom, and this ice when loosening may produce a formidable jam. Furthermore, in the rapids, the water comes into close contact with the air, with the result that, in cold weather, the whole stream gets saturated with ice needles, producing a troublesome ice sludge. When designing water power plants in Sweden it is therefore necessary to pay very close attention to the necessity of either dredging such rapids or submerging them by a sufficient raising of the water level in front of the dam.

As a matter of fact, for this and other reasons, plans for the suitable regulation of the river profile in steps have been worked out for the whole length of many Swedish rivers.

By creating a still-water basin, extending far up the river, the risk of ice sludge is, however, not altogether obviated, as ice sludge may set in during cold storms occurring before the water is covered with ice. When a cold storm blows upon the unprotected water, the strong wind prevents the forming of an ice sheet, and instead the whole water becomes safurated with ice needles which readily fasten on to any object in the water, thus gradually forming on this a piece of solid ice. In a comparatively short time enormous quantities of such ice needles can be formed. Conditions are still worse during snow storms, as the snow is blown from the adjacent fields into the water.

In the northern part of Sweden, all the waters, where the velocity is not too high, freeze early in the autumn, and as the ice usually lies intact up to the spring, the risk of ice sludge in this part of the country is generally restricted to a short time in the autumn only. In the southern part of Sweden, however, only short periods of intense cold occur, intercepted by periods of fairly mild weather. Thus the ice is often broken up, and therefore ice sludge may occur at any time during the winter.

An ice sheet being the best safeguard against sludge, its formation is often, especially in the northern part of the country, facilitated by artificial means in canals and streams, where the velocity of the water is so high that the surface otherwise would hardly freeze. To this end wooden ribworks or logs, floating upon the surface of the water are arranged in the stream. Thereby the surface velocity is decreased, ice needles will fasten on the logs and become nuclei for the forming of ice floes, and soon a sheet of ice will cover the stream from one shore to the other. It is of special importance that even small patches of open water in an ice field be covered up with ice, as otherwise, when a snow storm sets in, snow from the adjacent ice fields is blown into the water which may result in serious sludge.

On the occurrence of sludge the screens in the turbine intakes are apt to get clogged up, if adequate means are not provided to prevent the ice needles from fastening. Even the turbines may sometimes be clogged up, but this is not so much to be feared in modern big units with their very large openings. As to the screens, the most effective remedy is to remove them entirely, provided, however, that this is advisable with respect to the turbines, and allowed with regard to the fishing. As a matter of fact, the close screens at the power plants are generally accounted only as means of saving the migrating fish from being mauled in the

turbines, and this is the reason for special clauses in the Swedish law prescribing that in all intakes for power utilisation, screens shall be erected with no larger openings than 20 mm. (about ¾ in.). During the winter proper, the fish do not migrate, and it is therefore permissible to remove the screens or to replace the ordinary screens by screens with larger openings, preferably made of wood, as the ice does not as readily fasten on to wood as on to steel. In most places this can be done even with respect to the power plant, as the Swedish rivers carry only very small quantities of sand and gravel. The last method is, however, not sufficient at places where particularly serious sludge may occur, as even wooden screens are sometimes apt to clog. At such places very good results have been obtained by electric heating of the steel bars of the screen. At Lower Hemsjö, located in the southern part of the country, where sludge troubles previously were very frequent and serious, they are now entirely avoided in this way. In the screens the steel bars are electrically connected in such a way that the heating can be effected by electric current at 125 volts. The required energy is very small, amounting to only 10 kW. for each screen with an area of 15 square metres (about 160 sq. ft.) As no insulating material but wood is necessary, the installation is quite cheap, and it seems to the author that in this way, at any rate in properly designed plants, most of the difficulties due to ice sludge can be avoided at a comparatively small expense.

It is perhaps unnecessary to emphasise that the screens should be made of sufficient area that the normal velocity between the bars be rather low [not exceeding 0·8 to 0·9 m. (2·5 to 3 ft.) per second]. In that case the loss of head in the screen will not be excessive even if the screen to some extent be clogged, and debris and ice may easily be raked up, a very difficult operation if it be pressed against the screen under a high head. To shelter the men engaged in cleaning the screens and to prevent the forming of ice in recesses and on the water line, superstructures are erected, often extending over the whole turbine intake, and heated with hot air from the generators.

FORMATION OF SOLID ICE AND JAMMING OF MOVABLE PARTS.

Another effect of the cold is the formation of ice, which threatens to hamper the operation of Stoney gates and other movable parts. At the turbine intakes ice is likely to form in the recesses for the sluices above and around the water line. If such a formation of ice is left unheeded, it may happen that, in a case of emergency, the

gates will not move and precious time will be lost before the obstruction is removed. In those plants where a superstructure over the whole intake is considered too expensive, it has been found a good practice to cover up the whole intake with wooden floorings under which hot air is led from the generators. In this way, even the formation of ice on the surface and on the intake walls is prevented.

At the sluices in the dams, ice is formed on the upstream side on account of the conduction of heat through the gates and the surrounding masonry. Furthermore, leakage causes the formation of ice in the recesses and on the downstream side of the gates. All this ice tends to hamper the operation of the gates. It is, however, not necessary to provide means for the operation of *all* movable parts during the winter, as some of them are intended for flood discharge only and there is no need to move them during winter time. The precautions may thus be concentrated on certain sluices only, suitable for winter discharge.

To prevent ice from forming on the staunching rods, on their metallic guides and on the surrounding masonry, these parts can be electrically heated. This is now generally done by means of special radiators at 110 volts. A supply of about 2 kW. per square metre (0·2 B.T.U. per sq. ft.) is sufficient to prevent ice from fastening, even on the most exposed parts, at a temperature of—20° C. (—4° Fahr.).

With a view to preventing the formation of ice in the recesses, a good practice is to let heated air from the generators be blown out into them by means of ventilators. In many places where steam is available—for instance when the dam is located close to a factory using steam—good results have been obtained by utilising this for heating purposes.

Where Stoney gates, in winter, have to be moved only occasionally, and therefore electric heating is considered unnecessary, and if heated air or steam cannot be supplied to the recesses, the removal of the ice is much facilitated if the recesses are made so spacious that a man can easily climb down into them. In recent design of Stoney sluices the number of rollers has been decreased and the rollers have been made rather big, in order to dispense with small movable parts which are apt to be jammed. Stoney gates, 15·5 m. (51 ft. 1 in.) wide and 5·7 m. (18 ft. 9 in.) high, supported at each end by four rollers only, 40 cm. (16 in.) in diameter are now being installed at Sikfors, located in the northern part of the country. At these gates the lower roller has been placed so high up that it is never submerged in the stream of water passing through the gate opening.

In order to prevent the formation of ice on the upstream side of the gates, these are often provided on the downstream side with a wooden boarding, by means of which the whole steel structure is enclosed in a chamber which may be heated when necessary. At Untra, located in the central part of the country, where ice of a thickness of 0·5 m. (20 in.) previously used to form on the upstream side of the gates, no formation of ice has occurred after such boarding was provided, although no heating has been resorted to.

In steel pipe lines and surge tanks which are not protected against the cold, thick layers of ice may form, especially if water is not drawn off during the night. If ice has formed, and if afterwards the temperature suddenly rises, the ice may loosen and follow the water down the pipe line, producing a formidable jam at the lower end. Therefore steel pipe lines and surge tanks in the northern parts of Sweden are generally insulated against the cold by means of roofings or some other kind of superstructures, into which, as an additional precaution, hot air from the generators is often blown.

ICE PRESSURE.

Another difficulty is due to the pressure of the ice against the dams. This pressure is generally explained as follows. During periods of intense cold, the surface of the ice gradually assumes the temperature of the air, which results in tensile stresses and cracks. Some of these cracks get filled with water which soon freezes. Later, when a mild day comes, the temperature of the ice is raised to about 0° C. (32° Fahr.), which results in a pressure in the ice. If the ice abuts on a dam, this dam will suffer under the pressure. The magnitude of this pressure has, no doubt, in many cases been much over rated. As a matter of fact the ice acts very much as a viscoidal fluid slowly yielding under pressure. As considerable changes in the temperature of the air do not occur instantly, and as, in any case, it takes some time before any great change of the temperature of the ice ensues, especially when the ice is covered with snow, the ice will gradually yield and the resulting maximum pressure will be much less than has been calculated for in several extreme cases. In an interesting article[1] *N. Royen* shows that the pressure from an ice field will not exceed 30 tons per linear metre (9 tons per linear ft.) when the ice is 1 m. (40 in.) thick, and 20 tons per linear metre (6 tons per linear ft.) when the ice is 0·75 m. (30 in.) thick. Ice fields

[1] " Istryck vid temperaturhöjningar " (Ice pressures due to increase of temperature). Hyllningsskrift tillägnad F. Vilh. Hansen (Hansen Testimonial), Stockholm, 1922.

of such thickness naturally do not appear in Sweden except in the northernmost parts of the country. In the south of Sweden the maximum thickness of the ice fields is about 0·5 m. (20 in.) As the ice pressure is nevertheless inconvenient, many means have been invented to decrease or eliminate it. It has, thus, been proposed to give the dams a sloping upstream face so that the ice should slide up along the incline, or to introduce some plastic material between the facing and the supporting structure, thus allowing a certain yielding. It has, further, been proposed to resort to the method of blowing compressed air into the water in front of the dam as applied at the Keoukuk dam in the Mississippi River, or to melt away the ice by means of electric radiators ranged along the dam. Generally the dam owners content themselves with cutting slots in the ice in front of their dams, and with covering these slots with spruce brash and snow, or straw and manure, and, as a matter of fact, there have been very few instances in Sweden of the ice pressure causing any damage.

RÉSUMÉ.

En Suède, où les usines hydro-électriques se trouvent dans un rayon étendu du 56ième parallèle au delà du cercle polaire, on a acquis une certaine expérience sur les difficultés causées par la glace et sur les moyens pour les éviter.

Les rapides en amont de l'usine doivent être inondés en élevant suffisamment le niveau d'eau à l'aide du barrage. On doit faciliter la formation de la glace en amont des usines, car, si à certains endroits l'eau n'est pas couverte de glace, pendant les tempêtes, la neige tombe dans l'eau, ce qui transforme l'eau en un mélange épais d'eau et d'aiguilles de glace, qui bouchent les grilles. On peut éviter cet inconvénient en chauffant les grilles électriquement, ce qui prend très peu d'énergie.

Pour éviter la formation de la glace dans la prise d'eau on la couvre d'un hangar, qu'on chauffe avec l'air sortant des générateurs. Pour manoeuvrer les vannes on chauffe les organes d'étanchéité électriquement, on revêt les vannes du coté aval, on fait parvenir de l'air chaud ou de la vapeur dans les coulisses. Pour éviter la formation de glace dans les tuyaux et les chambres d'eau en tôle d'acier, on les isole du froid.

Le danger d'une pression de la glace contre les barrages a été très exagéré par l'omission de la viscosité de la glace dans les calculs. En Suède on se contente généralement de scier des rainures dans la glace en amont des barrages qu'on recouvre de branches de sapin et de neige, ou de paille et de fumier.

WATER POWER PRODUCTION—OPERATING CONDITIONS

DISCUSSION

Chairman: DR. ED. TISSOT (SWITZERLAND)

Friday, July 4th. *Afternoon Session*

THE CHAIRMAN, in opening the session, referred to the most important principles involved in planning or laying out a hydro-electric scheme on a river or on a stream. The regime of the flow of water had to be studied in all its details, including geological conditions, structure of the river-bed, the flow during high and low water periods, the time of change between the different periods, the ice conditions before and after regulation of the river, the carriage of sand and boulders, and all the phenomena which influenced the working of the plant. These considerations would determine the best site for the intake, canal, or forebay, power plant and tail-race, they would enable the engineer to choose the right quantity of water to be utilised in the plant, and to determine all the conditions for working the scheme with the highest possible efficiency and under the most economical conditions.

He intended to divide the session into two distinct parts. The first would deal exclusively with dispositions to be adopted or measures to be taken to avoid deposits such as gravel, sand, etc., settling in the forebays of the turbines or to eliminate such deposits as might have settled there. The second part would deal with measures employed of late to dispose of leaves or wood which had settled on the gratings of the power house. In this second part, they would also deal with appropriate measures to overcome ice trouble in the head water and to prevent ice from settling on the bars of the grating.

MR. H. E. GRUNER (*Switzerland*), stated that the rivers in Switzerland transported large quantities of floating material (débris or rubbish), especially in autumn and during high water; some of them also carried a considerable amount of gravel or sand. They had made the discovery that the situation of the plant in the river was of great importance. The Chevre plant on the Rhone and Rheinfelden on the Rhine, being situated on the convex side of the river, suffered very much from sand deposits in the forebay, and from obstruction of the screen by floating débris. The screens were cleaned by a mechanical device, and the newest construction was used, whereby the teeth of the cleaner extracted the wood by entering between the screen bars. He reminded them that the velocity of the water passing through the screen must not exceed 0·5 m. per second, and special arrangements had to be provided so that the whole surface of the screen was equally charged. In the new power plant on the Rhone, below Chevre, at Chancy, they had tried to avoid these difficulties. The power house was located so that the forebay was kept clear of gravel and sand as far as possible. No special device had been provided for the elimination of this material, and it had to be eliminated if necessary by pumps and steam shovels. On the river side, the forebay was closed by a wall on the water level guiding the floating material to the Stoney gates, and it was of the greatest importance that this wall should be as smooth as possible, and should show no protruding structures on the riverside. The lower part of this wall through which the water flowed was closed by a screen with bars with comparatively large openings. On another river, where ice troubles had been feared, the screen under the guiding wall had been eliminated.

At Chancy, the entrance to the turbines was closed by screens with openings 30 mm. wide, and these screens were cleaned by forcing the water in the opposite direction through them.

No great ice troubles had to be met with in Switzerland, but they had had occasion to make similar experiments to those of their Swedish and Norwegian colleagues on a plant in Yugo-Slavia. They had found that the basin created by the masonry dam of a height of 15 to 16 m. reduced the ice troubles to a great extent.

The conditions with high pressure plants were entirely different. They had power plants in Switzerland working under a pressure of 100 to 1,600 m., the quantity of water being from 30 to 100 cu. m. per second. It was of the greatest importance to free the water of all sand and gravel. They were now able to free the water of deposits larger than 0·7 mm.

They rendered the water calm by iron and wooden screens to obtain the same velocity in the whole section, and they arranged the canals so as to clean the basin while in operation in summer, when there was plenty of water and considerable deposit. When the water was freed from all sand, it was possible to work with a velocity of 3 to 5 cu. m. per second in their water tunnels. They had not much ice trouble in their works, even in the higher mountains, and it was very seldom that any difficulties with " frazil ice " were experienced. Various changes in formation and the strong radiation at such altitudes influenced their construction. Cement work especially suffered from the frost, and it was therefore recommended that concrete at great altitudes be protected by a surface of natural stone.

With reference to the construction of pressure galleries, they demanded in the first place a minute geological survey. It was now general practice to give their galleries a circular section and a concrete lining of 20 to 40 cm. thickness, according to the diameter of the gallery and the conditions obtaining. The rock conditions had to be taken into account, and the construction adapted to them. If the rock were not resistant and if it were not watertight, they put in a second lining of concrete and iron. This second lining was only 5 to 8 cm. thick and the concreting was done by the cement gun.

PROF. V. G. GLOUSHKOFF (*Russia*), referring to experiences they had had in Russia in connection with the origin of anchor ice, mentioned that there was published in the Journal of the Royal Meteorological Society for 1923, some information by Prof. W. J. Altberg on the cause of the formation of ice at the bottom of rivers. He had stated that the physical basis for the formation of ice in this remarkable position was not known, but Barnes and others had put forward the theory that water was transparent to radiation of a wave-length in the neighbourhood of 10μ*. Since this was about the position of maximum radiation for a black body at about 273 deg., abs., Barnes had suggested that the bottom of the river was cooled below the temperature of the water by outward radiation, which passed nearly unobserved through the water above it. Altberg had set out to disprove Barnes's theory. He stated that a review of the measurements of the absorption coefficient of water by Paschen, Rubens, Aschkinass, and others made it quite clear that there was no wave-length in the infra-red, for which water had not a high coefficient of absorption. It was shown that 1 cm. of water would cut off all appreciable radiation from a body at 273 deg., abs. Barnes's theory was thus shown to be wholly untenable.

COL. B. C. BATTYE (*India*), referred to a comparatively small plant which supplied the town of Simla, where their main trouble was silt. They had a plant which had to have a diurnal storage to enable them to meet the peaks of the light load at night, and this consisted of a reservoir about 14 ft. deep at the head of the pipe-line. During the monsoon season, this reservoir filled right up with a thick deposit of silt which was costly to remove. They had thought of trying to reduce the velocity to ½ ft. per second in silting chambers *en route* and put in some form of a grill charged positively, endeavouring to get some sort of osmotic effect which would attract the silt out of the deposit.

* μ = 0·001 mm.

He thought that was a possible method. What they had actually done was to put three silting chambers on the flume which reduced the velocity to one foot per second. The bottom of the chamber had a kind of saw tooth arrangement which went down gradually to a depth of about two feet below average flood level, and there were gates constructed in such a fashion that it was possible to open the gates and sluice out all collected silt in a few minutes.

They had found in dealing with the storage problem in the Himalayas recently, that they could effect very considerable reduction in cost in the case of a dam by adopting Jorgansen's constant angle arch dams. One of these had been built, he thought, in Alaska, and one or two in California. It would be helpful to hear of any experience with regard to them which had been gathered by those present. If certain opinions were borne out by further experience, they would all be building constant angle arch dams in the future. Siphon overflow was another point that he thought was going to cause considerable economy in civil engineering construction.

There seemed to be another possible means of development on the civil side, by making use of stream line valves by reducing them from the diameter of the pipe in which they were placed to the minimum possible, on the principle of a Venturi throat. They would all like information as to the extent to which it had been found possible to reduce the diameter of a valve on that principle.

With regard to constructional costs, they had now developed bridges in India that would enable them to cross rivers which were a mile in width in flood, and only few feet in width during the rest of the year. For 360 days of the year, the small bridge would serve. They bridged the small gap by a bridge that could be flooded, and they had a bridge that had had 20 ft. of water over it for a week at a time. With regard to temporary plant, one suggestion was to put down generating plant that could be used for auxiliary excitation purposes in the main work afterwards, and, in addition, the whole of the distribution system could often be made permanent. With regard to other forms of transportation, the caterpillar method was beginning to offer a solution.

M. GRUNER, stated that in Switzerland two dams of the arch type had been constructed in recent years, one 20 m. in height and one 52 m. in height; a third dam 72 m. in height had been constructed by Swiss engineers in Spain. These arch dams had been calculated theoretically, and the principal stresses had been established by calculating the temperature, the shrinkage and the water pressure. They went as far as 35 kilos per cm. for compression and about 10 to 15 kilos for tension. The main difficulty in all countries was to get this type of construction passed by the Government, as Government engineers were in general afraid of this construction. But if they had good abutments on both sides, these dams were more solid in appearance than the gravity dams. It would be interesting, if the experience with arch dams which had been gained in different countries could be collected and discussed at the next World Power Conference.

The question of overflows was very important in Switzerland, and still more important in Spain, because in Spain, during certain seasons, no water flowed along the river channel at all, and suddenly there were very great quantities discharged. Automatic sluice gates had been devised, but the speaker's experience with them had not been very encouraging. In Spain, he had tried a siphon system which the Spanish Government had accepted.

PROF. C. E. MAGNUSSON (*U.S.A.*), said that the Cushnon power project on the Pacific Coast, near the City of Tacoma, was constructed on the constant angle plan. The dams were nearly 280 ft. high and the plant would be in operation by about the middle of 1925. The use of this constant angle was resulting in a considerable saving.

M. G. DARRIEUS (*France*)‡, said that with reference to such dams, he would merely draw their attention to the contribution on this subject by M. Rabut,

‡ Translated.

Inspecteur Général des Ponts et Chaussées,* who had been responsible for many remarkable constructions in reinforced concrete. M. Rabut had recently pointed out the advantages that lay in the use of this material for the construction of hollow multiple arch dams, advantages which were apparent both on the score of safety with regard to permeation and of economy.

THE CHAIRMAN then closed the session.

* Génie Civil, 1924, p. 498, " Les Conditions de Sécurité des Barrages Massifs."

PREPARATION OF FUELS—
FUELS GENERALLY AND COAL

CHAIRMAN: DR. D. S. JACOBUS (U.S.A.)

Past President, American Society of
Mechanical Engineers

COMPLETE GASIFICATION OF COAL

PROF. DR. HUGO STRACHE

Professor of Fuel Technology and Principal, Fuel Testing Dept., High Technical College, Vienna

Compared with the employment of solid fuels, the advantages of heating by gas are well known, so that it is not necessary to say any more on the subject. To the ideal advantages of cleanliness and comfort are to be added the divisibility of the flame and the possibility of any desired formation of the same, which are of very great importance for many industrial objects. Further, the important economic advantage of the best utilisation of heat has to be taken into consideration, as the combustion is rendered possible with the smallest excess of air, and the hygienic advantage of keeping the air pure completes the series of advantages.

Hitherto heating gases have been utilised for two entirely different objects, namely, for the supply of gas to towns and as industrial gas, principally for producing high temperatures in large furnaces. For the object first mentioned, the chief aim is the greater advantage of cleanliness and comfort, while for the second object the possibility of producing the highest temperatures in an economical manner is the principal consideration.

Fundamentally the two groups of utilisation differ from one another in that a gas of a high calorific or heating power is favoured for town supply, for which the cost of 1,000 calories is not of any great consequence owing to the great advantages which cannot be expressed in terms of money, while for industrial objects it is not necessary to use a gas of a high calorific or heating power per cubic metre, as for the most part gases are required which render possible the production of 1,000 calories efficiency in the least expensive manner. Thus, coal-gas, which from the very beginning was used for the supply of towns with gas, has since that time been permanently employed for this object, while producer gas has been introduced for the use of the large industrial concerns. At first, the fields of application of the two kinds of gases remained distinctly separate. Only water gas, generated by passing steam over red-hot coke, is employed for the supply of towns with gas (as an additional

gas and pure water gas) as well as also for industrial purposes such as welding in glass factories and the like ; thus water gas is employed in both groups mentioned. However, its generation depends on the presence of a better-class coke and, therefore, is only possible in connection with the production of coke. Nevertheless, this has already shown itself to be gas, which may serve for the supply of towns, owing to its high calorific or heating power, and also for large industrial concerns, in consequence of its low price.

Still greater advantages, however, attach to a gas which is generated direct from coal and represents a mixture of coal-gas and water-gas ; for it has a still higher calorific value than the water-gas and also is cheaper in price than the latter, as it is not produced from coke but direct from coal. I term this new kind of gas " double gas."

Before I concern myself in detail with this, I must describe in a few words the different methods of gas production. Owing to the coking of the coal (distillation), coal-gas is produced in the small plants of the municipal coal-gas works, and coke-oven gas in the large plants of the coke works. In both cases about 30 cubic metres of gas of about 5,500 calories of calorific or heating power per cubic metre (in coke works slightly less) are produced from 100 kilograms of coal. In consequence of the higher temperature the greater part of the tar is decomposed and only about 4 to 5 per cent. remains as coal-tar. Also, the greater part of the ammonia is decomposed, so that only 20 per cent. of the nitrogen, contained in the coal is utilised. 60 to 70 per cent. coke remains, of which 12 to 25 per cent. serves for the furnace in the coal-gas production, while about the half of the coke-oven gas is used for the same purpose at the coke works.

During gasification in generators the residue of coke is fanned up to incandescence by air blown into the gas-producer and by steam blown on to the red-hot coal ; a mixture of carbonic oxide and hydrogen is thus produced, which is termed water-gas. Where air and steam are blown in simultaneously the mixture which leaves the producer is termed producer gas, while, by alternately blowing-in air and steam, the water-gas produced will be gas which is very nearly free from nitrogen. When using coal in the producers in place of coke, coal-gas is also mixed with the escaping gas, which increases its calorific value. By simultaneously blowing in air and steam, a high-class producer-gas is obtained from coal. During the alternate operation of air and steam the double gas is produced, which, as already mentioned, is a mixture of water-gas

and coal-gas. Though in the coal-gas and coking plants the distillation takes place at high temperatures and therefore the tar-vapours, the ammonia and partly also the gases are decomposed, the greater part of the same are retained in their original form in the producer plant; so that in place of the aromatic tar of the coal-gas works and coke plants the undecomposed low temperature tar is formed in large quantities, and the ammonia is also substantially retained. When using a large quantity of steam during the simultaneous injection of air and steam, the ammonia is retained in particularly large quantities, while a part of the carbonic oxide is transformed into carbonic acid, so that the calorific value of the gas is reduced. The producer gas generated at a very low temperature in this manner is termed Mond gas.

I will now give a survey of the different heating gases :—

Kind of gasification.	Yield of gas from 100 kg. of coal of 7,000 calories.	Gross calorific power of one cubic metre, 0 degree, 760 millimetres.	Yield of gas calorific power from the coal.	Yield of coke.	Yield of tar.	Output of nitrogen from the coal.
	cubic metres.	calories.	calories.	kilograms.	kilograms.	per cent.
Coal gas	28	5,500	154,000	65-15=50	5	20
Coke-oven gas ...	30—15=15	4,000	60,000	70	4	18
Producer gas	300	1,500	450,000	—	6	50
Mond gas ...	320	1,200	385,000	—	8	70
Water gas ...	150	2,800	420,000	—	—	—
Double gas	156	3,200	500,000	—	8	50

The kinds of gasification in which coke does not remain as residue I have termed "complete gasification," in accordance with a proposal made by Mr. Theodor Grothe, of Bochum.

From the table it will be seen that complete gasification carried out according to the double gas process results in the highest yield of calories in a gaseous condition, and I will now explain this process with the aid of illustration Fig. 1.[1]

The coal is fed into the retort *c* of the gas producer through a hopper which is provided with two shutters. As will be explained at a later stage the coal is distilled in the retort by the rising hot gases and the coke remaining behind sinks direct into the gasification chamber *a* situated below the retort. A grate of any convenient

[1] Breisig: "Double gas," a lecture delivered at Linz on the Danube on the 26th May, 1922, at the 41st annual meeting of the Institute of Gas and Water Experts of Vienna.

construction is arranged in the bottom portion of the gasification chamber. A revolving grate for automatic freeing from clinkers is to be preferred in gas-producers of a large size. The coke contained in the gasification chamber *a* is fanned up to incandescence by injecting or blowing-in air through the valve *b*. The gases of combustion, which contain a considerable amount of carbonic oxide and are hot, pass round the retort *c* and escape through the water-cooled valve *d* and are completely burned in the bottom

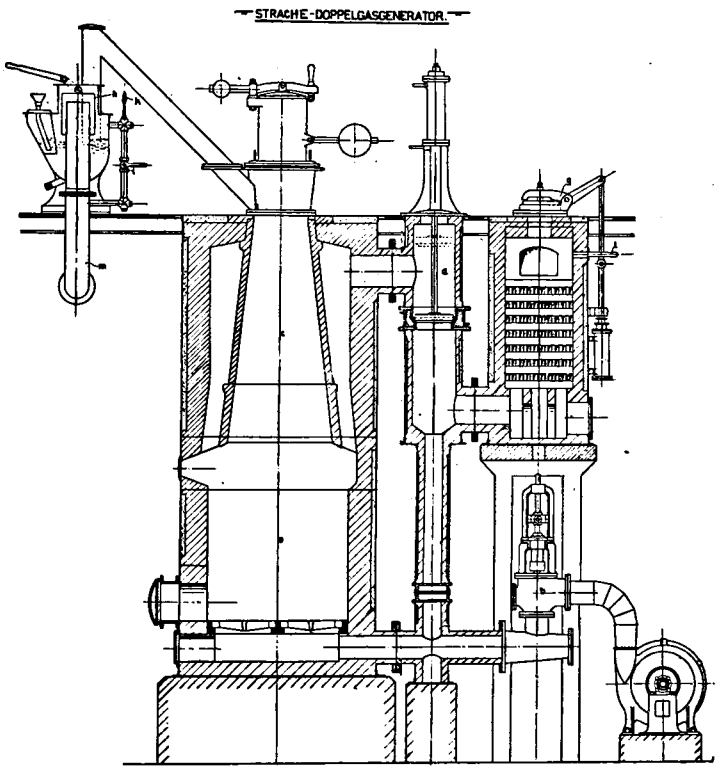

Fig. 1.

portion of the steam superheater *e* by an air-current branching off at *f*. The burnt gases escape through the opened valve *g* into a flue, arranged above the valve. The heat produced during the combustion in the superheater *e*, of the carbonic oxide containing hot blast gases, is collected or stored in the fire-bricks of the steam superheater. As soon as the coke-column in the gasification chamber *a* and the steam superheater are sufficiently hot, the

blast-valve *b*, the valve *g* for the escape of the burnt gases and the intermediate valve *d* are closed and steam is passed at *l* into the superheater. The steam passes through *e* and *f* and enters into the gasification chamber *a* in a highly superheated state and forms in the latter, water-gas, which is forced through the retort *c* in the hydraulic main. As the water-gas is of a very high temperature when it passes from the gasification chamber *a* into the retort *c*, and in the latter passes around each individual piece of coal, the latter is, during its sinking or downwards movement, at first distilled at a low temperature and thereafter is completely coked at a gradually increasing temperature. Therefore, in this case, we have to deal with a very complete low temperature distillation, so that the escaping gases and tar-vapours are not decomposed, and a good low temperature tar (Urteer) will result. The greatest part of this is deposited in the hydraulic main, from which the gas escapes through the pipe *m*. As soon as the gasification chamber *a* is cooled down too much by the steam, the valves are reversed again, and the entire system is again fanned up to incandescence and so forth.

The distillation gas, produced in the retort *c* during the hot blasting period, is led off by placing the bell *h* in the hydraulic main over the gas outlet pipe *m* in such a manner, that it dips into the shutting-off fluid. Therefore the gas coming from the retort *c* through the ascension pipe cannot escape here, but has to pass through the by-pass *i*. The latter is regulated by means of a controlling cock in such a manner that here only the distillation gas can escape and not also the hot blast gases from the gasification chamber *a*. This can be easily regulated by means of a flame burning at *k*, which on being extinguished indicates that, in consequence of the passage of the by-pass *i* being open too wide, the distillation gases are completely displaced by the hot blast gases.

The gases of combustion escaping from the superheater are still hot enough to heat a steam boiler, which supplies not only the steam necessary for working the apparatus, but also supplies an excess of steam for other objects.

In the following tables two balances of heat are mentioned, which have been carried out in the year 1920 on a double gas producer at the gas-works of Graz in Styria[1], and in the year 1923 on a double gas producer at the gas-works of Chemnitz.[2]

[1] Strache, Breisig and Gross, " Balance of heat of the double gas producer." *Journ. f. Gasbel. u. Wasservers.* No. 25 of the 19th June, 1920.

[2] Vater, " Studies on the heat proceeding of the double gas producer," Das Gas und Wasserfach (*Journ. f. Gasbel. u. Wasservers.*) 66 Jg. H.44 of the 3rd November, 1923.

ENTIRE BALANCE OF HEAT OF THE DOUBLE GAS PRODUCER AT GRAZ.

(*a*) Sensible heat :		
Proper heat of the fuel	1,000 Th.U.	0·1 per cent.
Heat of the steam	8,400 ,,	0·8 ,,
Heat of the air	4,200 ,,	0·4 ,,
Total	13,600 Th.U.	1·3 per cent.
(*b*) Heat of combustion :		
of the fuel	1,097,300 Th.U.	98·7 per cent.
Total	1,097,300 Th.U.	98·7 per cent.
Therefore employed heat	1,110,900 Th.U.	100·0 per cent.
(*a*) Sensible heat :		
Proper heat of the double gas ...	25,000 Th.U.	2·2 per cent.
,, heat of the steam	15,300 ,,	1·4 ,,
,, heat of the tar vapours ...	900 ,,	0·1 ,,
,, heat of the burnt gases ...	73,000 ,,	6·6 ,,
,, heat of the clinker	1,200 ,,	0·1 ,,
Total	115,400 Th.U.	10·4 per cent.
(*b*) Heat of combustion :		
Of the double gas	668,700 Th.U.	60·2 per cent.
Of the burnt gases	81,000 ,,	7·3 ,,
Of the tar	92,300 ,,	8·3 ,,
Of the carbon in light ashes and clinker	36,600 ,,	3·3 ,,
Total	878,600 Th.U.	79·1 per cent.
in addition to this the total radiation	116,900 ,,	10·5 ,,
results in the heat carried off ...	1,110,900 Th.U.	100·0 per cent.

Thus the efficiency of the double gas is :—

For double gas	60·2	per cent.
For tar	8·3	,,
Therefore the total efficiency ...	68·5	per cent.

BALANCE OF HEAT OF THE DOUBLE GAS PRODUCER AT CHEMNITZ.

Available in the shape of double gas	61·5	per cent.
,, ,, ,, low temperature tar ...	9·8	,,
Loss owing to the proper heat of the double gas current	9·8	,,
Loss owing to the hot blast gases	11·3	,,
Loss in the clinkers	0·7	,,
Loss owing to radiation, poking, leakage	6·9	,,
Total	100·0	per cent.

Thus the efficiency of the double gas process is :—

For double gas	61·5	per cent.
For low temperature tar	9·8	,,
Total	71·3	per cent.

In both cases the burnt gases contain considerable quantities of heat, partly in the form of unburnt carbonic oxide and partly in the form of specific heat. As previously mentioned, a large portion of this heat may be utilised for the production of steam, so that,

according to the last report received from Chemnitz, it will be possible to obtain an efficiency of 80 per cent.

Beside this high efficiency, which in practice cannot be obtained with any other gasification process, the double gas has the further advantage that it is not necessary to employ a good coking coal as is the case with the coal gas production and the coke plants, but any desired coal may be used, as it is not necessary to produce large coke for carrying out this process. On the other hand, a badly

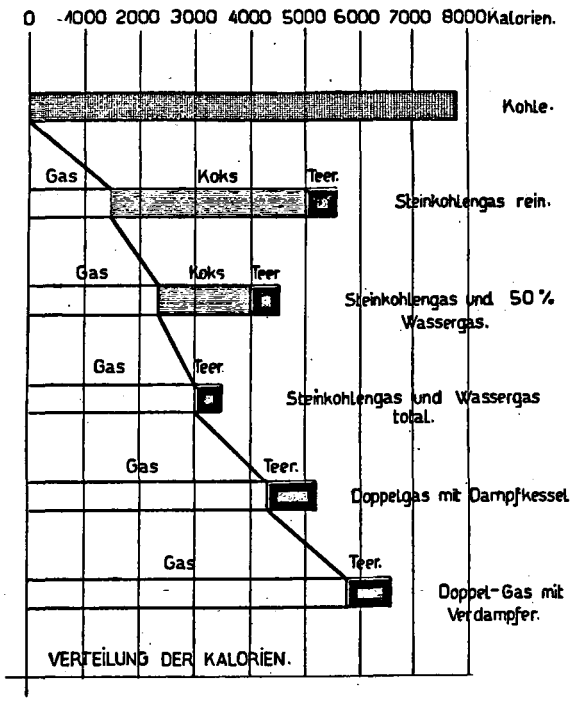

Fig. 2.

or little coking coal, which yields small coke, is to be preferred, as the latter descends more easily within the retort. Therefore, lignite or brown coal, alone or mixed with pit coal, can also very well be used, as also stated in the reports received from Graz and Chemnitz. Of course, the gas production is diminished in accordance with the quality of the coal. It is of interest, that the calorific power of double gas is the same for most kinds of coal, namely, between 3,100 and 3,300 calories per cubic metre. This is in

consequence of the fact that coals of a worse quality yield not only fewer distillation gases, but also less coke, so that the proportion of mixture between the distillation gases and the water gas always remains constant.

Out of 100 kilograms of pure coal the following was obtained :—

At Graz, with pit coal from Ostrau of 7,500 calories gross calorific power, 160 cubic metres double gas (not reduced) at 2,951 calories (not reduced). The gross calorific power of the gas, reduced to 0 degree, amounted to 3,334 calories per cubic metre.

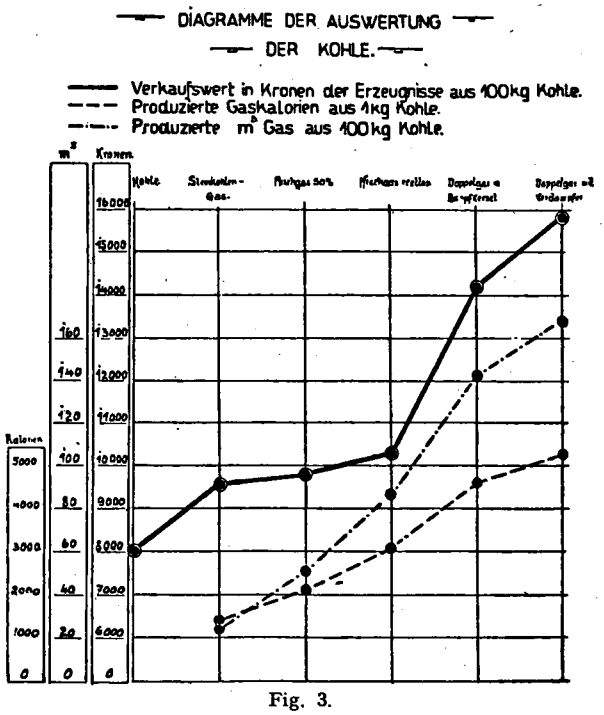

Fig. 3.

At Chemnitz, from a mixture of pit coal and lignite or brown coal of an average of 5,074 calories per kilogram, 111 cubic metres of double gas (0 degree, dry) with 3,110 calories of gross calorific power were obtained. From the statements for pure coal of a calorific power of 7,500 calories per kilogram, a total gas yield of 164 cubic metres for 100 kilograms of pure coal will be the result.

In his publication, mentioned above, Breisig has very clearly illustrated the heat-yields from coal with the different gasification processes (Fig. 2.)

The selling values for the products or yields obtained, are contained in a diagram as shown in Fig. 3, the prices being given in Austrian Crowns of May, 1922:—

		1	kilogram	coal	...	...	...	...	60	
		1	,,	coke	...	...	...	...	80	
		1	,,	tar	...	...	...	...	120	
		1	,,	NH^3	...	...	...	...	1,000	
1	cubic	metre	illuminating gas of			5,000	calories	...	...	226
1	,,	,,	Dowson gas, 50 per cent.			3,850	,,	...	...	174
1	,,	,,	Dowson gas, total			3,460	,,	...	...	156
1	,,	,,	double gas			3,400	,,	...	...	154

Although these prices are not in force to-day, they have increased in a quite uniform proportion, so that the values obtained

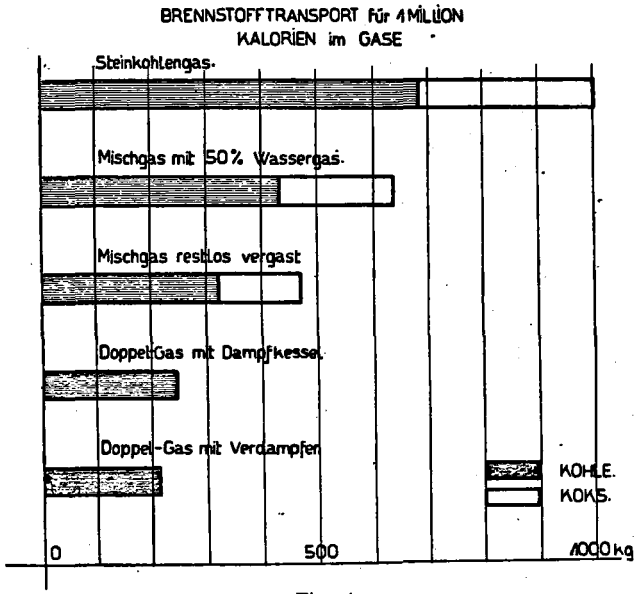

Fig. 4.

for the individual gasification processes can be compared with one another even to-day.

In coal-gas productions, as commonly carried out at present for the supply of towns with gas, coke remains as a non-gasified residue, and in these gasification processes the carriage and storage of the stock of coals and coke takes up very considerable space and requires a great deal of work. When, out of 100 kg. coal of 7,000 calories, 30 cubic metres gas of 5,500 calories and 50 kg. of marketable coke of 6,500 calories are produced, 330 kg. coal have

to be supplied and 165 kg. coke have to be conveyed away in order to produce 100 cubic metres of gas. Thus the carriage and storage of coal and coke amount to 500 kg. for every 100 cubic metres of gas, *e.g.*, for 550,000 calories in a gaseous condition. Therefore a manipulation of 91 kg. of fuel is required for 100,000 gas-calories.

With complete gasification, about 500,000 calories are obtained out of 100 kg. coal of 7,000 calories, thus for 100,000 calories a

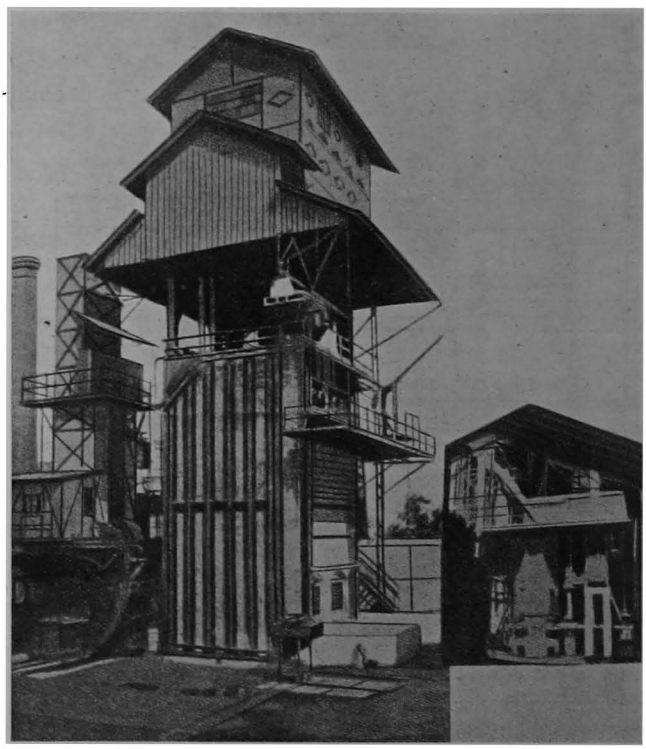

Fig. 5.

manipulation of 20 kg. fuel is required, which is less than a quarter of the manipulation necessary with the other kind of gasification. These conditions are clearly shown in Fig. 4. However, of particular interest is the required space and the cost of installation of such plants. Fig. 5 illustrates the difference in dimensions between an up-to-date chamber-oven plant and a double gas plant.

Further, the continuous readiness for working of the producers

also renders it possible to reduce the gasometer chambers, as a double gas producer is in working order half an hour after being fired up, while, as is well known, the retort and chamber furnaces of the coke plants and coal gas plants require many days, after having cooled down, and weeks until they are in working order. In the producers, which at present serve for the supply of gas to heating arrangements of industrial plants, gas tanks or gasometers are not used, and this point represents an essential difference between the pit coal gas plants and the coke plants on the one hand and the industrial heating gas on the other hand. The quantities of gas, required for larger heating plants are so large that storage of the gas cannot be taken into consideration. However, the producer must arrange that the production can be regulated in accordance with all fluctuations of the demand. Only in the case of gases which are produced in generators worked alternately, this state of affairs does not obtain, as they do not yield any gas for some minutes. Therefore, in this case, small tanks or receptacles have to be provided, which compensate for this irregularity. However, it is not necessary for these receptacles to be larger than that which corresponds to half an hour's yield of a generator. Storage over several hours is not absolutely necessary, as is the case with the coal gas production. This considerably reduces the initial costs, and also the required space, which is of the greatest importance for municipal plants.

If it is desired to employ complete gasification for the supply of industrial concerns which are far away from one another, it has to be considered whether the gas is to be produced either at the place where it is required, *i.e.*, decentralised in the individual concerns, or centralised in such a manner that it is supplied by means of a system of pipes, as in the case of municipal supply. However, a further problem is, whether or not the gasification ought to be carried out at the pit head. This is a question of the cost and length of the system of pipes. If we compare the different kinds of gases, the costs of the system of pipes per cubic metre are the same. However, as the calorific values are different, the cost of 1,000 conveyed calories will be smaller if the gas possesses a greater heating power. On the other hand, the cost of producing 1,000 calories will be smaller if the calorific value of the gas is smaller, as the inexpensive complete gasification yields gases of a smaller calorific power.

The result of calculating the total costs of the different gases when conveying them for various distances is indicated in Fig. 6,

which I take from an article called " Die Fernleitung des Gases," published by me in the year 1922.[1]

It will be of interest to know that for greater distances of conveyance of 40 to 200 kilometres and more, double gas involves the smallest total cost on the one hand, owing to the favourable efficiency during its production and on the other hand in consequence of its comparatively high calorific power. Ordinary producer gas can be produced at less expense, but the costs of conveyance are very large, if it has to be conveyed through a rather long system of pipes. Of course, the same applies also to Mond gas.

Of considerable influence on the costs of distribution is the rate or density of consumption, *i.e.*, the number of cubic metres which are passed through 1 kilometre of pipe in a day. The larger this number, the larger will be the dimensions of the pipes and therefore also the costs per kilometre, but as the gas passage increases approximately with the square of the pipe diameter and the costs are only slightly more than in proportion to the pipe diameter, the cost of conveyance per cubic metre will be smaller, the larger the density or rate of consumption. Of course, this increases with the length of the system of pipes.

In cases where industrial concerns produce the heating gases themselves, the density or rate of consumption is of the very smallest, as the length of the systems of pipes is very small, while the gas consumption is extraordinarily large. The smallest density of consumption is required for small towns with low buildings and with a small gas consumption per inhabitant. Therefore, the costs of the distribution of the gas will be very large in such small towns. In cities and large towns the conditions are far more favourable, but in spite of this, the costs of distribution are still of the greatest importance. They will be reduced in accordance with the increase in the gas consumption, and this again depends on the density or rate of consumption. Therefore if it is desired to reduce the costs of the gas, not only in the interest of the large concerns, but also in the interests of political economy, the consumers and hygiene, the costs of production have to be kept very low, in order that by a general use of the gas for heating, the density or rate of consumption will be increased to such an extent, that the costs of distribution are also reduced. In that case, also, a high distribution pressure will be of assistance, in the interests of the gas consumption, particularly if the gas to be consumed can be produced at small expense, such as, for example, water-gas and

1. Feuerungstechnik, X.Jg. H. 15, S.167, of the 1st May, 1922.

double gas, because the gases possess a high ignition-speed and therefore the apparatus to be supplied with the gas will work satisfactorily only if there is sufficient pressure in the burner.

The question has to be answered, whether the gases produced by the complete gasification are adapted to satisfy the gas consumer of to-day. The producer gas, which is one of the gases that can be produced at the very lowest cost and with very high efficiency, is scarcely suited for this object, as, owing to its high contents of nitrogen, its ignition speed is so small that the flames are not securely attached to the small nozzles of the burner and therefore are extinguished even by a small variation in the composition of the gas. Also the temperature of the flames of these gases is too low for domestic use unless they are pre-heated, and further they possess the drawback that they cannot be used for incandescent gas light. The properties of the water-gas and double gas are similar to those of the coal-gas and coke-oven gas, so that the same may be used in the present consumption devices with only a very slight alteration of the air supply. At first, the admixture of water-gas to the coal-gas caused very considerable inconveniences and disturbances to the consumers, but nowadays we are already used to a gas of 4,000 calories per cubic metre and in most cases the apparatus is provided with devices for regulating the air supply, so that, in case of an increased pressure in the system of pipes, and also when the calorific power is further reduced, the requirements of the consumers can be fully satisfied.

In Germany, originally, a calorific power of 5,000 calories was taken as normal for gas used in towns and at present 4,000 calories is the standard. In England, no definite calorific power has been fixed and it has been stipulated only, that the gas is to be supplied at a certain price for every 1,000 calories. Elsewhere also, however, it will be impossible to suppress the knowledge, that it is cheapest to produce a gas of 3,200 calories per cubic metre, as such a gas is produced by means of the complete gasification of the coal. Therefore it can be predicted, that still further reductions of the average calorific power of the gas will take place until the calorific power of 3,200 calories is reached.[1]

The employment of gas for the production of power has to be considered also from two points of view. In cities and larger towns, at any rate, the gas engine employed in small plants will be replaced by the electromotor, as the comfort and distribution of working

[1] STRACHE: "Zur Frage des Gasheizwertes" Ztschr. f. angew. Chemie Jg. 36, Nr. 77, S. 601 f. (Aufsatzteil) of the 17th, December 1923.

are so valuable that the higher working expenses are very soon compensated. For large plants gas engines have met with patronage chiefly where gas is available as by-product; they are therefore used mainly at smelting works, foundries (blast furnaces gas, waste gas), and at coke plants (coke-oven gas and so forth). Compared with steam engines, large gas engines possess the great advantage of a far better calorific efficiency, and the possibility of simultaneously gaining from the coal the by-products, tar and ammonia, would make for very economical results in the case of plants which completely gasify the coal, thereby producing these valuable by-products and working the gas engines, as, at an efficiency of the gasification of 80 per cent. and at an efficiency of the gas engines of 26 per cent., the entire commercial efficiency of the production of power from the coal can be valued at 20 per cent. This is considerably higher than is the case when burning the coal underneath the steam boiler to get power by the roundabout way of the steam engine or steam turbine. Unfortunately, the large gas engines are for 4,000 to 6,000 horse-power only and thus the necessity arises of erecting such a large number of individual aggregates in large plants, that greater complications will be the result, as is the case when employing steam turbines. This and the smaller reliability of the gas engines are the only reasons which are against the employment of this kind of power production on a large scale, and to me they do not appear to be sufficient to discourage the making of tests on a large scale in the interest of the very important saving of coal. The producer-gas, with its recovery of the by-products, would be of importance for such large gas engine stations or plants, since in this case the nitrogen ballast is not detrimental, as a high temperature of combustion is not desired.

At present it cannot be said whether the gas turbine will alter these conditions. The first designs justified good hopes for the future, but, apparently, development has now come to a standstill as far as improvement is concerned. However, constructions of other types of heat engines worked by gas promise to yield better results, and it is to be hoped that improvements will be made in that direction.

The firing of steam boilers with gas is the only other method of employing gas in the working of large power plants, which has been repeatedly taken into detailed consideration. In this case the first tests were made at places where gas is available as a by-product. All the advantages, which the gas possesses over solid fuels, are also present in this case, but for the furnace firing

gas will never effect the same economy as it does when utilised in furnaces of high temperatures, as the heating of boilers with solid fuels is so much improved that the losses only amount to 30 per cent. and, though heating by gas will be able to reduce them to 15 to 20 per cent., the gain is not so large as the losses in heat which arise during the production of the gas, and the troubles or inconveniences produced by gasification with the recovery of by-products. However, the heating of boilers with gas still allows of considerable improvement. Success in this direction can only be attained if the efficiency is increased to such an extent that a more favourable overall efficiency of the plant, including the production of the gas, can be expected.

Therefore, though the boiler furnace cannot be considered to be ideal for the employment of gas, heating by gas, and with it also complete gasification, cannot be fairly judged, if a boiler-furnace is taken as the basis for all calculations relating to the economy of the gasification of coal. The employment of gas is, naturally, best fitted for purposes where its advantages are particularly apparent; thus in cases where the flame is divided into small units, great cleanliness and the prevention of soot and dust in the gases of combustion are of importance; this is also the case where it is desired to obtain high temperatures.

Therefore there is still a great difference between the supply of towns with gas and the heating of boiler-furnaces. In the first case a good quality gas is necessary, even if it is costly, while in the latter case the gas may be of a smaller calorific power per cubic metre, but it has to be extremely cheap, so that self-production is not worth the trouble. The above methods of employment, for which the high temperature of the gas flame is of great importance and the cleanliness and other advantages of the gas must be taken into consideration, are intended to make up this difference. However, for this purpose a gas is required which possesses a high flame temperature, a great adaptability for dividing the flame and a high calorific power per cubic metre, in order that it may be economically conducted over great distances; it must also be so inexpensive that, besides its employment in households and for particular industrial objects, it may be extensively used for other purposes with the exception of the working of boilers.

In many cases complete gasification has been considered only from the point of view of the recovery of tar and ammonia, and the gas produced thereby has not had sufficient attention paid to it. If the gasification is carried out in generators or producers,

the gas is only in certain cases of any value. But if the gasification is performed in the double-gas producer, the gas will be a most valuable product owing to its high calorific power, if there is a sufficient demand for it, which however is not to be looked for in boiler firing.

Here a combination is present which is worthy of consideration. By continuous hot blasting of the double-gas producer, we are in a position to obtain any desired quantity of very heating hot-blast gases and to heat with them steam boilers, which can be very advantageously employed for working electric plants or for other purposes. From time to time double gas may be produced in the double gas producer by blowing in steam, and this gas being a high-class product is one of the most important means for ensuring the economic success of such a plant. Where a double gas produced in such a manner is utilised for the gas supply to a town, its price is high, but if the boiler-furnace with the aid of the hot-blast gases of the double-gas producer is used for working an electric plant, which also supplies the town with electric current, the coal is utilised at an unusually high efficiency, and the combination of gas plant and electric plant is extremely advantageous. Such a combination has already been frequently started, although it has been tried only at existing gas and electric works. A complete success, however, will be obtained only with the entire rebuilding or erection of new gas or electric works.

When calculating the economy of large gas stations or works, it has frequently been forgotten that the recovery of the ammonia from the coal produces values of economical importance. It is true that the synthetic production of the ammonia is so very successful, that it enters into keen competition with the nitrogen of coal, but it must be remembered that synthetic production requires a considerable amount of energy, which can be used for other objects if the ammonia is recovered from the coal. Considered from this point of view, the direct use of the coal underneath the steam boiler cannot be considered compatible with political economy and in this respect also, the coking of coal in coke plants and gas-works is not economical, as it transforms only 20 per cent. of the nitrogen of coal into ammonia, while the complete gasification yields 50 to 70 per cent.

In Austria, where there is a great scarcity of coal, the double gas employed in gas-works has already proved very successful. The Austrian towns of Graz, Wiener-Neustadt and Leoben are supplied with double gas partly in a pure condition and partly mixed with

coal-gas. The great value to Austria of this kind of gas supply, which does not depend on foreign coke-coal, may be seen from the fact that the greater part of the 900,000 tons of coal annually used in this country for the production of coal-gas, can be replaced by Austrian coal. However, in coal-gas production, about half is recovered in the form of coke, so that only 450,000 tons have been actually gasified. But even this amount represents an annual value of 252 milliards, at a price of 700,000 Austrian Crowns per ton, which alone is of great economical consequences.

Some towns also, in the countries which formerly constituted the Austro-Hungary monarchy and in Italy, already participate in the advantages of double gas, for example, the gas-works of Brünn and Ungarisch-Hradisch in Czecho-Slovakia, Fiume, Udine, Bologna, and Rome, in Italy, Marburg, Cilli, Subotica, Laibach and Sarajevo, in Jugoslavia. Further, it may be mentioned that in addition to the above mentioned large double gas plant of Chemnitz, Germany possesses such works at Kochendorf and Herzberg, and Finland uses the system at Helsingör.

Considering the short time that double gas plants have actually been completed, they have already entered a very vast field of activity. The difficulties opposed to this progress are principally the opposition of the vested interest, owners always having a tendency to conservé the existing plants, and therefore, being for the most part opposed to progress.

RÉSUMÉ.

Les différences d'emploi du gaz de chauffage pour les-usages domestiques et pour l'industrie sont expliquées et l'emploi des diverses espèces de gaz: gaz de houille, gaz de gazogène, gaz à l'eau, gaz double, gaz Mond est décrit. Un aperçu des rendements du gaz et de la puissance calorifique montre que le produit de la puissance calorifique, multiplié par le rendement du gaz est le plus élevé avec le gaz double car on obtient avec 100 kg. de charbon de 7,000 calories, outre 8 pour cent. de goudron, 500,000 calories sous forme de gaz. Suit alors une explication du procédé de fabrication du gaz double et des bilans thermiques qui ont été constatés dans les usines à gaz de Graz et de Chemnitz avec les gazogènes à gaz double. Il en résulte qu'en utilisant la chaleur d'échappement pour la production de la vapeur, l'effet utile de la distillation complète est d'environ 80 pour cent. Des graphiques montrent la répartition de la puissance calorifique du charbon sur le gaz, le coke et le goudron dans les différents modes de distillation, en outre les quantités de combustibles à transporter pour chaque million de calories sous forme de gaz, d'où il ressort qu' avec le procédé au gaz double, ou n'a à transporter que le quart du tonnage de combustible nécessaire avec le gaz tiré de la houille. On signale ensuite l'économie d'espace et le transport à distance des gaz de puissances calorifiques différentes, représenté également graphiquement. A une

distance minimum la même puissance calorifique peut être fournie au prix le plus bas par le gaz de gazogène, mais lorsque la distance attaint 40 km., le gaz double lui est supérieur à cause de sa puissance calorifique plus élevée et de la diminution des frais de transport par 1,000 calories qui en résulte. Un renvoi à l'augmentation de consommation occasionnée par la livraison du gaz à prix modique complète les considérations sur le transport à distance. Si par la distillation complète, c'est-à-dire, par la transformation en gaz du charbon entier, y compris le coke, une puissance calorifique de 3,200 Cal/m. est obtenue, il est à supposer que la diminution de la puissance calorifique du gaz pour l'approvisionnement communal ne s'arrêtera qu'à ce chiffre.

La production d'énergie par voie de distillation laisse prévoir une économie en combustible mais, à présent, elle est encore restreinte par l'imperfection des moteurs à gaz de grande puissance. Le chauffage des chaudières avec du gaz dans les grandes usines génératrices de force motrice n'est pas recommandable, et a été choisi par erreur de différents côtés comme base pour les calculs sur les avantages économiques de la distillation du charbon. La température élevée de la flamme et le bas prix du gaz double seront appelés à combler le vide qui existe à présent entre les gaz industriels pauvre à prix modique (gaz de gazogène) et le gaz de houille riche à prix élevé. L'obtention du goudron et de l'ammoniaque offre de grands avantages économiques sociaux car, avec la distillation complète, 50—70 pour cent. de l'azote du charbon sont transformés en produits utilisables.

En Autriche, en Allemagne et en Jougoslavie, ainsi qu'en Italie le procédé à gaz double est déjà en usage dans beaucoup de villes. En Autriche seule, son emploi général pourrait donner lieu annuellement à une économie de charbon importé de 450.000 tonnes, ce qui correspond à une valeur de 252 milliards de couronnes autrichiennes.

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The efforts to save fuels have considerably developed since the foundation of the testing department in the year 1909. This department was founded in consequence of a suggestion made by, and with the assistance of, the Austrian society of gas and water experts, and at an early stage was taken over by the State. At the start, problems of gas lighting were dealt with. However, very soon its scope of activity was extended to fuels and furnaces, and the latter are now its principal fields of activity. During the war, particularly in Austria, there arose the necessity to save coal, and many of the authorities and a great percentage of the population came to the conclusion that an institute of this kind should be encouraged. Similar reasons led to the foundation of a chair for the technology of fuels at the High Technical College of Vienna ; while the frequent applications for heat experts which were made by industrial concerns, finally resulted in the opening of a special class for heat and gas experts, which it is believed is at present the only one of its kind in the world. Its students have to master the principles of engineering and chemistry, and during the last two years of their studies, which extend over a term of four years, they are perfected in the special knowledge of the heating science. During recent years the testing department has been considerably enlarged, so that the students can study practical requirements.

The field of activity of the testing department, and of the college connected with it, extends mainly over four subjects :—

(a) Fuel examination, balances of heat and advice to industrial concerns on all heat problems.

(b) The working out of, and giving expert opinion on new inventions.

(c) Scientific working.

(d) Scholastic profession.

SECTION (a)

The testing department carries out all kinds of examinations of solid, liquid and gaseous fuels in a calorimetric as well as chemical manner, photometric works, perfection of complete balances of heat on furnaces and heating plants, as well as also the technical heat examinations of works or factories.

Every one of the chemical examinations is checked by a parallel analysis, as far as the nature of the analysis does not render this unnecessary, and thus a complete reliability of the results is achieved.

SECTION (b)

In many cases industrial concerns desire to have new processes and apparatus treated or worked out by the testing department, as in most cases the individual industrial concerns have not at their disposal the trained staff and apparatus necessary for the scientific examination of the subject.

The testing department is in a position to show very good results, particularly in the manufacture of new measuring instruments and in the utilisation of mineral oils and tars.

SECTION (c)

The scientific work at the testing department is carried on in close conjunction with the scientific work of the college for the technology of fuels; further, it is carried out in connection with the examination of inventions for industrial concerns, as in the latter cases the scientific rudiments have to be investigated before perfecting the inventions for practical uses. Quite a large amount of work was caused in the testing activities of the department in so far as new processes for the examination of fuels proved to be desirable. Some publications are stated in the following lines:—

Ueber moderne Photometrie, Ztschr. d. öst. Gasver. 1909, S.213.

The Efficiency of High Pressure, Gas Lighting Illuminating Engineer, London July, 1909.

Ein einfaches genaues Gaskalorimeter, Ztschr. d. österr. Gasvereines 1910, H.2

Einige Neuerungen in der Gasanalyse, Ztschr. d. österr. Gasvereines 1910, H.9

Die vorgeschlagene INTERNATIONALE Lichteinheit, Ztschr. d. österr Gasvereines 1910, H.24.

Eine neue Form des Autolysators, Ztschr. d. österr. Gasvereines 1911, H.3, S.58

Fortlaufende Bestimmung und Aufzeichnung des Kohlensäure-gehaltes von Gasen Journ. f. Gasbel. 1911, H.23.

Ueber eine neue Methode der Kohlenuntersuchung Ztschr. d. österr. Ingenieur— u. Architekten—Ver. 1911, H.24.

Ueber eine Erleichterung bei der Einstellung der Flammenhöhe der Hefnerlampe Ztschr. d. österr. Gasver. 1912, H.6.

Ueber objektive Photometrie und eine absolute Lichteinheit, Ztschr. d. österr. Gasvereines 1912, H.8 und 9.

Untersuchungen über den Bunsenbrenner, Ztschr. d. Ver. d. Gas—und Wasserfachmänner i. Oest.—Ung. 1912, H. 22 u 23.

Der Densograph, Ztschr. d. Ver d. Gas—und Wasserfachmänner in Oest.—Ung. 1914, H.10.

Einfluss der Flammentemperatur auf die Lichtstärke des Gasglühlichtes, Ztschr. d. österr. Gasvereines 1912, H.6.

Double Gas, The Gas World, 13.VI.1914.

Ueber eine einfache und genaue Art der Heizwert bestimmung mit dem Junkerschen Kalorimeter, Ztschr. d. österr. Gasver. 1915, H.1.

Die Strahlung unserer künstlichen Lichtquellen im Vergleich zum Tageslicht Ztschr. d. österr. Gasvereines 1915, H.8 u. 9.

Eine neue Methode zur Wasserbestimmung in Gasen, Ztschr. d. Ver. d. Gas—u. Wasserfachmänner in Oest.—Ung. 1916, H.1 u. 2.

Eine neue Methode zur Untersuchung von Gaskochern und anderen Bunsenbrennern, Journ. f. Gasbel. 1915, H.51.

Eine weitere Vereinfachung der genauen Heizwertbestimmung mit dem Junkerschen Kalorimeter, Journ. f. Gasbel, 1915, H.50.

Ein neues Verfahren zur Bestimmung der Nutzeffekte von Gasheizöfen und die Wasserabscheidung aus den Abgasen von Gasöfen. Ztschr. d. oösterr Gasvereines 1916, H.1 u. 2.

Ueber das Doppelgasverfahren, Ztschr. d. österr. Gasvereines 1916, H.2/6.

Zusammensetzung von Braunkohlenteeren, Montanistische Rundschau 1919, H.13/19.

Die Untersuchung der Kohle mit Rücksicht auf ihre Vergasung in Generatoren Mittlg. d. Instituts f. Kohlenvergasung 1919, H.5 v. 8/IV.

Die Produkte der destruktiven Destillation des Braunkohlenteers und der Mineralöle Oesterr. Chem. Ztg. 1919, H.11.

Ueber die Vergasung der bosnischen Braunkohlen von Zenica, Breza und Kakany Mttlg. d. Instituts f. Kohlenvergasung 1919, H.11 v. 8/XI.

Der Wert der Elementaranalyse zur Kennzeichnung der Kohle, Ztschr. Braunkohle 1920, H.8.

Wärmebilanz des Doppelgasgenerators, Journ. f. Gasbel. 1920, H.25, S.399.

Die Berechnung des Nutzeffektes der restlosen Vergasung, Ztschr. Braunkohle 1921, H.42/43.

Die Inventur der Brennstoffe in Hinsicht auf die neueren Kohlenverwertungsverfahren, Ztschr. Brennstoff—Chemie 1921, H.6.

Bestimmung der Entgasungswärmen von Kohlen im Kalorimeter, Zyschr. Brennstoff—Chemie 1921, H.7.

Der Taschengasprüfer SICCUS, Ztschr. Elektrotechnik u. Maschinenbau 1922, H.18.

Die Fernleitung des Gases, Ztschr. Feuerungstechnik 1922, H.14/15.

Wärmetechnische Ueberwachung der Betriebe, Ztschr. Elektrotechnik und Maschinenbau 1922, H.15/17.

Definition des Begriffes Kohle im allgemeinen und Torf, Braunkohle, Steinkohle, Anthrazit, Ztschr. Brennstoff—Chemie 1922, H.20 v. 15.X

Die untere Entgasungswärme der Brennstoffe und die Sauerstoffverteilung bei der Urverkokung, Ztschr. Brennstoff—Chemie 1922 H. 3v. 15/XI., S.337/340.

Der Taschengasprüfer-Apparat zur Gasuntersuchung auf trockenem Weeg Ztschr. Feuerungstechnik 1922, H.2, S.13 v. 15/X.

Feuerungskontrolle, Ztschr f. Dampfkessel—u. Maschinen—betrieb DIE WARME, 1923, H.29.

Zur Frage des Gasheizwertes, Ztschr. f. angew. Chemie 1923, H.77, S.601 f. v. 17.XII.

Zur Frage des Ursprunges des Kohlenstickstoffes, Ztschr. Brennstoff—Chemie 1923, H.16, S.244 v. 15.VIII.

Zur Kenntnis der Braunkohle, Ztschr. f. angew. Chemie 1923, H.59 v.15.VIII.

SECTION (d)

The lectures at the college for the technology of fuels have for their principal object the education and training of students in the heat and gas technical sciences. The students work for two years in the laboratories of the college and in the testing department. Lectures held four hours per week serve to train students of other departments, who desire to obtain only a slight knowledge of the science of heat technology.

Further, each year lectures are held for engineers who are already engaged with industrial concerns, even if they are heat experts, in order to increase their knowledge. For carrying out the work, also, volunteers are taken on at the testing department; these get a practical training in the examination of fuels, so that they are at a great advantage, even if they are not solely interested in heat-economy. By working on larger industrial examinations the students have an opportunity to improve their knowledge. Not only are the assistants and scientific auxiliary workers engaged on the carrying out the scientific work, but also candidates, who desire to take the examination for doctor of the technical sciences, carry on their work in the laboratories of the college and the testing department. In the latter, also, consulting engineers work out scientific problems, and also industrial concerns send engineers to the testing department in order to work out certain problems.

The want of space resulting from the extraordinary large amount of work, particularly on the part of industrial concerns, has been overcome in the course of this year by removing the testing department to a large building of its own, so that now the work can be carried out on a large scale.

The staff of the testing department consists of the manager, who at present is also the principal of the college for the technology of fuels, of an assistant auxiliary worker and a servant, all being engaged by the State. Further, in order to deal with the current work, auxiliary workers are engaged and paid by the testing department, the wages of these workers being defrayed out of the

testing-fees, and not having to be paid by the State. At present three such auxiliary workers are engaged, the number employed depending on the number of orders received by the testing department. The college for the technology of fuels has its own trained staff.

The testing department is managed on a commercial basis, so that only the assistant and the scientific auxiliary workers are paid by the State. By engaging the above-named auxiliary workers, who in most cases are young graduated engineers, the work of the testing department can be carried on with inexpensive but very skilled workers, and the young engineers have an opportunity of gaining their first practical experience at quite a reasonable salary.

A further result of the testing department is that industrial concerns of a similar character intend to form heat-technical centres, which are to be maintained by the industrial concerns, since this would be less expensive than engaging heat engineers at each individual firm. These centres are to be paid by the industrial undertakings, but will be a part or branches of the present testing department and under the supervision of its manager and thus also of the State. The choice of the neutral Technical College offers to these centres a very solid backing. At present the glass, ceramic, lime and cement industries intend to fit up such a laboratory, and it is to be hoped that other industries will follow their example.

RÉSUMÉ.

La nécessité d'économiser les combustibles a, dans les dernières années, excessivement animé l'activité de la Section d'Essais. Travaillant d'un commun accord avec la Chaire de Technologie des Combustibles qui lui est attachée, cette Section s'occupe de faire des analyses de combustibles, des bilans thermiques, de donner des conseils à l'industrie dans toutes les questions relatives à la technique de la chaleur, d'élaborer des inventions et des rapports motivés ainsi que de l'exploitation scientifique et de l'enseignement.

La nécessité d'insruire des ingénieurs versés dans les questions thermiques, a conduit à la fondation d'une sous-section à l'École Supérieure Technique de Vienne, pour ingénieurs s'occupant de la technologie du chauffage et du gaz qui sert à fournir aux étudiants les éléments nécessaires pour cette technologie du point de vue chimique et mécanique.

Uncours annuel de perfectionnement permet aussi aux ingénieurs de chauffage praticiens de se tenir au courant des perfectionnements réalisés dans cette matière. L'organisation de la Section d'Essais est telle que le Gouvernement ne paie que les directeurs, tandis que les appointements des autres employés et les frais accessoires sont couverts par les taxes d'examen. A la Section se trouvent rattachés des centres de certains groupes d'industrie s'occupant de la technologie de la chaleur de sorte que son activité sert aussi directement aux industries.

THE CONVERSION OF COAL INTO OILS

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Gch. Reg. Rat.

The practical importance of the conversion of coal into oils, that is to say, into liquid fuels, varies with different countries, depending upon the question whether crude oil is found in large or small quantities, but it is of common interest that the progressive study of chemistry is increasing the possibilities of complete or partial conversion of solid fuels into liquid fuels.

(1) DESTRUCTIVE DISTILLATION.

In order to find how to convert coal into oils, it should have been necessary to know the exact chemical constitution of coal. Practice and science, however, did not wait for this question to be answered. The destructive method of dry distillation, which for a long time has been employed to produce coal-gas and metallurgical coke, yielded the first oil-like products from coal, *i.e.*, tar and benzol. With this method, however, the yields of oil are relatively small, because on the one hand only certain constituents of coal can be converted into oils by destructive distillation and on the other hand, regarding the yield of oil, high temperature coking represents an exceedingly wasteful process of destructive distillation. The small yield of oil is due to the fact that the practical requirements, *i.e.*, the production of metallurgical coke or of coal-gas, demand the employment of high temperatures of about 1,000°C. in the distillation chamber. Therefore, the low temperature tar, which should be formed in much larger quantities, is reduced in quantity, changed in quality and obtained as high temperature tar, which, owing to its great percentage of solid constituents, such as Napthalene and Anthracene, is less suitable as a liquid fuel. On the other hand, owing to its great percentage of aromatic constituents, it has become the most valuable raw material for the organic chemical industry.

If it is required to obtain larger quantities of oil by destructive distillation of coal, it is necessary to work at as low a temperature as possible. Whilst in the production of coal-gas and coke, to throw coal into glowing distillation chambers and retorts, this may not be done when coking at low temperature. Though it is known that the mineral coals are impregnated with small quantities (0.1-0.5 per cent.) of oleaginous substances, the oils, however, resulting from the destructive distillation are mainly formed by the thermal decomposition of ulminous, resinous and wax-like constituents, *i.e.*, by destruction of the larger organic molecules. In this connection there is a given temperature which guarantees the highest amount in the yield of oil in low-temperature coking. The point of decomposition of the bituminous constituents is at temperatures, which, according to the quality of these substances, lie between 300 and 450°C. Any higher temperature is disadvantageous, changing the oils and forming coke and gas. Not only must temperature be kept below the point of decomposition of the bitumen, but also we have to take care that the oils yielded from the coal do not remain at the temperature at which they are formed longer than is absolutely necessary. Therefore, they must quickly be removed from the distillation chamber and cooled down. Otherwise their hydro-aromatic constituents are dehydrogenated and converted into aromatic substances or their aliphatical constituents are disintegrated into gaseous products such as ethylene and methane.

Accordingly, the production of oil by means of low temperature coking may be carried out with stationary or rotating vessels with external or internal heating as a mere process of distillation yielding semi-coke, low temperature tar and gas. Moreover, we may directly combine the production of oil with the gasification of semi-coke by means of gas producers in such a way that in the lower part of the apparatus the gasification of semi-coke is effected whilst in the upper part the products of distillation are swept out by means of the rising hot gas from the gas producer. Finally, we may also combine low temperature coking with the consumption of semi-coke by placing distillation chambers in front of the mechanical stokers. Thus the semi-coke is burnt on the grate and a portion of the hot fire-gas is driven through the carbonising chamber to distil the coal.

Though the production of oil by means of low temperature coking may thus be carried out in gas producers or in vertical

retorts in front of a chain grate stoker, it is the process of distillation yielding semi-coke which is the more valuable. For there is gained a valuable distillation gas of nearly 9,000 calories (about 70 cu.m. per ton of coal), the low temperature tar may be collected more completely and finally, the low boiling liquid constituents of the gas (gasoline) may be condensed in this relatively small volume of gas more easily than in the large quantities of gas from a gas producer, where distillation gas is diluted by producer gas to about seventy times the volume.

While in the production of oil by means of a gas producer or in distillation chambers situated in front of the stoker, no semi-coke is gained, its quality, therefore, being of no interest, in the process of distillation the solidity and density of semi-coke is very important. For in this case, at a yield of about 70 per cent. (using flaming-coal) it represents quantitively the main product of the distillation. Unless special precautions are taken a very porous and easily friable semi-coke is usually formed owing to the swelling of the coal during distillation. It is possible, however, to produce a dense and firm material in such a way that solidification is effected in the furnace itself during the stage in which the coal is plastic. Methods for this process have been suggested by *Parr* and *Olin* (using a plunger) and later on by myself (enclosing a roller in a rotating horizontal retort). I must, however, admit that a practical and successful adaption of this idea has not yet been possible in the industry owing to the constructive difficulties. After distillation, the porous and levigable semi-coke was briquetted with pitch, gasified in gas producers or used as means of leanness when coking bituminous coal. Furthermore, being easily pulverised it has been employed as a powdered fuel in coal dust furnaces.

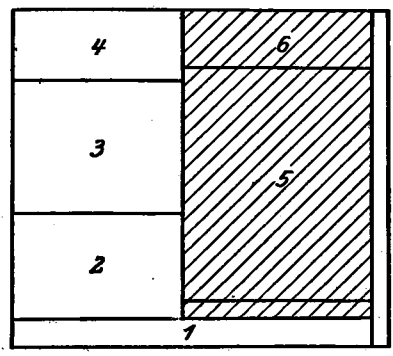
The most suitable method would be to distil silt-coal or fine grained coal and thus, making use of the fact that coal spontaneously becomes plastic, to produce a dense semi-coke, a valuable smokeless fuel, but as long as constructive difficulties block the way, we may reach the real goal of the immensely important low temperature coking only in so far as concerns the production of oil, and not as a means to the recovery of smokeless coal. A summary of the yields and constituents of low temperature tars of several mineral coals is given in the following table:—

Yields of low temperature tar of several mineral coals.

Specimen of coal	Low temperature tar (free of water)	Low temperature tars containing solid paraffin per cent.	phenols per cent.
Lean Coal	about 1.5	?	0
Fat Coal	„ 3.5	1—2	15—20
Gas Coal	„ 8	1—2	about 30
Flaming Coal	„ 12	1—2	„ 45
Cannel Coal	„ 29	?	5—10

The more exact composition of a low temperature tar, gained from a flaming-coal, is given by the following figure (1).

Fig 1



Such a low temperature tar of mineral coals is entirely liquid and gives only a small precipitation of paraffin. Its specific

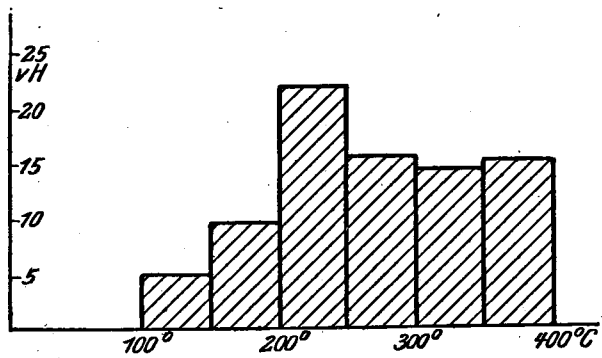


Fig. 2.

gravity at 25° amounts to about 1.04 and its calorific value to nearly 9,000 calories.

On the left side of the figure there are designed the neutral constituents and on the right, the phenols. The numbers of the single squares relate to the following substances: (1) tar gasoline, (2) non-viscid oils, (3) viscid oils, (4) neutral resins, containing paraffin, (5) liquid higher phenols, (6) semi-solid acid resins. This diagram is only valid if the tar is distilled by means of superheated steam. By distilling at ordinary pressure a great part of the viscid constituents are destroyed.

The effect of distillation at ordinary pressure is given by the following figure (2):

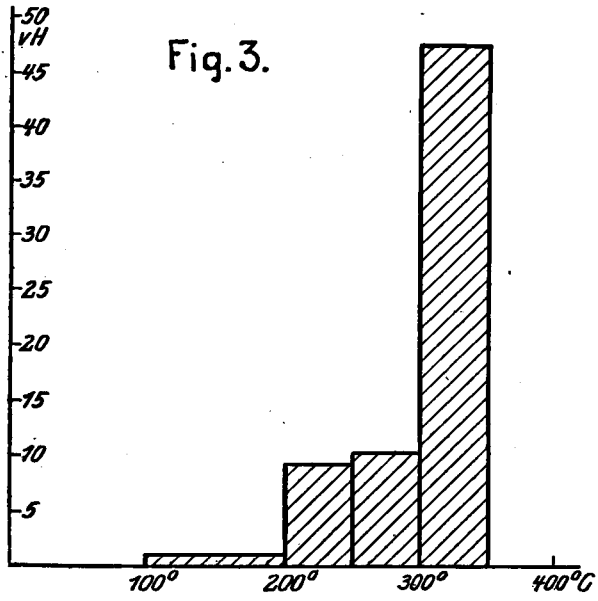
It will be noticed that but about 10-15 per cent. boil below 200°, all the rest boiling between 200 and 400°.

The fraction distilling between 200 and 250°. occurs in the largest quantities of all.

(2) HYDROGENATION OF COAL.

As opposed to destructive distillation, hydrogenation is a method which converts coal into oleaginous substances up to the weight of the coal and even, according to some assertions, to a still greater yield. Using a young mineral coal of the composition C, 82.2 per cent., H, 5.2 per cent., 0, 8.7 per cent., the essential problem is to remove the oxygen as far as possible and to substitute hydrogen or else to annex hydrogen to the molecules until liquid or easily fusible hydrocarbon-like substances have been formed. Berthelot was the first to carry out such a hydrogenation, using hydriodic acid. This method, of course, cannot be employed in the industry. In the same way sodium formiate, at a higher temperature easily produces nascent hydrogen which is especially suitable to remove and take the place of the oxygen. In this process, the sodium formiate is converted into carbonate from which it may be regenerated by means of carbon monoxide. Nevertheless, this process is very expensive, as pressure devices must be employed at 400°, and moreover because in such apparatus working continuously with solid substances is very difficult. For instance *Schrader* and myself mixed Rhenish brown coal with twice its weight of sodium formiate, added the same quantity of water and heated the mass for three hours to 400° in an autoclave. In doing so, 45 per cent. of the brown coal became dissoluble in ether, and this extract yielded as distillate a viscid high boiling oil. The latter may be obtained directly from the product of reaction by means of distillation.

The ethereal extract produced by hydrogenation of the brown coal is semi-solid at ordinary temperature and shows the following average elementary composition: C, 86 per cent., H, 8.6 per cent., O, 5.4 per cent. It will be noticed that it is not free from oxygen. The oil gained from this product by means of distillation boils in a manner as shown by the following figure (3):



The process takes a similar course if hydrogenation is carried out in the presence of water by means of carbon monoxide instead of sodium formiate. In this case, the ephemerally appearing formic acid might be the active substance, *i.e.*, the product delivering hydrogen. The carbon monoxide was used under high pressure up to 140 atm., and in this case too, the temperature of 400° proved the most suitable.

Hydrogenation of brown coal by means of molecular hydrogen, according to *Bergius*, proved less advantageous, yielding but half the quantity gained by means of the other process.

The products of reaction received by hydrogenation are only partially liquid, the other part being solid but soluble. If on *Bergius'* principle, the coal, which is to be hydrogenated, is

impregnated with tar oil, the solid constituents are dissolved and the whole coal becomes liquefied. Nevertheless, I cannot say that for the present direct hydrogenation of coal has proved a practically realisable process for obtaining valuable liquid motor-fuels, although it is of great theoretical interest.

(3) SYNTHESIS FROM GASES.

Carbon monoxide itself or as water gas may easily be produced by gasifying any solid fuels. For a long time we have known that substances soluble in water, such as Methanol and Acetone and a small quantity of oleaginous products insoluble in water may be obtained by thermal destruction of certain formiates, such as calcium-formiate, which may easily be produced from calcium hydroxide and carbon monoxide under pressure.

Calcium formiate at 420-430° decomposes according to the equation:

$$2\ Ca\ (HCO_2)_2 = 2\ CaCO_3 + 2\ CH_2O = 2\ CaCo_3 + CH_4O + CO.$$

Thus, theoretically, 1 molecule of methanol may be gained from 2 molecules of calcium formiate. Practically, by disintegrating calcium formiate, we may obtain up to about 50 per cent. of the theoretical quantity and by using Barium formiate, nearly 70 per cent. Lithium formiate proves much less advantageous; the other alkali formiates do not yield any organic liquid at all. Methanol does not prove a good motor fuel, but the higher boiling oils show better properties.

Instead of producing the formiates by means of carbon monoxide under pressure and then disintegrating by heat, it became possible to make the formiates occur but ephemerally in a contact process or else to attempt the catalytic reduction of carbon monoxide by means of hydrogen under pressure.

Until quite recently, statements about this point were only to be found in the patent files. The Badische Anilin und Sodafabrik claims to be able to obtain liquid or easily liquefiable hydrocarbons, if mixtures of hydrogen and carbon monoxide, especially with carbon monoxide exceeding the quantity of hydrogen, are made to pass over certain contacts at a temperature of 300-400° at a pressure of about 100 atm. Later on *Tropsch* and myself gave full particulars about the production of oil-like substances in a similar way, but the products were practically free from hydrocarbons and mainly consisted of higher alcohols and cetones. We named the synthetic oil mixture "synthol" and studied its formation and its properties.

A suitable contact proved to be iron filings impregnated with alkali, and a suitable gas, water gas, if possible containing a larger quantity of hydrogen than of carbon monoxide. The temperature may vary within certain limits (between 390 and 430°), the temperature of 410° proving most suitable. To carry out the synthesis we compressed the water gas to a pressure of 100-150 atm.

The production of synthol according to this contact process might be carried out more easily than for instance the synthesis of ammonia, according to *Haber*, as the temperatures required are lower and, furthermore, because the steel tubes do not

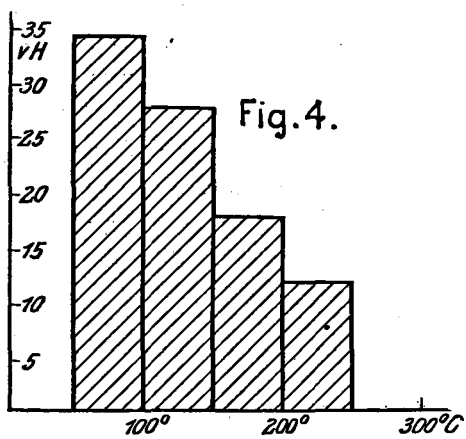


Fig. 4.

become brittle. At first, however, one difficulty in particular occurred. If the suitable conditions are not observed; if, for instance, the temperature rises above the desired point, or if the gas contains too large a quantity of carbon monoxide, then the undesirable reaction $2CO=C+CO^2$ takes place. Thus, by the separation of carbon, the carbon monoxide is consumed and the apparatus will become obstructed, but if we work according to the instructions, the process may go on for several weeks without any disturbance, and, in addition to a small quantity of watery liquid, we obtain an oil having the following properties: light yellow, thin liquid, odour of amylalcohol and acetone, mixable in any ratio with alcohol, benzol and gasoline, fusing point—30°, specific gravity 0.8289 and calorific value: 7540 calories. Elementary analysis: C, 69.3 per cent., H, 12.25 per cent., O, 18.46 per cent.

The curves of distillation are given in the following figure (4):

It will be noticed that nearly 88 per cent. of the crude synthol boils below 200°, and, indeed, we found that the synthol may be regarded an excellent low boiling motor fuel. Experiments of driving showed that in spite of the lower calorific value the synthol is apparently superior even to benzol.

Before the question as to the yield relative to the water gas can be answered reference must be made to the fact that the gas passing through the tube of contact is converted into oils in a relatively small proportion (about 8—10 per cent.). If, however, the products of reaction, after having passed out of the tube of contact, are taken off at an ordinary temperature, which may be done without reducing the pressure, then by passing the gas over the contact once more synthol is again formed in a quantity which varies with the equilibrium. If in such a way the compressed water gas is made to pass over the same contact several times as much as 30 per cent. of the calorific value of the water gas may be obtained as synthol. Furthermore, there remains a gas of great heating power.

I wish to lay stress upon the fact that these results, though they still need improvement, are especially interesting in view of future developments, since to produce water gas, coke or semi-coke of any fuel may be employed to combine the production of synthol with recovery of low temperature tar. On the one hand, the latter yields 10—12 per cent. of tar-oils, mainly boiling above 200°, and, on the other hand, starting from semi-coke for the production of water gas we gain synthol, usually chiefly below 200°.

Concerning the theory of the synthol process it may be borne in mind that by means of the hydrogen transferring iron, formaldehyde is formed as the first product, according to the equation: $CO+H_2=CH_2O$, and that owing to the impregnation of the iron the formaldehyde will be condensed to alcohols and cetones more or less rich in carbon.

Furthermore, we have been able to show that under certain conditions the alcohols of the synthol may be converted into gasoline hydrocarbons. To carry out this conversion it is only necessary to keep the synthol alone for a certain time under pressure at a temperature of about 400°. Thus, water is delivered from the alcohols, and the occurring olefines are

converted into napthenes. The gasoline and petroleum product obtained in this manner from synthol was named "synthin."

Although probably the production of synthin will never reach a practical value, I feel I ought to make some reference to its relation to the origin of petroleum. If one considers that in lower strata of the earth, steam, acting upon free or carbideous carbon, yields water gas, it is possible that in the higher strata containing iron and alkalis or metals of the alkaline earths, where the temperature is about 400°, the water gas, rising up under high pressure, will be partially converted into synthol, and that the latter will be transformed into synthin or napthenic petroleum. Indeed, from volcanoes there are escaping gases containing hydrogen and carbon monoxide; as these have been found by *Moissan* in a gas sample from Mount Pelé. With regard to the occurrence of petroleum, it is not without interest that besides the crude oils formed by a biological process, petroleum gained from water gas might be found, and might even be continuously produced at suitable depths.

Finally, it should be mentioned that, passed once over our contact, carbonic acid and hydrogen do not yield any synthol at all, only producing water and carbon monoxide. Yet, if the water is continuously condensed, cooling down to ordinary temperature, and if the remaining gas mixture will be passed again over the contact without diminishing the pressure, synthol is produced even from this gas. Thus, the studies of the conversion of coal into oils have shown that in principle at least it might be possible to produce the liquid motor fuels so urgently needed from the constituents of air and of water, provided that suitable sources of power were at our disposal. Carbonic acid might be obtained from air, and hydrogen might be produced electrolytically. Thus, fuels would be gained by methods similar to those occurring in the ordinary process of assimilation.

SUMMARY.

(1) Only certain constituents of coal can be converted into oils by means of destructive distillation. In this way the larger molecules of the bitumen are broken up into smaller molecules. About 10 per cent. of the low temperature tar is low boiling and has the characteristics of gasoline; the greater part boils above 200°. The principles of low temperature coking are set forth.

(2) Theoretically, it is possible entirely to convert coal into hydrocarbons by means of hydrogenation. Practically, however, attempts that have been made show that coal is only partly liquefied, the rest becoming soluble only. The products of hydrogenation are chiefly high-boiling.

(3) A third possibility for conversion of coal into oils is provided by synthesis from gases. As opposed to the destructive distillation and hydrogenation, larger molecules are synthesised from smaller molecules. By gasifying coal to water gas, the latter may be transformed into synthetic oil by means of a high pressure contact process. The synthetic oil mixture, synthol, boils below 200°, and as it proves to be a suitable substitute for gasoline or benzol, may be employed as motor fuel.

RÉSUMÉ.

1). La distillation destructive de la houille ne permet de transformer que certains de ses constituants en huiles. Il s'agit principalement d'une destruction de grandes molécules en faveur de plus petites. Environ 10 pour cent du goudron primaire entre en ébullition à une température basse, la plus grande partie bout au dessus de 200°. Les principes, suivant lesquels la distillation à basse température peut être vérifiée, sont éclaircis.

2). Théoriquement il est possible de transformer totalement la houille en carbures d'hydrogène par hydrogénation. D'après les observations faites jusqu'à présent la liquéfaction ne se fait que partiellement. Les produits de l'hydrogénation ont un point d'ébulition assez haut.

3). En outre une voie est ouverte pour la transformation des houilles en huiles par la synthèse en partant des gaz. Au contraire de la distillation destructive et de l'hydrogénation ici, des molécules plus grandes sont synthétisées par des plus petites. Si l'on gaséfie de la houille ou du coke en gaz d'eau, on peut transformer le gaz d'eau en huiles synthétiques en utilisant un procédé catalytique à haute pression. Le mélange d'huiles synthétiques, nommé "Synthol" à un point d'ébullition inférieur à 200°, et peut être utilisé comme combustible liquide à moteur au lieu de l'essence on du benzol. Dans l'avenir ou peut prévoir le traitement de la houille par carbonisation à basse température afin de récupérer les huiles, puis de gaséifier le semi-coke, et de transformer le gaz d'eau en Synthol.

THE LIQUID BY-PRODUCTS OF COAL CARBONISATION AS SOURCES OF POWER

W. GORDON ADAM, B.A.

A study of the sources of power involves, amongst other important considerations, the assurance of an adequate and certain supply. This should be regarded not simply as a business of finance to be exploited in times of peace; it is a matter of national interest, of national security, and a discussion of it must always include the possibility that our national activities may seriously be endangered by unfriendly relationships with foreign powers, or by industrial strife at home or abroad. Every civilised country has seriously to consider how, and to what extent it should assist or encourage the development of home supplies. The nature of the best internal source will depend upon such factors as the coal or oil wealth of the country, its climate, and the wealth of its vegetation. Thus, whilst a purely agricultural country, practically devoid of coal deposits, would direct attention to cellulose, starch, etc., and their decomposition products, Britain, possessing extensive coalfields, would seek economically to husband this great primary source of heat and power.

The use of coal must be considered from the standpoint of delivery to the consumer as a source of power either in the form of raw coal or of a number of products prepared therefrom; it must also be considered from the aspect of the efficiency of power development from these products. In the general economic scheme for power, light and heat development in Britain, the Gas industry may well claim to occupy an important position, its claim being based on its past achievements, and its future scope and possibilities. The carbonisation of coal under gas works' conditions produces with relatively high thermal efficiency the splitting up of the raw material into a gaseous fuel, a solid smokeless fuel, and liquid by-products that are in part available as sources of energy development. These three classes of products are capable of employment with satisfactory results from economic, thermal and hygienic points of view. Carbonisation under coke oven conditions yields equally good results, the solid fuel in this case being destined for metallurgical purposes.

It is not within the province of this paper to pursue further the study of the gaseous and solid products of coal carbonisation; we have to consider rather the liquid organic or oil by-products. For this purpose it is necessary to detail briefly the general scheme of coal carbonisation as practised to-day, and its bearing on the yield and nature of the products; likewise to indicate some possible future developments.

The bulk of the coal carbonised in gas works in this country is treated in horizontal retorts which, during the past twenty years or so, have in part been replaced by vertical retort systems, generally continuously operating units.

Horizontal retort carbonisation is essentially a high temperature operation, and the gaseous and liquid products are composed to a certain extent, of secondary products formed by the decomposition of primary compounds initially due to the action of heat on the coal. The yield of tar depends, *inter alia,* upon the class of coal employed and on the carbonizing conditions.

Vertical retorts operate under conditions in which, although a high temperature is finally reached, a large part of the liquid and gaseous products have passed out of the sphere of action in the earlier and cooler sections. From the vertical retort the modern systems of complete carbonisation have developed, whereby the available material in the coal is entirely converted into gas, the coke being transformed by the water-gas reaction and the liquid oil or tar products by cracking.

Coke ovens generate their products under high temperature conditions, and owing to the nature of the coal employed and the long period of heating, the yield of tar per ton of coal is lower than in gas works practice but, as a general rule, a good quality tar of relatively low free carbon content is obtained.

The average yields in gallons of tar under horizontal and vertical retort and coke oven conditions are approximately 10.5, 14, and 8½ gallons respectively.

Recently much attention has been directed to low temperature carbonisation, the purpose of which is to obtain a solid smokeless fuel suitable for industrial and domestic purposes, whilst retaining a high yield of liquid oil by-products. The results vary with the nature of the original coal, the temperature employed and particular system of carbonisation. As a general guide, the yield of tar may approximately be estimated as 20 gallons per ton of coal treated.

The commercial merits of this type of process have yet to be proved, but for our present purpose it is sufficient to observe that a relatively high yield of tar is shown.

The British gas industry at present carbonises about 16½ million tons of coal per annum, producing 168 million gallons of tar as a by-product. The coke ovens under maximum conditions consume 18 million tons of coal, and produce 153 million gallons of tar. Low temperature carbonisation enthusiasts hope to see their solid products adopted in place of coal by other heavy solid fuel consumers for domestic, railways, electric power and factory purposes, which represent respectively about 15, 8, 4, and 25 per cent. of the home consumption.

If the whole of this fuel could economically be supplied by a low temperature process, the tar available would be 1,900 million gallons. These figures exclude the possible recovery of light hydrocarbons by further scrubbing of the gas; the latter in all these cases would yield approximately 2¼ gallons per ton of coal treated. This subject is further developed in the sequel.

Tars produced according to these systems have different properties, the essential features of which are summarised in the following table:—

	Horizontal Retorts.	Vertical Retorts.	Coke Ovens.
Specific Gravity of Tar at 60° F.	1·202	1·112	1·18
Free Carbon in Tar... ...	17·51%	5·7%	9·0%
Yield of Oils per 1,000 galls. Tar, 5% Liquor basis...	374 galls.	460 galls.	400 galls.
Yield of Pitch per 1,000 galls. Tar, 5% Liquor basis...	3·33 tons	2·805 tons	3·20 tons

From the viewpoint of power supply the properties of these tars, with the exception of that produced by low temperature carbonisation, may be considered together. They consist in the main of aromatic compounds, principally hydrocarbons together with varying percentages of phenols and a small content of bases. Horizontal retort tar is distinguished by a relatively high content of pitch, naphthalene and anthracene, and the absence of paraffin hydrocarbons; that from vertical retorts contains a smaller percentage of solid hydrocarbons and of benzene and a higher content of phenols, toluene and xylenes; paraffin hydrocarbons are present to a small but definite extent. Coke oven tar is inter-

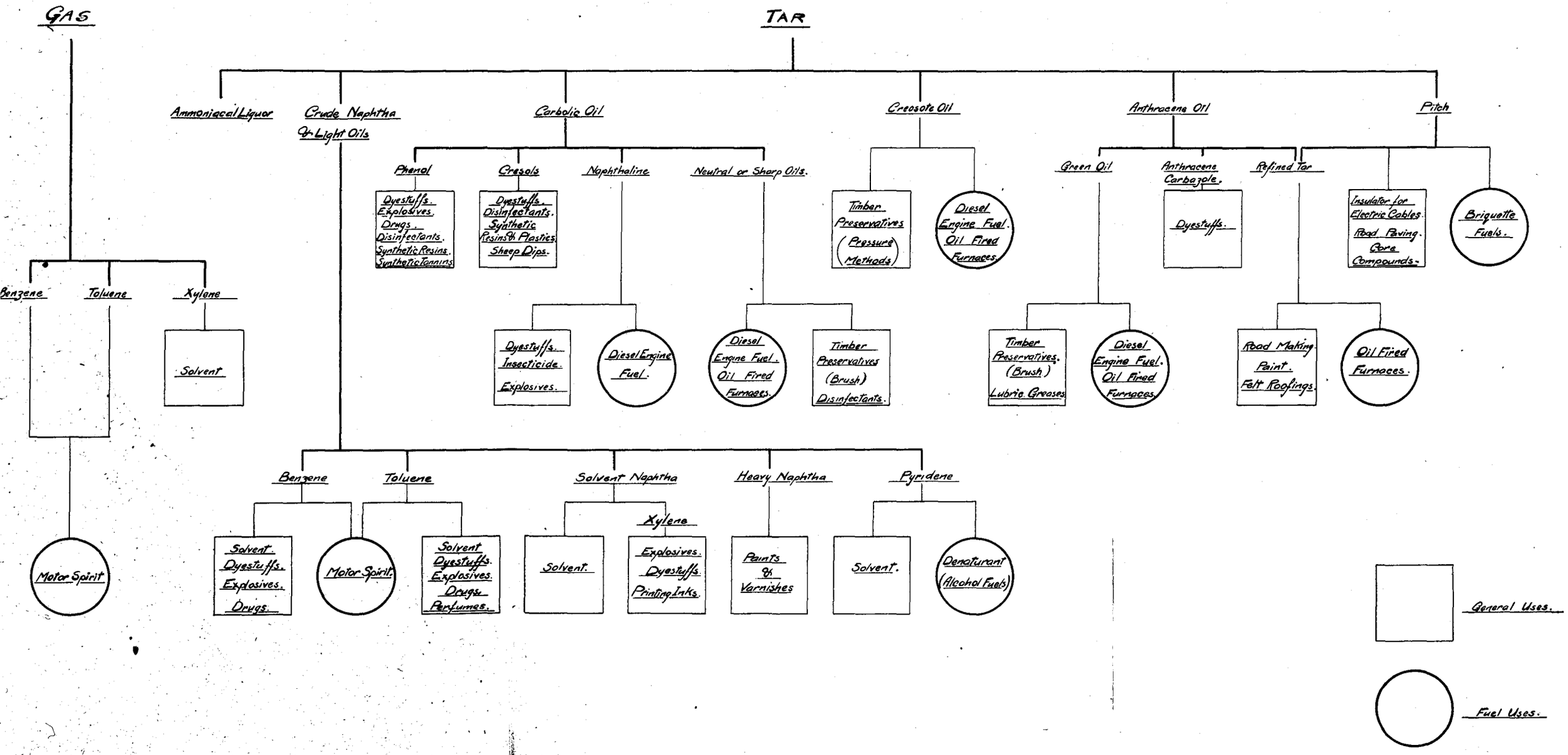
mediate between the other two. The commercial employment of all these tars is in general determined by the factors that are common to each.

In the early days of the gas industry, tar was but a necessary evil, and a constant source of annoyance; all that could be done with it was to use it as a liquid fuel for firing retorts. The development of aniline dyes led to a full investigation of its composition, and the isolation from it of a number of compounds. As a consequence, certain fractions obtained from tar by distillation reached a value which removed them from the region of low-priced waste products. The remaining fractions, consisting of creosote oil and pitch found special applications, the former as a timber preservative, and the latter as a binding material for the briquetting of small coal. Pitch remains to this day the best agent for preparing briquettes, and thus it has made available all that small coal and dust which previously represented a mining loss.

Raw tars, more especially those derived from vertical retorts and low temperature carbonisation are suitable for Diesel engines. Carburetted water-gas tar is also an excellent fuel for Diesel engines, but for this purpose it is necessary to resort to filtration or centrifugalling to remove that fritted material from the cracking plant which so frequently occurs in this type of product, and which would entail scoring of the valves.

Crude Tar is divided into a number of fractions by distillation from continuous or intermittently charged retorts, the range of the distillation process rising from ordinary temperatures to approximately 400°C. The general scheme is shown in the diagram, the further treatment of these fractions also being indicated. The chemical uses of the products are marked by a square, and possible means of employment as fuels by circles.

The employment of creosote as a timber preserving agent has now conferred on it a value which places it out of court as a source of fuel, and there seems little prospect of the demand for this purpose decreasing in the near future. During the past 15 years there has been a steadily increasing utilisation of prepared tar by the road engineer—either for the production of tar macadam or for surface treatment as a dust allaying and waterproofing agent. Thus tar, suitable as a liquid fuel for consumption under boilers and in industrial furnaces generally, and creosote, which


GAS
TAR
Ammoniacal Liquor
Crude Naphtha & Light Oils
Carbolic Oil
Creosote Oil
Anthracene Oil
Pitch
Phenol
Cresols
Naphthaline
Neutral or Sharp Oils.
Dyestuffs. Explosives. Drugs. Disinfectants. Synthetic Resins. Synthetic Tannins.
Dyestuffs. Disinfectants. Synthetic Resins & Plastics. Sheep Dips.
Timber Preservatives (Pressure Methods)
Diesel Engine Fuel. Oil Fired Furnaces.
Green Oil
Anthracene Carbazole.
Refined Tar
Dyestuffs.
Insulator for Electric Cables. Road Paving. Core Compounds.
Briquette Fuels.
Dyestuffs. Insecticide. Explosives.
Diesel Engine Fuel.
Diesel Engine Fuel. Oil Fired Furnaces.
Timber Preservatives (Brush) Disinfectants.
Timber Preservatives. (Brush) Lubric Greases
Diesel Engine Fuel. Oil Fired Furnaces.
Road Making. Paint. Felt Roofings.
Oil Fired Furnaces.
Benzene
Toluene
Xylene
Solvent
Motor Spirit
Benzene
Toluene
Solvent Naphtha
Heavy Naphtha
Pyridene
Solvent. Dyestuffs. Explosives. Drugs.
Motor Spirit.
Solvent Dyestuffs. Explosives. Drugs. Perfumes.
Solvent.
Xylene
Explosives. Dyestuffs. Printing Inks.
Paints & Varnishes
Solvent.
Denaturant (Alcohol Fuels)
General Uses.
Fuel Uses.

is an excellent fuel for the same purposes or which may be used for internal combustion engines of the Diesel type, are at the present time, and will probably remain in the near future, too expensive in comparison with the petroleum products, for employment for power development purposes in this country. They are, however, available for such purposes and indeed were so used during the late war. The matter of the employment of tar oils in Diesel engines has been the subject of numerous papers, but the following give especially useful information:—

E. J. Constam and P. Schläpfer, Zeits. Vereins deutsch. Ing. 1913, *57*, 1576, 1620, 1661.

J. S. Brame, J.Inst.Pet.Tech., 1917, *3* 194.

G. Porter, Engineering, 1917, *104*, 77 and 105.

H. Moore, J.S.C.I., 1918, *37* 572A; 1916, *35*, 345.

The present day interest in coal carbonisation in so far as by-products for power purposes are concerned, is almost exclusively confined to the light distillates—benzole and toluole—obtained in part directly from the tar, and in greater amounts by the process of gas scrubbing.

The light oils from tar on fractionation yield benzene, toluene and xylenes in yields of approximately 6, 4 and 6 gallons per 1,000 gallons of tar, the actual figures depending on the conditions of the tar formation. These amounts correspond to a yield of 10¼ gallons of motor spirit per 1,000 gallons tar, or 0.1 gallons per ton of coal. The bulk of the benzole hydrocarbons formed in the carbonising process are, however, not condensed with the tar, but remain as vapour in the gas. Since 1890 the coke oven industry has adopted the oil washing process for the recovery of these compounds—the gas being submitted to a washing process with a tar or blast furnace creosote oil, or with straw gas oil, in towers or rotary gas washers. The rich oil is then submitted to steam distillation yielding a crude spirit containing 10 per cent. of heavy oil, and which on further fractionation yields crude motor spirit; this requires refining treatment before being placed on the market. Before the war the Beckton Gas Works had employed this process on a small scale, and when the occasion demanded, it was developed, and its application to town's gas in this country yielded a very large volume of benzole and toluole for explosive purposes. On the cessation of hostilities benzole extraction from town's gas almost immediately ceased at the majority of gas works,

the value of the hydrocarbons as therms in the form of constituents of the gas, plus cost of extraction, being higher than their value as crude spirit extracted from the wash oil for motor purposes. Under present day conditions, oil washing is only being practised by two or three favourably placed gas works, which can refine their own product, and there is little doubt that if an economical process could be found the supplies from this source might be largely increased.

During the past two years considerable attention has been devoted to the use of absorbent materials, such as silica gel and active charcoal, as a means of removing the benzene hydrocarbons from gas. The use of the former has been developed by the Silica Gel Corporation in America, and of the latter by the Union Carbide Laboratories Inc. in America, by the Bayer Co. in Germany and by the Urbain Co. in France.

Silica Gel, according to published literature, is obtained by the acidification of a solution of sodium silicate, followed by the removal of the sodium salts from the gelatinous silica so formed, and subsequent elimination of water at gradually increasing temperatures up to 600°C. A highly porous product of excellent absorptive capacity is obtained.

The American Charcoals are produced from wood, etc., by a controlled carbonising process, followed by steam oxidation of the remaining hydrocarbons (cf. Chaney, J.Ind.Eng.Chem., 1923, *15*, 1244).

German Charcoals would appear to be obtained by a preliminary carbonisation of peat, wood, lignite and the like, followed by the addition of an inorganic salt, such as iron or zinc chloride, further carbonisation, and then removal of the salt by leaching. A product is obtained which, whilst showing a high absorptive capacity, has the additional merit of a high resistance to disintegration by mechanical action or by steam. Active Charcoals of British and French origin and of high absorptive capacity are also now available.

It is not yet possible to compare fully the relative merits of the two materials as absorbents. The distinguishing properties of the silica gel are firstly, that it shows a preferential attraction for water, and secondly, that being highly resistant to chemical and thermal action, it can easily be reactivated by submission to

relatively high temperatures which serve to burn off the "poisonous" material absorbed from the gas.

Charcoals, on the other hand, can be employed in a moist condition, containing 10-12 per cent. of water when operating on a gas of normal benzole content, that is, in the condition in which it is left after removal of the absorbed hydrocarbons by steam at 130°C. The product once poisoned cannot be reactivated by carbonisation without a loss of 10-12 per cent., but this difficulty is avoided in practice by the use of a prefilter containing a cheaper charcoal, the part loss of which is not a serious economic factor. This prefilter absorbs the napthalene and those gum forming hydrocarbons that may be present in the gas, and ensures in the main, a prolonged life for the main benzole filters.

Silica gel is employed in either a static process, in which gas is passed through a bed of the absorbent until the latter is saturated, and the hydrocarbons are then removed by a current either of steam or of hot air, or, alternatively, in a dynamic process whereby the powdered gel is blown by the gas under treatment through a series of absorbers, the gel and gas passing in countercurrent, and gel is finally recovered in cyclone extractors. Removal of the hydrocarbons may then be effected in a rotary activator heated to a suitable temperature by hot gasses passing through a series of hollow shelves.

Charcoal by virtue of its relatively lower resistance to abrasion does not readily lend itself to the latter procedure, and the benzole is therefore removd by steaming *in situ*.

The recovery of benzole hydrocarbons from gas by means of such solid absorbents seems widely to extend the possibilities of increasing the benzole production of this country. In 1918, that is, during the war period when gas washing was in practice at the more important gas works, the production reached 26.4 million gallons. By 1921, gas works had—with two or three exceptions, owned by companies which were favourably placed in that they were able to rectify their own crude product, and market the finished article—ceased to recover benzole except in so far as it is condensed with the tar, and the total production was 14 million gallons. During 1923 an expansion in the coke oven output increased the total production of benzole to 18 million gallons. The coke oven proportion fluctuates with the conditions obtaining in the metallurgical industry, but gas works in this country are

carbonising coal steadily year in and year out in quantities which show a regular tendency to increase. The increased heating load has tended to flatten the consumption curve, and the regularity of the operations offers a good foundation upon which to build further developments. If all the gas works of this country were to install by-recovery plants working at a 66 per cent. removal of benzole from the gas—equivalent to 1⅞ gallons of benzole per ton of coal carbonised, a figure that has been found suitable to gas works conditions—the annual production of the United Kingdom would be increased by 27 million gallons, and the total production in this country from coke ovens and gas works could be brought up to say 45 to 50 million gallons.

This amount of motor spirit would not be sufficient to meet the nation's needs, the imported petrol in the month of January, 1924, figuring at 29,370,824 gallons. Nevertheless, the supply in the competitive market would at least be such as to ensure that the price of petrol imported from foreign countries would be kept within reasonable limits, and the quantity would provide a useful safety factor in time of national stress. Again the advantages shown by aromatic hydrocarbons as constituents of petrol are now fully recognized, and the Government specification for aviation spirit calls for a definite minimum content of benzole hydrocarbons.

This desirable movement requires firstly, that the removal of benzole should financially be profitable, and secondly, that the plant processes should be simple in character and lend themselves to easy operation by such labour as is available on small gas works.

The first requirement demands that the market value of benzole be higher than its thermal equivalent in the gas (1 gallon benzole is equivalent to 1.62 therms), or rather, that it should be higher than the cost of replacing at the gas works the therm removed in the form of benzole. Where water-gas plant is available, the cost of the equivalent carburetted water gas in the gas work's holder may be assumed for the purpose. Alternatively, one must allow for the additional quantity of coal to be carbonised. With a removal of 1⅞ gallons of benzole, this latter amount may be placed at 23 tons of coal per 1,000 gallons refined benzole recovered. There is also required a low operating cost for the recovery process. The main factor in oil washing is the cost of steam, which approximates to 6 to 8 lb. per lb. of crude benzole

recovered, and a further 0.75 lbs. of steam is used at the rectification stage. In the charcoal recovery process, the steam consumption is 3 to 4 lb. per lb. benzole recovered.

The product recovered by the oil washing process contains unsaturated compounds, partly removed as such from the gas and partly formed by the decomposition of the wash oil. Certain of these unsaturated compounds readily polymerise to form gums, and on this account must be removed from the spirit. This is effected according to present practice by a treatment with sulphuric acid of 95 per cent. strength, and separation of the acid tar thus formed, followed by washing with water and alkali and redistillation. This process is drastic in nature, removing not only the gum forming compounds, but also practically the whole of those unsaturated compounds that are not detrimental; an additional loss occurs owing to sulphonation of benzene hydrocarbons, the latter depending on the care exercised in controlling the process. The method when properly applied, yields an eminently satisfactory product free from gum forming compounds and elemental sulphur. As above indicated, it errs on the side of caution, affording a large margin of safety at the expense of a somewhat unnecessary and heavy loss of valuable hydrocarbons. It would appear to be desirable that a control specification for motor spirit should be imposed which would ensure the absence of gum forming compounds, but at the same time would not unduly limit the percentage of the unsaturated hydrocarbons. Such a change would permit the revision of the initial chemical treatment, the acid used being reduced in quantity and strength. Alternatively the employment of silica gel offers interesting possibilities in this connection. The use of this solid absorbent for the removal, in the liquid phase, of gum forming compounds, and of heavy sulphur derivatives, has been fully demonstrated in the case of light petroleum spirits; the results so far obtained with benzole show good promise. In place of the acid treatment, crude benzole is agitated in three stages in counter-current with 3 per cent. of its weight of the gel. The mixture is passed through totally enclosed rotary filters, and the spirit submitted to a final cleaning distillation. Reliable figures are not yet available concerning the losses which may be expected when this process is applied to an oil recovered benzole, but present information indicates that it may be possible to reduce the loss to 2 to 3 per cent.

Such a revision of the benzole motor spirit specification would open up another possibility of increasing motor benzole supplies. There is strong evidence that the gum forming compounds already mentioned are derived largely by decomposition of the wash oil, and that the product recovered from gas by means of solid absorbents will be free from such impurities. Mr. F. M. Potter has examined for the author a number of samples of benzole directly recovered from a well cleaned town's gas by the charcoal process; the product was found to be of excellent quality and suitable for use as a motor spirit without further refining. Subject to certain modifications of the reactivation process, silica gel promises to yield similar results. This achievement is of the highest importance as it throws open the possibility of recovering benzole at all gas works, seeing that the process could be applied locally. It does not necessitate such chemical treatment as can only be satisfactorily carried out at a tar distillation works or benzole refinery. Having thus simplified the refining process, it will only be necessary to determine whether silica gel or charcoal is the best absorbent for benzole recovery from town's gas under given conditions as to capacity, etc., in order to design complete units for motor spirit production of such a nature that they can be readily and economically operated in both large and small gas works.

Amongst other problems that the future would seem to have in store is the economic possibility of utilising hydrogenated coal tar products. Up to the present, work on these has proceeded in four different directions:—

1. Naphthalene Derivatives:—The chief compounds concerned are tetraline and decaline. The possibility of using them will depend on their price, and that is a measure of the basic price of naphthalene, which is largely determined by the demand for it in other industries. As more vertical retorts are installed, naphthalene, owing to a diminished production, and consequently also its hydrogenated derivatives, will appreciate in value. Under artificial economic conditions tetraline was employed in Germany as a substitute for pertol. It has been claimed that its cost of production enables it to be sold at a cheaper rate than benzole. This has yet to be proved; certainly, French experience is to the contrary. Experiments have been made in Germany to devise processes whereby crude naphthalene might be employed, and to substitute water-gas, or coke oven gas for the more

expensive pure hydrogen, but concerning the failure or success of these endeavours the Germans have displayed quite naturally a marked reticence. Unless, therefore, altered circumstances arise that would release large quantities of naphthalene at a low price, it is difficult to see how tetraline can become a serious competitor to benzole in so far as motor fuel is concerned. These remarks apply *a fortiori* to decaline, which labours under the additional disadvantage that it does not seem to be suitable for either high compressions or high temperatures.

2. Phenol Derivatives :—As has already been indicated, the price of the phenolic constituents of tar is at present determined by its demand in the chemical industry, and by the cost of extraction from tar oils. Until the demand ceases to a great extent, there can be no question but that the catalytic hydrogenation of these products to cyclohexanol derivatives is not an economic process in so far as power supplies are concerned.

3. Hopes have been entertained that it might be possible to hydrogenate primary low temperature tars according to the Bergius process. Such tars yield approximately 35 per cent. of hydrocarbons, 40-50 per cent. of phenols, and 20-30 per cent. of pitch containing but little (2-3 per cent.) of free carbon. The Bergius method (cf. Z. angew. Chemie 1921, *34*, 341) consists in submitting the material to the action of hydrogen at about 400°C., under considerable pressure—for example 100-150 atmospheres. The reaction is essentially comparable to the process of cracking, and has for its end the production of a low boiling point fuel, with the avoidance of that polymerisation and carbonisation which accompany the customary methods of cracking. Apparently lignite tars by this process have given encouraging results. How far it will be successful in the treatment of low temperature primary tars remains yet to be seen.

4. The reduction of phenols to benzene hydrocarbons has been investigated by F. Fischer and his co-workers at Mannheim. The essential of the process is to secure the reaction by passing the phenol mixed with hydrogen through tinned tubes heated at 500°C. Hitherto the method does not seem to have been applied on an industrial scale. In some respects, should it succeed, it might possess distinct advantages over the catalytic reduction in presence of nickel, the more so as it should be patient of application to a crude phenolic product. The process,

however, has been so little investigated that it would be idle to speculate concerning its practical possibilities.

Possibilities also seem latent in recent work by F. Fischer and Tropsch, according to which carbon monoxide and hydrogen were made catalytically to react under pressure (up to 150 atmospheres at 450°C. in presence of iron and potassium carbonate): the aliphatic mixture thus formed, consisting of aldehydes, ketones, alcohols, etc., on further heating under pressure in an atmosphere of nitrogen produced a mixture of liquid hydrocarbons. Naturally, considerable elaboration will be necessary before this avenue of power is explored; incidentally in connection with such an aliphatic mixture, the synthetic production of alcohol from ethylene in coke oven gas by the Bury and Ollander process developed at Skinningrove may also be mentioned.

RÉSUMÉ.

La nécessité de prévoir d'abondantes ressources d'énergie est une question d'importance nationale ; la Grande Bretagne possédant des bassins houillers très importants dirigera naturellement son attention sur les produits du charbon, et en particulier, sur les méthodes de carbonisation du charbon. Les rendements en huiles ou en goudrons obtenus par ces méthodes dépendent naturellement des conditions de carbonisation ; avec des fours horizontaux et verticaux ainsi qu'avec des fours à coke, les quantités sont respectivement de l'ordre de 10,5 ; de 1 . ; et de 8,5 gallons de goudron par tonne de charbon carbonisé ; la carbonisation à basse température produit environ 20 gallons de goudron par tonne de charbon.

L'industrie du gaz en Grande Bretagne produit actuellement environ 168 millions de gallons de goudron comme sous-produit et les fours à coke jusqu'à 153 millions de gallons ; et pour la plupart des besoins de force motrice cette quantité totale, dérivée des trois systèmes de carbonisation, peut être considérée ensemble.

Les goudrons bruts et les huiles de goudron, en particulier ceux obtenus dans les fours verticaux et par la carbonisation à basse température, sont utilisables pour les moteurs Diesel ; le goudron provenant du gaz à l'eau peut après un traitement mécanique préalable, être utilisé dans le même but. Mais l'utilisation, dans ces dernières années, de goudron préparé pour la construction des routes, et l'augmentation de l'emploi de la créosote comme agent de préservation des bois, ont conféré au goudron et à ses dérivés, une valeur financière qui, pour l'instant, ne permet pas de l'utiliser pour les besoins de force motrice, en raison de son prix élevé par comparaison avec les produits du pétrole, à l'exception toutefois de conditions locales spéciales.

Au point de vue de la production de la force motrice, l'intérêt de la distillation du goudron de houille est confiné principalement aux huiles légères et au brai. Ce dernier représente 50 à 60 pour cent. en volume de la quantité de goudron, c'est le meilleur liant existant pour la préparation des briquettes de charbon ; les huiles légères contiennent le benzol et les hydrocarbones qui

sont séparés et vendus comme combustible pour les moteurs à explosions. Les hydrocarbones récupérés du goudron ne représentent qu'une partie de la quantité totale d'hydrocarbones légers fournis par le charbon ; de plus grandes quantités sont obtenues par extraction directe du gaz en employant, soit des dissolvants, soit des absorbants. La première méthode comprend les divers systèmes de lavage des huiles et c'est maintenant la pratique courante utilisée dans les installations de fours à coke, mais seulement par quelques usines à gaz favorablement placées et qui peuvent raffiner leurs propres produits. La dernière méthode dépend de l'emploi de substances telles que le " silica gel " ou le charbon de bois activé. Beaucoup d'attention a été récemment donnée à ces absorbants solides et il n'est pas encore possible de décider lequel, du charbon de bois ou du " silica gel," est le meilleur : chacun possède ses propres avantages distinctifs. Les possibilités de ces absorbants semblent ouvrir un vaste champ pour la récupération intensive du benzol ; il en résulterait, étant donné la production journalière de gaz par les usines à gaz, une production domestique régulière de benzol, production qui pourrait atteindre 27 millions de gallons par an en plus et au dessus des ressources actuelles que l'on estime à 18/20 millions de gallons par an. Cette production supplémentaire aiderait à limiter le prix de l'essence : ceci permettrait également de mélanger le benzol à l'essence et de rendre cette dernière plus susceptible d'être utilisée pour les moteurs à forte compression. En dernière analyse, le succès pratique ou l'échec d'un procédé d'extraction du benzol dépend naturellement des facteurs financiers.

Le produit obtenu par le lavage de l'huile du gaz de charbon, perd pendant la purification un pourcentage particulièrement élevé de constituants coûteux, des hydrocarbones non saturés et non polymérisants suivant les méthodes habituelles. Si les spécifications de contrôle du benzol pour moteurs étaient légèrement modifiées, le traitement pourrait être changé de telle façon que cette perte n'existerait pas. Des expériences utilisant du charbon de bois ou du "silica gel" absorbant en supposant ces spécifications modifiées ont donné des résultats très promettants, et il semble possible que dans l'avenir, aussi bien les petites que les grandes usines à gaz soient à même d'installer un procédé d'absorption de ce genre et puissent produir un excellent combustible pour moteurs, sans avoir à faire un autre raffinage. L'emploi de " silica gel" comme reactif, au lieu de l'acide sulfurique usuel, dans le raffinage du benzol provenant de l'huile, promet également de fournir une économie intéressante.

Des propositions ont été faites pour utiliser comme combustible, les produits hydrogénés de la naphthaline et des phénols, mais à moins que les prix des matières préliminaires considérées, ne diminuent beaucoup, ces propositions ont peu de chance d'avoir un succès commercial.

Finalement on peut mentionner l'application du procédé Bergius à l'hydrogénation des goudrons à basse température ; dans certains cas le procédé a fourni des résultats encourageants, mais son application certaine à ces goudrons doit encore être prouvée.

THE TREATMENT OF COAL WITH SPECIAL REFERENCE TO LOW TEMPERATURE CARBONISATION

HENRY E. ARMSTRONG, *F.R.S.*

1. Coal is a subject so serious that all others fade into insignificance beside it, for coal has made us what we are, at least in numbers, besides making us both the absolute masters and the helpless slaves of machinery: gradually, through its use, we are being deprived of the use of our hands and of the power of doing work worthy to rank as artistic and an outcome of individual effort: indeed, whilst under its subtle influence we can glory in the accuracy of our mechanical achievements, we must deplore the almost complete decay of the craftmanship which is man's prerogative and was once his pride. Food we must have and much of it is only to be purchased with coal itself—from those who need coal: we are, in fact, forced to sell much coal as mere raw coal at but poor profit, for the products we can make with and from coal are not in sufficient demand to permit of our developing to its utmost the value of a very large proportion that is raised from our mines. There is great need of a clear statement of the economics of coal at the present time. We little realise how this fuel governs the nations and that their activities are interlocked with its use; even our agricultural policy must be largely regulated in conformity with the dictates of this, our black master, in satisfaction of the needs of others, rather than in response to our own desires. It is strange that, though all but our sole—certainly our main—means of livelihood, we continue to treat the mineral with such scant respect, the owners and chief users especially. There is no public Coal Conscience; of so little avail is our scientific knowledge, so slight is the use we are wont to make of scientific method in our affairs. We quarrel over it daily but just as dogs do over bones—for " 'tis our nature to," without any real consideration of the vast interests underlying its possession. To understand it and the problems of its use, to treat it fairly, comprehensively, above all, reverently, apparently

is a task beyond our reason; we seem only to consider it in entirely selfish ways.

In this essay no attempt will be made to enter into details but only to consider the broad principles, in so far as these can be stated, which may be assumed to underly the calculated use of coal in the future.

2. The days of raw coal, other than that of anthracitic type, are clearly numbered. Public opinion will soon compel the use of smokeless fuels. No statement of arguments is necessary to establish this proposition. The task before us is to carry such mandate into effect. It is not an easy one; if it were, we should long since have succeeded. The difficulty to be surmounted is chiefly that of overcoming prejudice and the inertia of public opinion—of overcoming the many vested interests. Given the exercise of a little intelligence, the actual production of suitable smokeless fuels involves nothing which is not well within the compass of existing experience. The attempts hitherto made to solve the problem have been but partial and always unsystematic in character. If we are to succeed, the work must be undertaken in no narrow spirit but with due regard to the magnitude of the task and the many interests concerned.

3. The material dealt with, the process of carbonisation and the products, can only be understood by the chemist: success will be achieved only when chemist and engineer are led, if not forced, to work in close co-operation and harmony. The gas industry has only recently been driven to bow to the fact that it is essentially and primarily a chemical industry and that it cannot be conducted efficiently except by placing the engineer's operations under specially competent chemical control. To effect our purpose, we have to restore the gas industry to the position it occupied at its commencement and to include in its operations all coal that can be carbonised with advantage.

4. The production of a smokeless, easily combustible, solid fuel by carbonising bituminous coal at a low temperature is, however, in no way the only, if indeed the chief, object we have in view in advocating the treatment of all coal in such manner. The main object is the better utilisation of coal as a fuel. Coal is not merely a combustible solid. It is a material which breaks up when heated into an astounding variety of products, gaseous, liquid and solid; each member of this triad has special value as a fuel; we

now recognise that it is advantageous to collect the three separately and to make individual use of them. Gas is already highly popular as a domestic fuel and is daily increasing in popularity. Oil fuel may be said to have no domestic use, but the oil engine like gas, is already popular and has an infinite future before it. Oil may also be used with great advantage as a boiler fuel, as well as in heating operations in which it is essential to maintain an even regulated temperature.

5. The solid smokeless fuel produced by carbonising coal at a low temperature has to be thought of in many connections:—

(a) *As a domestic fuel.* This, at present, is the only aspect before the public but, in point of quantity, the amount eventually used for such purpose will be relatively small and probably the production of such fuel will be a distinct industry, linked up, in the near future, with the town-gas industry. In former times, the gas companies supplied both gas and an easily combustible coke, which was in great demand; it is to be desired that this position be recovered.

(b). *As an industrial fuel, for home and export use.* Many advantages are foreshadowed in this use of a low-temperature, smokeless fuel and many problems are to be considered in connection with its production and use.

6. In the first place, it is necessary to consider how solid fuel may be burnt with the greatest advantage—in what form. The value of gaseous fuel is generally recognised but to produce it on the small scale is troublesome; moreover, its production, on any scale, involves considerable loss of heat and skilled labour is essential. The use of the gas-producer has been advocated mainly on two grounds—because it made possible the recovery of more or less of the nitrogen in the coal and because it permitted of the use of very inferior grades of fuel. In practice, this latter advantage has sunk into insignificance, the more as the price of coal and the cost of labour have been raised. The desire to recover ammonia is no longer what it was, now that the synthetic process can be worked with efficiency; the recovery plant, moreover, is very costly to erect and to maintain in repair. The trend of practice is to use the producer only when gaseous fuel is essential and one of low calorific power is suitable; it is likely to be of special value whenever it is necessary to avoid transmission charges on poor coals and to use up tailings, when the producer can be erected in close proximity to the point of supply and there

is an outlet for the gas. On the other hand, the use of powdered fuel is rapidly being developed, especially in the U.S.A.

7. " Dust Fuel " is clearly the solid industrial fuel of the future. Coal, however, has disadvantages, when used in finely powdered form. There is the liability of dust explosions; also it is prone to fire spontaneously; thirdly, a good deal of mineral dust (ashes) may be carried forward and ejected from the smoke-stack. If a " low temperature coke " were used in powder, the liability to explosions would at least be lessened and doubtless it could be so prepared that it would not be spontaneously combustible.

8. The question of ashes is a grave one—the gravest, perhaps, and the most worthy of consideration. It is to be considered from two points of view. The smoke abatement idealists have played upon public credulity in calling attention only to the evils of black smoke. They have talked of this as productive of fog—probably it has little, if anything, to do with the mere production of fog and only serves to give it " texture." We shall get rid of black fog only if we use a smokeless fuel. The acid products of combustion and the volatilised " common salt " and ammonium salts are the real sinners, in producing fog; the soot, apparently, serves but to give substance to their activity. Much of the dirt we complain of in the atmosphere of towns is probably but dust from traffic and from open fires; even gas fires give off acid fume into the atmosphere. Smokeless fuel, therefore, whether sulphury gas or solid coke, will take toll of our buildings, of our paint, of our furniture and even of our lungs. To diminish the evil, we must cleanse our fuels from sulphur, not merely whiten their smoke. The gas companies must be required to remove sulphur from the gas to the lowest limit within their power and all fuels should be freed, as far as possible, from sulphur.

9. Of far greater importance is the removal of incombustible matter from coal. We do worse than carry coal to Newcastle, in these days. We carry " dirt "—shale and what not—in large quantity from every mine to every consumer of coal. The handling, over and over again, the carriage of this dirt, has to be paid for by everyone. The seller sells it as coal and gains, the carrier charges for it as coal and gains; the poor user, however, loses at every point: he not only pays for it but has to pay for putting it upon the fire grate, as well as for removing it as ashes or clinker and for carting it away to the dust heap or dump.

The cost of this dirt, in the aggregate, to the community, is very great.

10. The great task to be faced, in fact, is the reduction of the mineral matter in coal to a very low proportion by some treatment *carried out very soon, if not immediately, after it is raised and before it is carbonised.* The problem is largely chemical: in some way the coal must be protected against oxidation during the grinding process and subsequently, as it deteriorates very rapidly on exposure to air. If this difficulty can be overcome—theoretically there is reason to hope that it may be—the "mechanical" separation of the mineral from the combustible matter could be undertaken with confidence, though the disposal and use of tailings may introduce difficulties. When such separation has been effected, assuming a wet process to be used wholly or in part, the difficulty will remain of sufficiently removing the water associated with the fine coal as far as possible before carbonising.

11. Against the cost of so purifying coal, we may set, not only the increased value the fuel prepared from it will have but the diminished cost of mining. All coal, however small, should be convertible into a high class fuel and it should be possible to revolutionise mining practice, as it would no longer be necessary to raise coal in massive form. It might all be raised as smalls, if the small coal could be cleansed and carbonised at a low temperature without delay and so converted either into a compact fuel or into a "small coke" easily reducible to powder.

12. As to the manner in which carbonisation is to be effected, this will necessarily be regulated in accordance with the character or quality of the raw coal but mainly to meet the special demands of different classes of user. Probably, the product may be varied in character, particularly in combustibility, to a very considerable extent: this is one of the directions in which exhaustive scientific study of the problem will be needed. For domestic use, solid fuel must be supplied in pieces of suitable size, as a compact material, not too easily broken into powder. It may not be out of place to urge that such fuel be sold only by weight, with the guarantee that it is free from water and contains at most a certain stated proportion of incombustible matter. The powder produced in handling such fuel creates a difficulty from which the domestic consumer will need to be relieved, either by exchange for compact fuel, at intervals, of any accumulation or by the introduction of some special way of burning it with advantage. Maybe an

efficient burner for domestic use, suitable for heating water, can be constructed, perhaps on the principle of the ordinary forge fire, needing air at a regulated rate: now that electricity is so generally available, this could perhaps be provided by a small electrically driven blower.

13. The mode of production and the amount of compact fuel produced will depend naturally upon the extent to which powdered fuel is brought into use and on the form in which solid fuel can be exported. The plant for the production of such small fuel will necessarily be more or less different from that used in producing compact fuel. The plant should be one that could be operated upon a larger scale and with greater rapidity, therefore more economically, than one producing compact fuel suitable for domestic use. The small-fuel plant would be one in which any variety of coal, caking or non-caking, could be directly carbonised.

14. A compact fuel, suitable for domestic use, can only be produced directly from coal if a caking coal be carbonised at a low temperature, though it is often not only possible but desirable to carbonise such coal in admixture with more or less non-caking coal, both in order to prevent expansion on heating and for reasons of economy. However small the coal or mixture of coals which is charged into the retort, it becomes compacted during carbonisation. The low temperature process, however, has certain limitations. In particular, the exchange of heat through the walls of the retort and within the mass takes place relatively slowly at low temperatures. On this ground alone it is essential to use iron retorts in carbonising.

15. The important discovery has, however, been made by Mr. E. C. Evans, that if a caking coal be ground and mixed with a certain proportion either of ground coke or of non-caking coal and the mixture be briquetted by pressure alone, the briquettes may be carbonised at the high temperatures customary in town-gas practice and gas produced similar both in quantity and quality to that now obtained and yet the coke produced is easily combustible, not hard and difficult to burn as is the ordinary gas-works coke made by direct carbonisation of coal at a high temperature. This discovery has put a new aspect upon the smokeless fuel problem. Mr. E. C. Evans has carried out experiments at the South Metropolitan Gas Co. from which it is possible to form a clear picture of the advantages gained by subjecting coal to this treatment. (They are described in his Cantor Lectures at the Royal Society

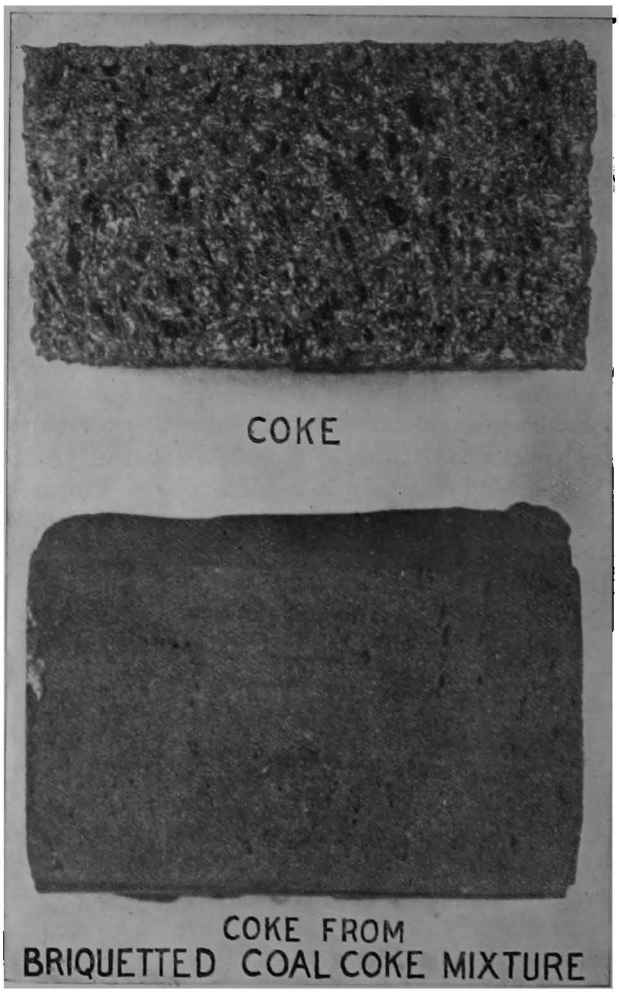


Fig. 1.

of Arts, this year—see *Gas Journal,* Feb. 27, March 5 and 12). He calls attention, in the first place, to the peculiar vesiculated structure of the coke produced by directly carbonising coal and to the entire disappearance of this structure when the ground consolidated mixture is substituted for coal. Using 25 per cent. of coke in admixture with the coal, the product is close-grained

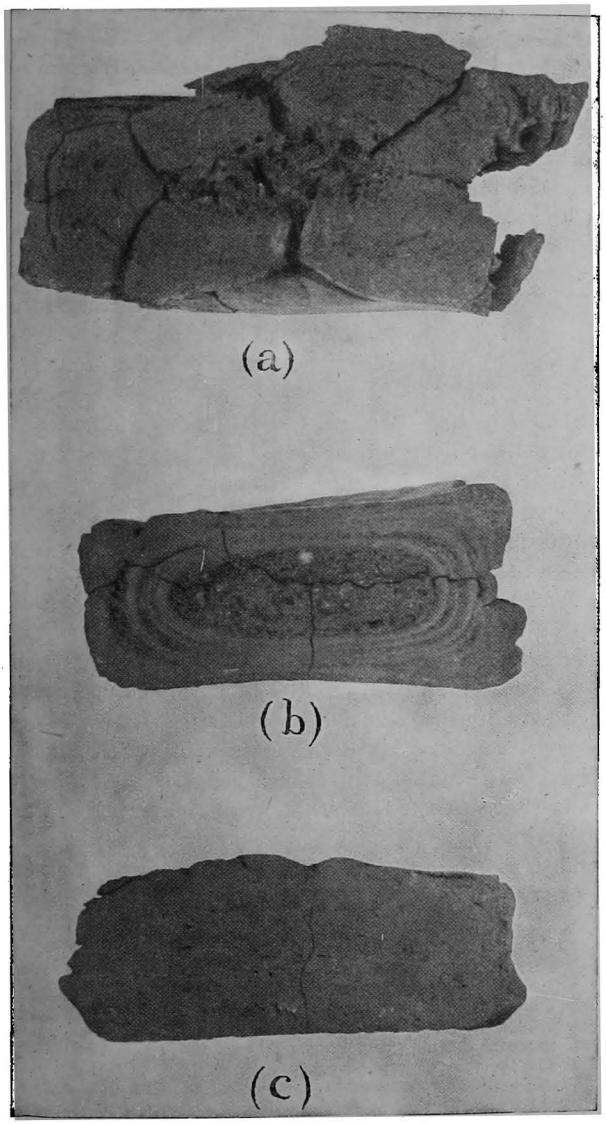


Fig. 2.

throughout. Moreover, carbonisation is complete in half the time required to carbonise the raw coal. The coke burns readily.

In amount and quality, the gas produced is almost the same as that obtained from the equivalent amount of raw coal. The only respect in which the result differs disadvantageously from ordinary high temperature gas works practice is that the tar appears to be neither high nor low temperature tar but, as it were, a compromise between them.

16. The difference between ordinary coke and that prepared from a briquetted mixture of 75 parts coal with 25 parts coke is shown in Fig. 1.

The need of using the right proportion of coke is well brought out in Fig. 2 showing the appearance of briquetted fuels made by coking, (a) the raw, powdered coal; (b) a mixture of 85 parts coal and only 15 parts coke; (c) a mixture in the proportion of 75 : 25.

Such composite coke, Mr. E. C. Evans points out, is a better conductor of heat than ordinary coke, the reason being that the mixture that is carbonised never becomes continuously plastic when heated, consequently, the expansion which attends the coking of ordinary coal is prevented and the ultimate product consists of small cells; the coke, therefore, not only burns more readily and rapidly than ordinary coke but the ashes are almost free from carbon.

17. The extraordinary difference in the behaviour on carbonisation of a 75 : 25 briquetted mixture of powdered coal and coke, as contrasted with that of coal, is wonderfully shown in thermal models constructed by Mr. E. C. Evans, of which Fig. 3 is a photograph. The rapidity with which the gases are evolved from the mixture will be noted; also the great shortening of the time of carbonisation.

The results (shown in the appended table) obtained in an experimental plant are:

RESULTS ON CARBONISING DURHAM COAL AND BRIQUETTED MIXTURES OF SAME COAL AND COKE (75 : 25)

	Ordinary Coal	Briquetted Mixture A.	Briquetted Mixture B.
Yield of gaseous therms per ton of coal ...	74.7	68.2	71.1
Yield of tar therms per ton of coal	16.1	31.0	27.5
Total yield of volatile therms per ton of coal	90.8	99.2	98.6

In series A, in which 22 tons of briquettes were carbonised, the temperature in the combustion chamber was about 50 deg. lower than in series B, in which 12 tons were used. It will be noted that,

notwithstanding the 25 per cent. of inert material, the throughout of coal was greater and also the total make of " volatile therms."

18. The products of ordinary gas-works practice are in no sense primary products of decomposition, at least for the most part; they are largely the outcome of a complex series of secondary changes in and between the immediate products and to some

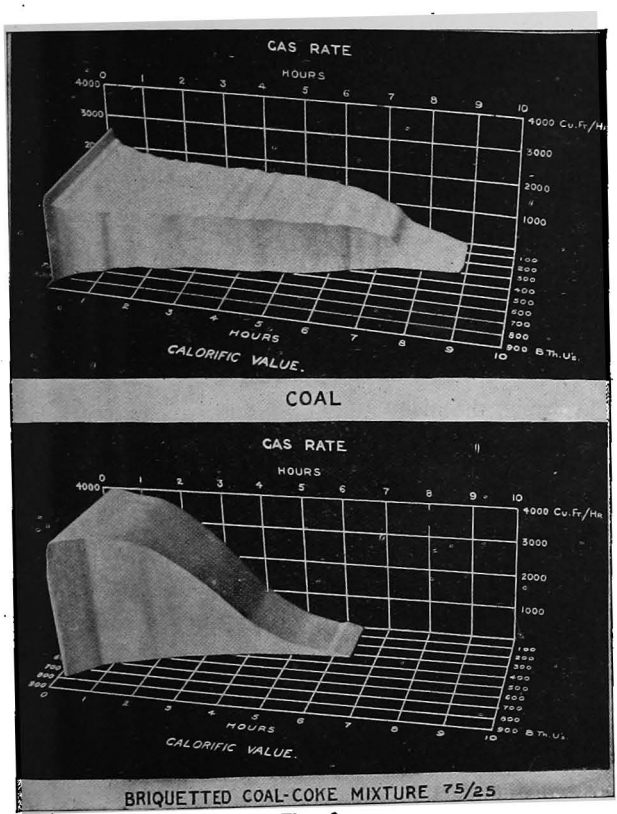


Fig. 3.

extent of interactions in which the heated, solid, carbonaceous mass is concerned. The lower the temperature at which carbonisation is effected and the more rapid the escape of the vapours, the more nearly will the products be those of the primary changes. These primary products are, in part, of a highly

unstable nature; in fact, it is known that low temperature tars undergo more or less change merely on keeping.

19. The only constituents common to low and high temperature tars are the phenolic compounds. Low temperature tars are particularly rich in cresols (cresylic acids). They are, therefore, of considerable antiseptic value. Benzene and other benzenoid hydrocarbons (naphthalene, anthracene, etc.) are *not* obtained on carbonising coal at low temperatures. They are produced only at relatively high temperatures, partly by direct synthesis and partly by reduction of the phenolic compounds split off in the primary decomposition of the coal material. Whether such hydrocarbons can be economically produced by cracking or otherwise treating the low temperature tars has yet to be ascertained; judging from the experience thus far gained, the outlook is not hopeful. Whether it will pay to extract the acid oils must be largely a question of supply and demand. There is little prospect, at present, that the demand for the acid oils will suffice to absorb more than a fraction of the possible supply, if all coal were carbonised prior to its use as solid fuel.

20. Probably, the main value of the low temperature tars will be as oil fuels. Coal oil or *Coalitoil*, as it may well be termed, may be used with effect as such, either in engines of the Diesel type or burnt, best after removal (probably by simple mechanical treatment) of the so-called carbon—the pitchy matter—suspended in it, which tends to clog taps and jets. *Coalitoil* differs so entirely in consistency and general character from ordinary gas-works coal tar that it cannot well be applied to most of the purposes for which coal tar is now largely used; nor is it to be made equivalent to coal tar by distillation; nor should it be distilled, in my opinion, unless products (lubricants, etc.) of specially high value can be separated which justify the sacrifice of a large fraction. If it be necessary to raise the flash point by removal of the most volatile fraction, the distillation should be effected under reduced pressure and at as low a temperature as possible; when the oil is distilled, it apparently undergoes a radical change and only about one-half passes over; the residue is brittle when cold and in no way the equivalent of coal tar pitch. Still, it would be premature to say what can or cannot be done with such a product —it is so entirely novel; as yet, however, we have no right in any way to exaggerate its value. The following diagram, taken

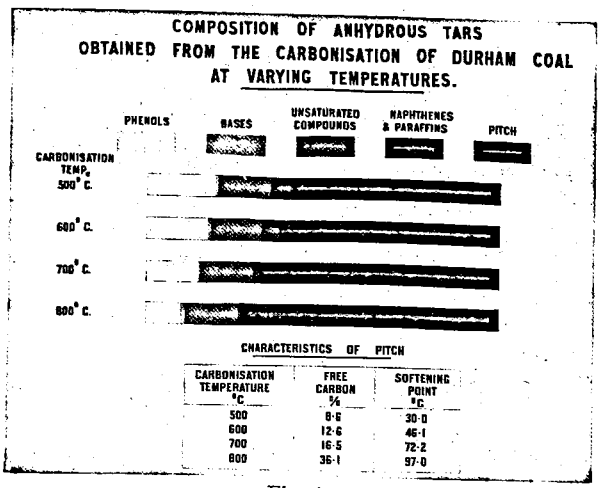


Fig 4.

from Mr. E. C. Evans' paper, is of interest as showing the "sensitiveness" of the tar to heat changes.

21. The "distribution" of thermal energy in the products on subjecting coal to carbonisation at high and low temperatures is

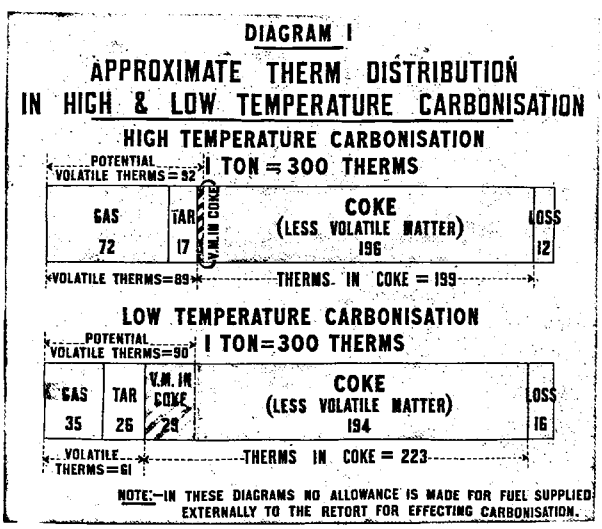


Fig. 5.

well shown in the diagram (Fig. 5) taken from Mr. E. C. Evans' lectures.

22. Though the volume of gas produced is much less at low than at high temperatures, low temperature gas is of high illuminating power. By "scrubbing" the crude gas, a considerable amount of volatile hydrocarbon may be recovered, which is suitable for use as a motor spirit. The use to be made of such gas, scrubbed or crude, has yet to be determined. Doubtless it will vary with the conditions. When produced in towns, it will undoubtedly form part of the gas supply. If it be produced at the mine, the question will arise, to what extent it can be properly "piped" to a distance and if so, under what pressure. Our mines are all so close to towns that an outlet for the gas should easily be found. It is of far too high a thermal value to be used on the spot, either in firing the retorts or boilers. Producer-gas made from tailings would obviously be the proper fuel to use in such cases.

23. A few years ago, the tendency of opinion was towards the use of a weak gas for domestic purposes but, of late, the advantages of a supply of relatively high thermal power and of standard quality has been more generally recognised. The problem has to be regarded from at least two points of view: these are the efficiency of heating appliances and the size of the street mains and the possibility of meeting the public demand for gas without making these unduly large and costly. Distribution under higher pressures has to be considered. There is great waste of gas in practice and heating appliances are in no way developed to the degree of efficiency we may contemplate as possible. One improvement called for without delay is the removal of the sulphur from gas supplied to domestic consumers.

24. One of the chief reasons for demanding the carbonisation of all bituminous coal prior to burning, apart from this being the one effective means of ridding our cities of much gloom and dirt, is the need for oil fuel. The prospective use of oil fuels is, however, so great that even if all the oil thus obtainable were produced, it may well be supposed that the supply will not even then meet the demand unless, indeed, it be found possible to develop the use of powdered fuel to a point at which it can vie in efficiency and ease of application with that of oil. Attention may therefore be directed to the remarkable results achieved by Dr. Bergius in converting heavy oils and even coal into volatile liquid

products by the action of hydrogen under pressure at an elevated temperature. The process has been developed during the last ten years and its success has recently been vouched for by competent Belgian inquirers. The quantity of Petrol in demand being much beyond the natural supply, large quantities are produced at the present time by "cracking" heavy oils by heat; the oils are apparently resolved into fragments, one of which, in the process, takes hydrogen from the other, forming a product which is considerably more volatile than the original oil, whilst the remaining, unsaturated fragment combines with itself, yielding an oil which is less volatile than the original. Dr. Bergius appears to have found that the formation of the "heavy" product is prevented if the cracking process be carried out under pressure in an atmosphere of hydrogen. The material to be hydrogenised is placed in a strong vessel which is charged with hydrogen under a pressure of 59 atmospheres; the temperature is then gradually raised to 430 deg.; the pressure rises to nearly 140 atmospheres and then gradually falls as action takes place. Coal containing up to about 85 per cent. of carbon, suspended in oil, when treated in this manner is entirely liquified. Tars, asphalte and pitch, are all amenable to the treatment; there is little doubt that it would be applicable to the heavier coalite oils and that in this way they could be both stabilised and rendered more volatile. The development is one of extraordinary interest and prospective importance but has to be confirmed.

25. In concluding this summary, reference may be made to the present position of the smokeless fuel industry. The subject has been before the public during more than 20 years past. It has excited great interest and large sums of money have been spent in devoloping the ideas of various inventors. As yet, however, neither here nor in the U.S.A., has any process been carried to the point of complete practical and economic efficiency. Most perfect solid fuel has been produced but no one has yet succeeded in making a "gas-tight" plant from which all the products can be collected without loss and without in-leakage of air. That a satisfactory, compact, smokeless fuel, suitable in every way for domestic use, can easily be produced is beyond question. The sole reason why an effective economic complete process has not been developed is that the work has been undertaken only by enthusiasts, without technical knowledge, who have put their faith in individuals instead of working upon systematic and

scientific lines. Large plants have been erected before any proof has been given that the primary unit could be operated effectively and this seems, in fact, to be the only way in which the "engineer" can work—he has yet to learn the art of experimenting and he is not alive to the peculiarities and complexities of the problem of carbonisation. It is work in which the specially competent chemist and the specially competent engineer must co-operate at every stage and in every detail. Say what we may, coal is now our master. Sensational statements have been made of late, based mainly upon the behaviour of the great riddle of our universe, radium, foreshadowing a time when we shall have learnt to make use of the vast store of energy we believe to be imprisoned within the elementary atoms. We should do wrong if we were to attach the slightest value to surmises of the kind. Not only have we reason to believe that the work to be done in letting such energy loose would exceed that to be gained but we may well fear that, if the necessary disturbance of the order of nature were set up, the consequences might be very serious. In any case, we have no right to be spendthrifts of our present fortune, trusting blindly that some day another will be left to us.

26. In fine, we need some organisation to inform and maintain both public and political opinion on this subject of coal and its treatment. The problems are of extreme urgency and in need of consideration in all their bearings by Government. They should be submitted without delay to complete discussion by competent minds. We greatly need a body of Fuel Commissioners, whose duty it would be to take cognizance of everything concerning coal, who would be in a position and competent to advise on, if not to regulate, scientific and technical inquiry, as well as to criticise, if not to control, those who desire to develop practical schemes. The voice of science must be raised in protest of the continued thoughtless waste of the capital balance funded for us in the far distant past by our great Solar king; nay, it must do more; it must force the hand of ignorance and insist upon attention to counsels of wisdom.

It should be our pride to cultivate the garden solar activity once created—to cultivate it with jealous care, not to trample, as we ever do, upon its flowers, taking no note of their sweetness and beauty.

RÉSUMÉ.

Le préjudice et l'inertie de l'opinion publique, d'après l'auteur, sont responsables de l'hésitation à adopter le combustible sans fumée ; actuellement la production d'un tel combustible ne présente aucune difficulté si le chimiste et l'ingénieur travaillent intimement en coopération.

Le combustible solide sans fumée peut-être considéré comme un combustible domestique ou comme un combustible industriel pour la consommation intérieure et pour l'exportation.

Discutant l'utiilsation du gazogène, l'auteur signale que la tendance de la pratique actuelle est de n'utiliser le gazogène que lorsqu'on a besoin d'un combustible gazeux de valeur calorifique peu élevée.

La question de réduction de la fumée est examinée et l'auteur montre qu'il n'est pas seulement nécessaire de blanchir la fumée afin de maintenir une atmosphère propre, mais que le combustible doit également être nettoyé de son soufre. Dans un intérêt d'économie il doit être également libéré de sa charge de cendre, ceci de préférence à la tête du puits.

Il discute ensuite les méthodes permettant de produire un combustible ainsi nettoyé, à l'appui de cette discussion des résultats d'expérience sont donnés sous forme de tableau et d'illustrations. L'auteur préconise la carbonisation de tous les charbons bitumineux, à la fois en raison de la propreté et pour répondre aux besoins grandissants d'huile lourde comme combustible.

En concluant, l'auteur déplore le manque de coopération organisée et la non utilisation des connaissances disponibles, qui seules peuvent permettre d'arriver à la solution finale. Le devoir du monde est d'économiser et non pas de gaspiller les bénéfices répandus sur lui par l'activité solaire.

THE NATIONAL ECONOMIC POWER OF SOLID FUEL IN RELATION TO ITS SCIENTIFIC UTILISATON

With special reference to Distillation and Pulverisation of Coal.

LEONARD C. HARVEY.

"Can we afford to burn two tons of coal where one will pull the load?"—GEORGE OTIS SMITH, *Director, U.S. Geological Survey.*

The beneficial results of applying solid fuel in pulverised form are now acknowledged the world over, so that greater stress has been laid herein upon the urgent necessity of economising in fuel consumption and the lowering of costs of production.

The word "power" as used in this paper must be taken in its broad sense in its application to fuel; the expression "power of fuel" is intended to represent the ultimate collective benefit to a community introduced by the scientific application of solid fuel.

The bearing of fuel economy upon power generation and the cost of general production of steel, machinery, and commodities is thus briefly reviewed herein, and it is hoped that the points of national consequence raised will be given critical attention in discussion.

The writer contends that industrial prosperity in Great Britain and in any manufacturing country must be built up on the foundation stone of "distillation of coal" and that the keystone of the main arch of successful fuel utilisation processes will be found in "pulverisation of solid fuel." Great Britain has been taken as a basis in this paper but the main arguments apply to all countries in which solid fuel is used.

The bearing of fuel economy upon the internal wealth of a nation is realised only by individuals. No concerted community effort has as yet taken concrete shape. Without fuel, national industrial life cannot exist; labour, materials and prepared foods are dependent thereon.

It should be the first duty of any present day Government to enforce fuel economy in industry—in preference to scientific investigation of purely theoretical subjects, oft-times an expensive procedure and frequently productive of negative results.

By the distillation and pulverisation of solid fuel great economy can be introduced. A combination rendering practically all grades

of solid fuel virtually equal in their effective power as heat-giving substances. Endeavour will be made to outline the manner in which these two processes are positive in their relation to internal trade economy.

The situation in France can be taken as an example. France produced, in 1923, 31,915,609 tons of coal and lignite, 10,264,467 tons of coke, and 2,828,803 tons of patent fuel; whilst she imported respectively 22,334,126 tons, 5,140,183 tons, and 1,422,374 tons.

In view of the astounding progress in America, France has already adopted the principle of pulverised fuel firing and when the added benefits of distillation are recognised, she will in course of time undoubtedly reduce, and perhaps entirely eliminate, her importation of coal. To whatever degree such an accomplishment is possible in any coal importing country, there must result a beneficial reaction upon internal cost of production, upon food prices, and upon the gradual improvement of the national trade balance.

It should not be necessary for any country possessing solid fuel to import much, if any, raw coal from far off countries at great expense for ocean carriage. Why should India, for instance, import coal from South Africa, or Belgium coal from the United States, or even from China as she is reported to have done in the past.

The utilisation of the lower grades of coal, as herein suggested, should render available a great quantity of usable coal from sources nearer at hand. In this manner it is possible to bring into the industrial market—Brown coal, Lignite, soft varieties of sub-bituminous coal, pit waste, culm and washings—(on account of its water content, peat is excluded from these present suggestions).

THE BURNING OF SOLID FUEL COMMENCES IN THE MINING OF COAL.

The cost of fuel thereafter enters into transportation; into daily expenditure by many thousands of users; it represents fully 20 per cent. of the cost of steel and machinery, of general commodities and of many chemicals. In the generation of power and in factories, fuel is burned in very few cases efficiently. The cumulative effect of high fuel costs due to wasteful consumption in so many operations goes far to establish the ultimate selling price of commodities. A controllable factor to which little attention has been paid.

In the almost endless cycle of industrial fuel consumption, it can be claimed that less than 10 per cent. of the primary heat value is usefully absorbed, upwards of 90 per cent. of the " cost " of coal being lost.

The burning of raw coal in the household grate is reprehensible notwithstanding the fatuous statement in the Report of the British Fuel Research Board (1918-1919)—thus:

"The pleasant British practice of sitting round an open fire is amply justified from '*the scientific point of view*,' when we know that so much as one-fifth of the total heat of the coal is immediately available for absorption by the sitters '*if they constitute themselves into a sufficiently close screen around the fire.*'"

No thought is given to the valuable products passing up the chimney from a "*scientific point of view.*" No consideration is given to the greater period of "radiant heat" loss when green coal is added to the fire. A more "*unscientific statement*" it is difficult to conceive.

The everyday average amount of heat directly transmitted to the atmosphere of a room is nearer 5 per cent. than 20 per cent. of the heat value of fuel burned in the usual open grate. The highest domestic efficiency is undoubtedly given by the radiant gas fire. Even in the production of electric power the station efficiency of conversion is no greater than 20 per cent. at the bus bar. In modern generating stations there are used for average load 20,000 B.Th.U per kWh. The equivalent of 1 unit is 3,410 B.Th.U. giving a discrepancy of 16,590 B.Th.U. lost in conversion of coal to electric power, or about 83 per cent.

The efficiency of apparatus for re-conversion in the home from electric power into heat and light is about 40 per cent., so that the ultimate proporation of the original heat value of raw coal, as used in the home, is no higher than 8 per cent. and more often below 5 per cent. when transmission losses are taken into account.

From 1,000,000 tons of raw coal burned either in the domestic grate or under Power House boilers, with approximately equal terminal efficiency in each case, there are wasted at least 20,000,000 gals. of liquid products containing say 2,500,000 gals. of motor spirit, and 15,000,000 lbs. of Sulphate of Ammonia.

Yet, in Great Britain, there is imported every year foreign oil to the value of £45,000,000. Great Britain could be more than self-supporting both as regards liquid fuel and supplies of motor spirit. Her annual internal consumption of coal amounts to some 187,000,000 tons, of which more than 100,000,000 tons are required for transportation and for general industrial purposes, and 35,000,000 tons are sold for domestic use.

Of the former it can be assumed that upwards of 50,000,000 tons are used perhaps in at least five operations, in each case at the

reasonably high estimate of 10 per cent. efficiency. This means an ineffective destruction of 45,000,000 tons of coal. Records in other countries show that a saving of 20 to 50 per cent. can be introduced in many operations by the adoption of pulverised fuel firing.

A saving of only 25 per cent. on but half of the 45,000,000 tons, taken at a cost of only £1 per ton, would result in a reduction of £5,625,000 in the costs of industrial production.

Economy in labour, increased output of furnaces, reduction of metal losses, incidental to the introduction of pulverised coal firing; at the mines; throughout transportation and in factories; for coal shunting, distribution and ash removal, etc., will undoubtedly treble the value of coal eliminated, bringing the overall direct and indirect value of fuel economy up to £15,000,000 per annum.

There is, however, a question of far greater importance even than actual economy in fuel consumption. It is time to realise that of the great mass of coal used in industry and for domestic purposes, the immense value of its volatile constituents is entirely lost. In few instances only, at City Gas Works, patent coke ovens, producer gas plants, etc., are the liquid products of distillation recovered. The collective value of the refined products of these volatile constituents are to-day placed at upwards of £1 per ton of coal net profit after cost of recovery (see Tables of costs for crude products, A and B). A dead loss in Great Britain considerably in excess of £100,000,000 per annum.

Half of this could certainly be recovered, at the same time providing for city users an attractive smokeless fuel which will not foul the atmosphere, will ignite readily and burn brightly, a "prepared" fuel having 50 per cent. greater radiant heat value than raw coal and commanding a market price equal to the top price for domestic lump coal. This, moreover is a product obtainable by the distillation of many smaller and cheaper grades of coal now considered either useless or of little commercial value.

The national economy figure suggested has now risen to £50,000,000 plus £15,000,000 per annum. A total of £65,000,000 per annum. An estimate advanced in all reason and no doubt capable of exceeding £100,000,000 per annum in Great Britain, even when elementary considerations and applications are alone taken into account.

A national economy to an extent of anything like £100,000,000 per annum in any country must tend to reduce selling prices of commodities, thus placing industries in a stronger competitive

position with greatly increased employment on production resulting therefrom ; *and the cost of living would undoubtedly fall.*

Further : by the direct use of friable and low grade classes of coal in pulverised form many million tons of such fuel would become available for industry at a cost much below that of fuel extracted from deep mines under difficult conditions. Much of these additional supplies would be passed through distillation retorts for recovery of liquid products and the augmenting of supplies of smokeless fuel.

According to analyses supplied by the Low Temperature Carbonisation Co., Ltd., the relative figures for raw coal, low temperature domestic smokeless fuel and gas works coke are as follows for the three classes of solid fuel, (dry) :—

	Raw Coal.	Low Temperature Smokeless Fuel. (70%)	Gas Works Coke.
Fixed Carbon	50·5%	83·0%	85·5%
Volatile Matter	27·5%	8·0%	1·0%
Sulphur...	2·0%	0·5%	0·5%
Ash	10·0%	*7·0%	13·0%

*Reduction of ash due to washing.

"Domestic" smokeless fuel must be produced in lump form without expense as to briquetting, and this can be readily accomplished in vertical intermittent retorts, such as the Parker Retort, used at the Yorkshire Plant of the Company mentioned (see Arrangement A)[1], or perhaps in the Caracristi-Piron Continuous Retort now being developed by Henry Ford in America.

"Industrial" smokeless fuel however, can be made in very much less expensive plant, in a rotary distillation cylinder, such as the Stainer-Hutchins Continuous Fusion Retort (see Arrangement B)[2], in which breakers free to fall as the retort rotates break up the coked fuel. The product is discharged in a semi-pulverised state and usually passes through a $\frac{3}{8}$-in. sieve, size of product depending somewhat upon the nature of the coal and temperature of distillation.

The proximate analysis of such fuel is as follows :—

Raw Coal		Smokeless Fuel Residue (75%)	
Fixed Carbon	56·4%	Fixed Carbon (at 800°C)...	73·6%
Volatile matter	30·0%	Volatile matter ,, ...	13·7%
Ash	9·2%	Ash ,, ...	12·7%
Moisture	4·4%		

It will be clearly seen that by the recovery, refining and sale of liquid products of coal and of smokeless fuel, an increased profit of at least £1 per ton of coal as mined can be obtained. The coal owner could then afford to reduce his prices for raw coal necessarily

[1] See p. 898. [2] See pp. 899 and 901.

used by consumers, *and at the same time pay better wages to his miners.*

Cost of raw coal is still excessively high. 1923 terminal wholesale prices being for Durham coal 35s. to 37s. 6d. per ton for large sizes, 25s. for small coal, and 80s. for patent coke. Householders in March last were forced to pay a further 20s. per ton on these industrial prices. Yet we find that coal prices in Germany during 1923 fell from 5 per cent. to 17 per cent. according to the class of fuel.

The usual or known methods of burning, or utilising the heat content of solid fuel have undergone but slight improvement so far as reduction of the great recurring losses are concerned.

The major portion of raw coal used is still burned upon hand fired grates in industry and in domestic fire places. With hand fired boilers one finds efficiencies as low as 40 per cent., the burning of double the amount of fuel that should be necessary, and the continual pollution of the atmosphere by reason of smoke emitted.

For hand fired grates attendant labour is required in excess of economical standards, a loss of man power for more skilled work and a direct cause of high production costs.

Mechanical stoker firing at efficiencies of 70 per cent. to 80 per cent. (continuous load) has made an advance upon hand firing, but not without certain limitations. To the initial cost of a stoker installation must be added the not insignificant annual revenue derived by the manufacturers for the numerous spare parts required to maintain the equipment in workable condition, a figure reaching as high as 60 per cent. of total boiler-house maintenance costs.

The moving parts of mechanical grates are subjected to severe heat strains and to the destructive action of clinker. An overload much above normal rating cannot be obtained owing to the fixed grate area.

The danger of entire breakdown through a burn out of the grate is always present. Moreover, many stokers must be fed with a relatively high grade coal.

At times of heavy load the forcing of stokers results in a great volume of products of combustion, often taxing the capacity of flues and chimney stacks beyond their efficient limit.

The excess of air supply for pulverised coal firing remains constant at 20 per cent. for all loads, a condition which ensures a maximum of heat transmission to the boiler surfaces and a minimum volume of products in the flues and chimney.

Producer gas firing with an efficiency figure of 75 per cent. at the

generator and a capacity to gasify a wide range of fuels is a method of utilising the combustible value of solid fuel to great advantage.

Owing to the low value of the gas made, usually between 120 and 200 B.Th.U. per cu. ft., it is necessary to incorporate with high temperature furnaces costly and extensive regenerator chambers.

Pulverised coal firing practically eradicates all the deficiencies mentioned for mechanical stokers, and compared with producer gas firing is equally suitable for high or low temperature furnace work when the presence of fine ash dust is not an objection.

In the distillation of raw coal by any low temperature process (500°—800°C.) there is evolved a rich gas of about 700 to 600 B.Th.U. per cu. ft., a calorific value higher than that of ordinary city gas—450 to 500 B.Th.U.

With such a distillation plant running in conjunction with a producer gas plant it would be profitable in many instances to condense the volatile constituents of raw coal and subsequently to enrich the low value producer gas : a combination carrying with it the profitable disposal of valuable liquid products and smokeless fuel.

It has been recorded during the past two years that Belgian competitors can afford to export steel to Great Britain at £4 to £6 per ton under current British prices. Even in February of this year complaint was made that Belgian billets could be purchased in Great Britain at £6 17s. 6d. per ton, whereas British makers would lose money at £8½ per ton, quoting at a loss in some cases at £8 5s. to £8 10s. per ton.

Such underselling has been wrongly ascribed to one cause only, the fall of exchange, and many British producers have clamoured for protection—the very worst thing possible in view of the fact that Belgium, France, the United States and other countries have realised that economy in cost of production is the decisive factor and have taken steps to introduce means to this end.

In these great steel and iron producing countries pulverised fuel firing now plays a conspicuous role.

In American puddled iron works, fuel consumption has been cut from 3,000 lbs. to 1,400 lbs. per ton of iron with an increase of furnace output of 20 per cent., and with smokeless stacks.

Steel is treated in re-heating furnaces with a fuel consumption in some instances of 250 lbs. per ton against a previous consumption of 500 lbs., also with increased furnace output and metal losses reduced by half.

In Sheet and Pair furnaces a previous fuel consumption of 500 lbs. per ton has been reduced to 300 lbs., also with furnace output

increased. In the annealing furnaces a reduction of over 50 per cent. in fuel used and a greatly extended life of boxes.

It is of interest to make comparison with the pre-war total production of Pig Iron and of Steel in the four great producing countries (German figures for 1923 are unavailable). The figures are as follows (*Times Engineering Supplement*) :—

	Pig Iron—Tons.		*Steel—Tons.*	
	1913	1923	1913	1923
United Kingdom ...	10,260,300	7,400,000	7,633,900	8,450,000
U.S. of America ...	30,966,200	41,082,000	31,300,900	43,520,000
France	5,126,000	4,860,000	4,614,000	4,570,400
Belgium	2,445,600	2,089,400	2,427,600	2,172,000
Germany	16,492,000	—	17,349,000	—

It will be seen that the reduction of Pig Iron production in Great Britain for the period is 39 per cent., with an increase of only 10 per cent. in output of Steel. In America, the home of pulverised fuel, we find an increase of 33 per cent. in Pig Iron and 38 per cent. in Steel. Production in France and Belgium is now approximately up to the pre-war level.

Of the 30,000,000 tons or so of coal used in British Iron and Steel industries, it is safe to say that a reduction of at least 3,000,000 tons of coal could be made, with furnace output increased, losses reduced, and life of annealing boxes and life of rolls greatly improved. A collective economy of far greater permanent benefit than an artificial atmosphere of a protective tariff upon imports.

The items making up the plant required for the preparation and application of pulverised fuel is wide and varied, and its nature depends upon the layout of the works, the size and number of furnaces and many other considerations.

Whether the works are large and can usefully accommodate a complete pulverising plant with power distribution of the fuel—or whether self-contained pulveriser and burner units are preferable, are conditions to meet which suitable plant has been designed.

The types, systems, costs of plant and their operation, the savings realisable, and methods adopted by the users throughout the world, are fully covered in the writer's book on " Pulverised Fuel, Colloidal Fuel, Fuel Economy and Smokeless Combustion."

In addition to many Metallurgical operations *the application of fuel in pulverised form has now been definitely adopted as being the most efficient means of firing the immense steam boilers of modern super-power stations.*[1] Whereas an evaporation of 6½ lbs. of water from

[1] The present largest contract for pulverised fuel plant for Power-House Boilers, is that placed by the Columbia Power Company, U.S.A.

and at 212°F. was considered good continuous working for the original types of water tube boilers fitted with mechanical stokers, it is now possible to obtain 13 or 14 lbs. (per square foot of heating surface) continuous full load evaporation with pulverised coal firing.

The cost of pulverised fuel equipment and mechanical stoker equipment has been proved in practice to be approximately equal for equal quantity of fuel burned. In the latter case mechanical stokers cannot operate continuously, even when high evaporation modern boilers are installed[1] at the increased rate of fuel feed. The cost of pulverised fuel equipment is but slightly increased for the double duty in fuel feed ; the capital cost of boiler plant remains unchanged ; the heavy burden of repair parts for mechanical stokers is done away with.

Capital expenditure for boilers is thus half that required for equal continuous steaming with mechanical stokers ; one half the number of boilers occupy half the ground space and require but half the manual attention ; and there is introduced the possibility of using small fuel at perhaps half the cost of the higher grade coal required for stoker firing.

Upon the overall cost of production of electric energy at the bus bar, these factors of economy must be of considerable influence.

It is quite natural that the older established makers of water tube boilers, hide bound by their profitable policies, do not welcome the advent of pulverised coal firing. As a natural sequence we have seen many great super-power station boiler contracts passing to more enlightened makers, capable of supplying single water tube boiler units of 20,000 to 30,000 sq. ft. of heating surface and guaranteed for continuous steaming at over 13 lbs. evaporation per sq. ft. and this with peak load reserve in addition.

In the United States, electric power is produced at some 3,000 to 3,500 individual public service stations. The monthly " power " return during a summer month—June—when the lighting load is insignificant, records returned by 85 per cent. of existing stations show that 12,665,309 k.W. capacity is installed producing :—

from water power	1,220,972,000 units	(39%)
from fuel of all kinds ..	1,879,182,000 ,,	(61%)

The fuel consisted of :—

3,007,815 (short tons) of coal.
662,770 barrels of oil.
1,693,401,000 cu. ft. of natural gas.

[1] Stirling, Ladd, Belleville, Vickers-Spearing, Clayton, etc.

It will be found that this amount of fuel represents an expenditure of about 42,000 B.Th.U. per kWh.

George Otis Smith, Director, U.S. Geological Survey, in one of his lectures on electric power production said:

"The story of waste in our national career is not a pleasant one. The coal burned per kilowatt hour is approximately 1·3 to 3 lbs. and even more. Motive power for steam rail needs accounts for 30 per cent. of the total cost, and for 10 per cent. of the expenditure on electric railways. In industry the power cost lies between 2 per cent. and 12 per cent. of total production costs. In the Boston—Washington region 10,000,000 tons of coal per annum are used in the electric stations and perhaps 25,000,000 tons of coal on the railroads of this area alone."

"Can we afford to burn two tons of coal where one will pull the load?" Lowering the cost of electric power invites greater use, and greater use permits greater output at lower cost.

The electrification of railways, it would appear from the above statement, suggests a means of effective reduction in the running costs of existing steam power lines, to the benefit of freight rates, passenger rates, and to investors in such property.

These are arguments of equal force in all countries in which perhaps hundreds of small inefficient local power plants are operating, many of which ought to be shut down and the supply of power taken at bulk rates from centralised power stations.

In Great Britain there are some 600 Authorities supplying electricity in quantity ranging from approximately 130,000 units to 200,000,000 units per annum. Annual total cost of generation ranges from 0·49d. per unit to 8·07d. per unit and the average charge for current supplied from 1·01d. per unit to 9·68d. per unit.

The following figures show the relation between average cost of coal per unit sold and the ultimate total cost of generation and price realised per unit sold. (These figures have been based upon the tables and data published by the *Electrical Times*).

Generation of electric power in many countries, and certainly in Great Britain owing to its small area (no important industrial town being many miles from a coal field) ought to be located for the sake of national welfare and economy at or near the coal fields, alongside water supply adequate for condensing purposes.

A relatively small number of super-power stations interlinking their supplies at high voltage transmission could supply all electric power required in Great Britain, at a fraction of the present day cost at numerous individual and many grossly inefficient plants.

SUMMARY OF ANNUAL RESULTS OF THE LARGER BRITISH POWER STATIONS.

(Nine Metropolitan Municipal Authorities, ten Metropolitan Companies, and forty-eight Provincial Authorities and Companies each selling over 10,000,000 Units per annum).

	Total Units Sold.	Average Units Sold.	Average Cost of Fuel per Unit Sold.	Load Factor. Units x 100 / Max. Load x Hrs.	Average K.W. Capacity of Station	Units sold per K.W. installed.	**Total Works Costs per Unit Sold.**	**Total Average Price obtained per Unit Sold.**
9 Metropolitan Municipal Authorities	187,835,054	20,835,421	·549d.	20·08%	17,226	1,209	**1·29d.**	**1·953d.**
10 Metropolitan Companies	346,015,603	34,166,628	·55d.	*23·49(9)%	31,075	1,113	**1·675d.**	**3·212d.**
48 Provincial Authorities and Companies	1,879,998,136	39,166,628	·452d.	26·44%	29,086	1,347	**1·102d.**	**1·925d.**
Total ..	2,412,838,793	—	—	—	—	—	—	—

* Average for nine Stations.

The high price charged for current by Municipal Companies is noticeable. Agitation has been commenced against such heavy costs for electric power and light in view of the advantage which has been taken of war emergency legislation permanently to **increase distributed profits, in one instance, from** 5% (1914—1918) to 14·5% (1923).

It is said that the danger of interruption of supply coupled with the heavy capital charges for transmission lines render this idea impractical.

From the distillation of coal that would be used for the whole of our power requirements, say 80,000,000 tons[1] per annum, there would be recovered at only 10s. per ton for the crude liquid products of distillation, an increased revenue of £40,000,000 per annum.

The gas produced would be burned under the steam boilers in fertiliser medium calcining plants or supplied to municipalities.

The smokeless fuel, if of industrial quality, *i.e.*, small partially ground fuel, could be either sold or pulverised in conjunction with low grade raw coal in order to complete the quantity of fuel required for steam generation, a pulverised fuel mixture free from any danger of spontaneous combustion.

From the sale of liquid products, from domestic smokeless fuel (if produced), from fertiliser medium combined with the sulphate of ammonia there would be profit enough to make any capital charge on transmission lines look ridiculously small.

Besides this, there are numerous towns in which the average price per unit charged is well over 3d. per unit, to which towns it would be profitable to supply electric power in bulk at a price in the region of 1d. per unit.

There would still be a margin of 2d. and upwards per unit resold by many supply authorities and companies, a margin which would enable a big reduction to be made upon the local cost of electric power, and in no way adversely affecting dividends upon capital invested.

The bulk supply of electric power from the coal fields would be distributed at uniform high voltage throughout the country, thus making the interlinking system possible, and standardising all primary transformer sub-station plant.

Whether local supply is now alternating or direct current would not affect the principle, for each town would operate a secondary conversion station to suit its local requirements.

The network of distribution mains in districts and towns would remain unchanged and local voltages also need not be altered.

On the other hand it is possible to introduce a considerable saving in "cost" of fuel at most of the smaller individual power stations by the installation of pulverised fuel equipment, at the same time making it feasible to double the available duty of the boiler plant.

[1] A figure given as far back as 1918 by the Ministry of Reconstruction, Coal Conservation Committee's Final Report.

These latter are no doubt considerations great in themselves, but they fall far short of the national economy programme of generating electric power in bulk at the coal fields, where every opportunity exists for the collective recovery of the volatile constituents of solid fuel.

In every industrial country the day is approaching when the public services—Coal—Transportation—Power and Lighting Supplies—must become mainly controlled by the nation.

The production and distribution of city gas are matters for later consideration. Low temperature distillation should be undertaken by such companies. The production of cheaper gas with supplies of smokeless fuel should be encouraged. The national control of railways cannot be undertaken without serious expenditure of capital by way of compensation to the investing public, but the reduction of transportation costs can be governed by legislation assuring a better use of the " power " of solid fuel.

National control of public services, however, can be readily and reasonably considered in relation to Coal and Electric Power Supply.

If super power stations, located at certain selected coal mines, are erected at public expense, with a right to purchase coal at pit head prices and to market the liquid products and smokeless fuel for industrial purposes, then these distillation and power producing centres will be more than self-supporting.

With electric power supplied at cheap bulk rates, the revenue earning capacity of the undisturbed capital invested in local electricity works will appreciate, in direct relation to present cost per unit generated and the price at which bulk supply is obtainable.

Mine owners would realise pit head profit for coal used at the national centres and would still be free to market coal, or smokeless fuel, to recover coal products for themselves, to export coal, and to supply fuel for railways, for industry, and for domestic uses.

With electric power available at minimum rates, railway companies would then be placed in a better position to undertake the systematic development of electrification of railways, under most favourable conditions as to capital expenditure.

In the fulfilment of any broad programme of distillation, pulverisation, concentration of power generation and fuel efficiency in any country wherein such can be applied, the works required will be of such magnitude that the resuscitation of engineering industries and the great relief of unemployment on work of national value will be brought about in the most speedy manner possible.

If, in addition to the engineering trades, it is possible to introduce assistance to agriculture, the collective national value of the programme as a whole is materially increased. It is suggested that this is possible.

The chemical fertilisers—sulphate of ammonia, and nitrogen products are hygroscopic. The price to the farmer is between £15 and £20 per ton and he frequently receives deliveries in wet condition and in container bags partially destroyed. The result is uneven distribution over the land, costly fertilisation, and patches of chemically soured soil.

If chemical fertilisers could be mixed with a bulk medium, in itself a weak fertiliser, so that the mixture (a relatively non-hygroscopic mixture, could be evenly distributed, then the farmer would know that every ounce he purchases would be efficiencly used.

It is suggested that such a bulk fertiliser medium can be recovered from the waste dumps at the coal mines. Coal waste generally contains fertilising agents such as lime and phosphate rock, potash feldspars, and nitrogenous organic matter, and in some cases 30 per cent. or 40 per cent. of combustible. When the latter has been extracted by washing, the fuel so recovered can be passed through to the distillation plant.

The liquid products distilled from the recovered coal will be a net asset, the smokeless fuel produced sold as such, and the surplus gas utilised to calcine the residue waste material to form the fertiliser medium.

It can be accepted that about 5 tons of coal will be sufficient to burn 100 tons of dry fertiliser medium. There should thus be a surplus of 20 to 25 tons of recovered coal available for distillation, in the event of pulverised coal being used for firing the kilns in place of surplus gas from the distillation process.

The total production of sulphate of ammonia in Great Britain was for 1923—340,000 tons, of which 140,000 tons were used within the country.

In Germany for the same year, there were produced and used internally 350,000 tons of fixed nitrogen, an increase of 50,000 tons on the previous year. It is expected that the output for 1924 will be 500,000 tons and in the near future 800,000 tons. This is mainly the result of the Haber-Bosch process, the secret of which France has recently acquired in order to augment her supplies of fixed nitrogen, which are now mainly obtained by the Claude process.

In times of peace France will thus have all supplies necessary for agriculture, and in war full security for the production of explosives.

As a means of utilising the power of surplus gas at distillation centres, it is further suggested that electric generating plant for the fixation of nitrogen from the air could be installed.

The overall efficiency of such a plant is stated to be from 3 per cent. to 5 per cent., an efficiency not appreciably less than the final efficiency of using electricity in the domestic home. This cheap and abundant source of gas supply must be turned to the best account in the general interests of a nation, whether this be in the production of industrial power or in the fixation of nitrogen. It might be possible and profitable in so doing to supplant the importation of natural Chile nitrate.

In 1913-14, America imported 564,061 tons of Chile Nitrate valued at $17,951,355. and 166,753,754 lbs. of Ammonium Sulphate valued at $4,880,563. (69 per cent. of the latter coming from Great Britain, 20 per cent from Germany and 11 per cent. from other countries).

America absorbed internally in 1915 some 500,000,000 tons of coal. At 15 lbs. per ton of coal the above amount of Ammonia fertiliser would be recoverable from the distillation of under 12,000,000 tons of coal, in which event America would make herself self-supporting as regards this product. At the same time her diminishing supplies of liquid fuel (and motor spirit) would be augmented by 240,000,000 galls., and there would be brought into use for city purposes, over 8,000,000 tons of high grade smokeless fuel.

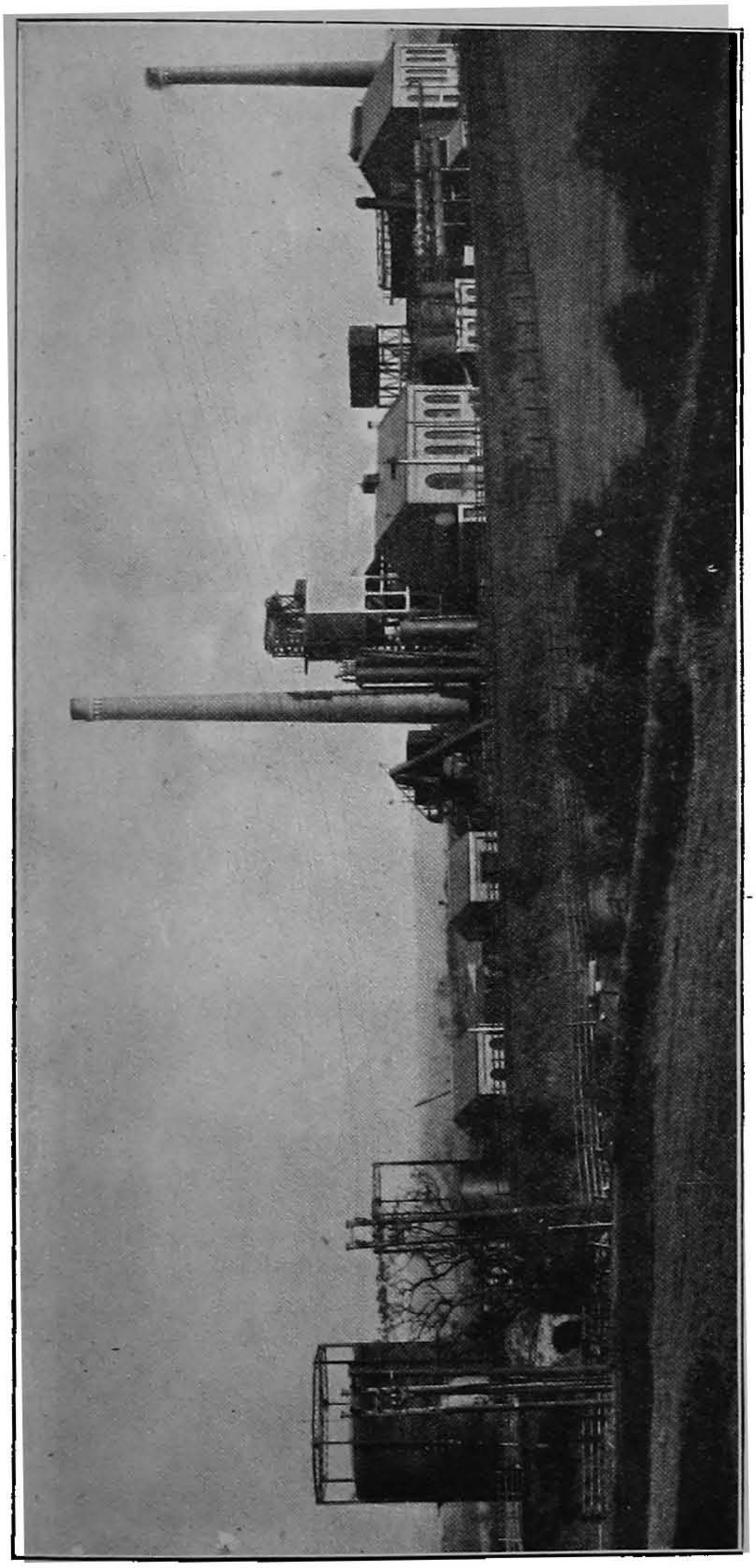
The Washington Bureau of Mines in recording the above figure for America's coal requirements stated that " if this coal had been used with the highest efficiency it is probable that some 125,000,000 tons, or 25 per cent., would have been saved."

This paper has been presented as an indication of the possible collective economies attendant upon the more scientific utilisation of the " power " of solid fuel. These economies are so vast that they urgently require national attention in all countries in which solid fuel is consumed.

The distribution of cheap electric power ; the recovery of motor spirit, heavy and light oils, fertiliser materials ; the construction of a vast amount of engineering plant ; the reduction of works' costs for power and fuel used in operations. All these considerations must bring a fuller mead of general employment and a lowering of the cost of living.

To this end " Distillation " and " Fuel in Pulverised Form " are destined to revolutionise the internal economy of any country possessing solid fuel, to the lasting benefit of national prosperity.

Low Temperature Distillation Plant.
Arrangement A.
The " Parker " Vertical Retort.
(The Low Temperature Carbonisation Co. Ltd.)



View of Works of Low Temperature Carbonisation Company, Ltd.
(Capacity of Plant not stated).

Publications of particular importance, bearing upon the two main subjects referred to in this paper, and issued by the Department of the Interior, Bureau of Mines, Washington, U.S.A.

DISTILLATION OF FUEL..." Production and Briquetting of Carbonized Lignite," by E. J. Babcock and W. W. Odell. (*Bulletin* 221).

PULVERIZED FUEL..." An Investigation of Powdered Coal as Fuel for Power-Plant Boilers." By Henry Kreisinger, John Blizard, C. E. Augustine and B. J. Cross. (*Bulletin* 223).

FINANCIAL ESTIMATE **A.**

FOR LOW TEMPERATURE DISTILLATION OF COAL IN "PARKER" STATIONARY RETORTS

(The Low Temperature Carbonisation Co. Ltd.)

FOR PRODUCTION OF DOMESTIC SMOKELESS FUEL.

Distillation Temperature. 800°C.

Retort Plant treating 1,000 tons of coal per 24 hours producing therefrom :—

Per ton.		*Per 1,000 tons (per day).*	
3,000	cu. ft. Gas.	3,000,000	(Surplus Gas, the value of which has not been taken into account).
700	B.Th.U. per cu. ft.	700	
20	Galls. of Crude Oil. including 3 galls. motor spirit).	20,000	(including 3,000 galls. of motor spirit.)
15	lbs. Ammonium Sulphate.	15,000	
70	% Smokeless Fuel in Lump Form.	700	tons.

Approximate disposal price of Domestic Smokeless Fuel say 35/- per ton.
Approximate disposal price of Crude Oil..... ,, 6d. per gal.
Approximate disposal price of Sulphate Ammonium..... ,, 1d. per lb.

Capital Cost of Plant to treat 1,000 tons of Coal per day of 24 hours and consisting of

640 Retorts (27 cwts. Coal Capacity per 8hours) with chimneys, pyrometers, elevators, overhead storage bunkers, travelling chargers, conveyors over bunkers, and covers over bunkers, etc., crude oil condensers, tanks to receive crude oil (3 days capacity), plant for stripping the light oil out of permanent Gases, plant for treating the wash oil used in the stripping plant, plant for recovery of Ammonium Sulphate from the ammoniacal liquor, motors for driving plant, delivered, erected and started to work, including buildings and foundations (power generating plant excluded), approximately £500,000

Note. The Crude oil condensing plant and crude oil collecting tanks are included above, but no plant for the refining of the crude oil.

FINANCIAL RESULTS.

Capital Expenditure.

640 stationary Retorts—treating 1,000 tons of coal per 24 hours ; plant operating 365 days per annum.

Capital cost as above..... £500,000

Debit.

365,000 tons Slack coal @ 10/- per ton	£182,500
Labour, fuel for heating retorts, power for driving retorts, etc., and water for condensers @ 4/- per ton of coal retorted	91,250
Removal and delivery of domestic smokeless fuel (70% of original coal) from retorts to purchaser's waggons or f.o.r. say.	5,000
Cost of recovery of Ammonium Sulphate @ ·75d. per lb. for 5,475,000 lbs., say	17,109
Standing charges, oil, stores, repairs and upkeep and proportion of office and management expenses @ say 1/6d. per ton.	27,375
Depreciation @ 10% on £500,000	50,000
Royalty on crude oil and upon smokeless fuel produced @ say 1/- per ton of coal treated	18,250
	£391,484

Credit. (20 galls. of crude oil per ton).

7,300,000 galls. crude oil @ 6d. per galon	£182,500
5,475,000 lbs. Ammonium Sulphate @ 1d. per lb.	22,812
	£205,312

Approximate cost of 255,500 tons of domestic smokeless fuel in lump form would be :

£391,484 — £205,312 = £186,172
or 14·5 shillings per ton.

Selling value of smokeless fuel @ 35/- per ton...	£447,125

(value of surplus gas is an additional asset).

FINANCIAL ESTIMATE **B.**

FOR LOW TEMPERATURE DISTILLATION OF COAL IN " FUSION " ROTARY CONTINUOUS RETORTS.

(The Fusion Corporation Ltd.)

FOR PRODUCTION OF INDUSTRIAL SMOKELESS FUEL.

Distillation Temperature. 500°C.

Retort Plant, treating 1,000 tons of coal per 24 hours producing therefrom :—

Per ton.		*Per 1,000 tons (per day).*	
1,960	Cu. ft. Gas	1,960,000	(Surplus Gas, the value of which has not been taken into account).
600	B.Th.U. per cu. ft.	600	
20	Galls. Crude Oil, (including 3 galls. of motor spirit).	20,000	(including 3,000 galls. of motor spirit).
75	% Fine residue smokeless fuel	750	tons.

Grading of smokeless fuel leaving retort all through ⅜-in. holes.

When Coal " dust " is treated in the retort the residue is all fine powdery material.

Approximate disposal price of industrial smokeless fuel for subsequent pulverisation ..... say 15/- ton.
„ disposal price of crude oil ..... say 6d. per gall.

Ammonia is not recovered in this process. Owing to the low temperature at which material is treated very little ammoniacal liquor is produced.

Capital Cost of plant to treat 1,000 tons of material per day of 24 hours and consisting of:

Twenty Retorts (50 tons each per 24 hours) with chimneys, pyrometers, elevators, overhead storage bunkers, conveyor over bunkers, and covers over bunkers, etc., crude oil condensers, tanks to receive crude oil (3 days capacity), plant for stripping the light oil out of the permanent gases and plant for treating the wash oil used in the stripping plant, motors for driving plant, delivered, erected and started to work, including buildings and foundations (power generating plant excluded), approximately £125,000

Note. The crude oil condensing plant and crude oil collecting tanks are included above, but no plant for the *refining* of the crude oil.

FINANCIAL RESULTS.

Capital Expenditure.

20 Fusion Rotary Retorts to treat 1,000 tons coal per 24 hours; plant operating 365 days per annum:

Capital cost as above.....	£125,000

Debit.

365,000 tons slack coal @ 10/- per ton.....	£182,500
Labour, fuel for heating retorts, power for driving retorts, etc., and water for condensers at 2/3d. per ton of black coal retorted	41,063
Removal and delivery of dry smokeless fuel (75% of original slack coal) from retorts to purchasers premises or f.o.r.... say	5,000
Standing charges, oil, stores, repairs and upkeep and proportion of office and management expenses at, say 1/- per ton.	18,250
Depreciation @ 10% on £125,000.....	12,500
Royalty on crude oil and upon smokeless fuel produced @ say 1/- per ton of coal treated.....	18,250
	£277,563

Credit.—(20 galls. of crude oil per ton).

7,300,000 galls. crude oil @ 6d. per gall.....	£182,500

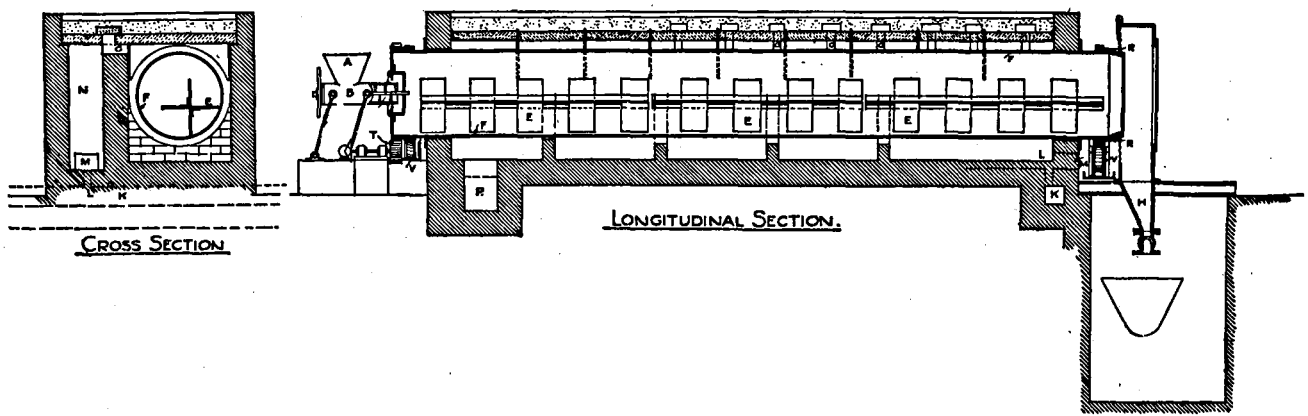
Approximate cost of 273,750 tons of fine dry industrial smokeless fuel as delivered for pulverisation would be:—

£277,563 — £182,500 = £95,063 or 6·9 shillings per ton.

Selling value of smokeless fuel @ 15/- per ton = £205,312

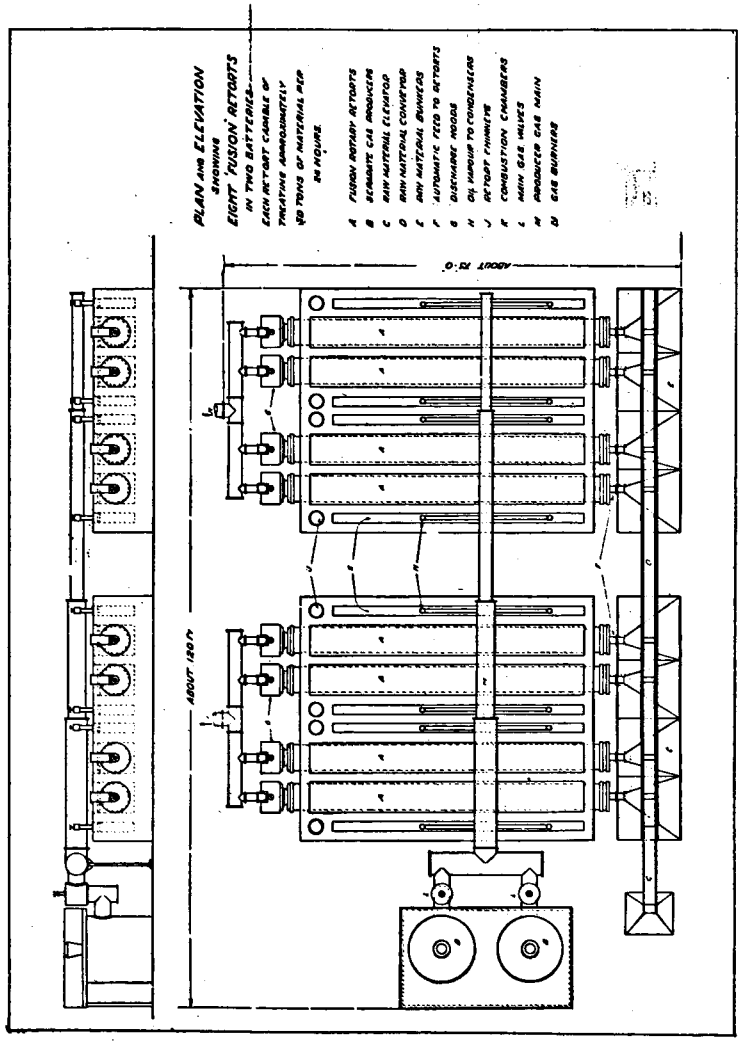
(Value of Gas is an additional asset).

LOW TEMPERATURE DISTILLATION PLANT. ARRANGEMENT B.
THE FUSION ROTARY RETORT. (The Fusion Corporation Ltd.)



THE FUSION ROTARY RETORT.

A. Raw Material Hopper.
B. Air-tight Automatic Feed Valve.
E. Breaker or Pulverizer.
F. Rotating Tube.
G. Ports with Dampers for conveying the products of combustion to the heating chamber round the Rotating Tube F.
H. Hopper with air-tight automatic valve for discharge of spent material.
K. Gas Feed Conduit.
L. Gas Inlet to combustion chamber.
M. Air Inlet to combustion chamber.
N. Combustion Chamber.
P. Flue to Chimney.
R. Gland for making joint between Rotating Tube and End Chamber.
T. Gear for Rotating Tube.
V. Rollers upon which the Tube rotates.



FUSION ROTARY RETORT PLANT FOR 240 TONS PER 24 HOURS.

THE FUSION ROTARY RETORT.

RESULTS OF TESTS CARRIED OUT.

Material treated.	Moisture in Raw Material %	Gallons of oil (water free) per **Wet** ton	Specific Gravity of oil	Cu. feet of gas per **Wet** ton
South African Torbanite	0·5	96	0·9175	1770
English Oil Shale ...	12·58	31·5	1·016	1850
*Sawdust	13·79	17	1·1274	2200
Indian Coal	10·92	23·8	0·9592	1125
Peat	28·65	9	1·051	3000
English Coal Slack ...	6·72	16·4	1·122	1025
English Cannel Coal...	1·54	60	0·912	870
Esthonian Shale ...	4·18	65	0·9671	1340
Brown Coal	27·0	22·5	1·102	1300
South African " Duff " Coal	3·65	14·6	1·050	1570
Nova Scotia Shale ...	1·75	28·2	0·9871	1120
English " Duff " Coal	2·3	21·5	1·120	1960

* In addition to the oil recovered there were 102 gallons of acid liquor of 1·26% acidity.

The above figures of Oil Yields do not include the Light Spirit recovered from the permanent gases by " stripping " or " gas washing."

RÉSUMÉ.

" Pouvons-nous nous permettre de brûler deux tonnes de charbon là où une seule tonne tirera la charge."—George Otis Smith, *Directeur—Service Géologique des Etats Unis.*

Dans ce rapport, des suggestions basées sur de larges conceptions Nationales, sont mises en avant dans l'intention d'insister sur le gaspillage inutile et la perte des constituants volatiles précieux des combustibles solides, lorsqu'ils sont brûlés dans leur état naturel.

Dans la consommation des combustibles solides pour production de vapeur, dans les Industries du Fer et de l'Acier et dans les Usines en général, on trouve très fréquemment que cette consommation est bien supérieure à la pratique récente, d'utiliser les combustibles solides sous forme pulvérisée. Des faits sont cités.

L'auteur préconise l'utilisation des combustibles solides de qualités inférieures en les distillant au préalable ; les combustibles sans fumée résultant de cette distillation seraient brûlés dans des foyers domestiques ou sous forme pulvérisée pour les besoins industriels, ou serviraient de supplément aux fournitures de combustibles (en raison du succés prouvé de l'application de ces qualités inférieures sous forme pulvérisée) ; toutes ces applications ont une haute importance Nationale.

L'auteur insiste en conséquence sur les possibilités de découvrir dans les divers pays un combustible solide utilisable, éliminant ou réduisant ainsi le tonnage importé et placant au Crédit des ressources Nationales et aux prix courants du marché, des sous-produits tels que : goudron, huiles lourdes et

légères, essence, sulfate d'ammoniaque ; produits récupérés du lignite, de la houille brune, du charbon à longue flamme et du charbon friable bitumineux.

Des renseignements sont donnés sur les grandes supercentrales actuellement en existence ou en cours de construction, où le chauffage par charbon pulvérisé a été ou sera adopté ; également sur l'influence qu'à l'économie de combustible ainsi réalisée, sur les prix de revient dans la construction mécanique et les produits de fer et d'acier. L'influence Nationale de l'économie de combustible sur les prix de transport et des commodités, sur le prix de la vie et sur la réduction du chômage, dépendent de l'utilisation des combustibles solides sur des bases plus scientifiques.

L'auteur explique comment, à l'heure actuelle, ces procédés pourraient être réalises au plus grand bénéfice de la communauté, et que leur introduction permettrait d'espérer des rendements financiers additionels tant aux propriétaires de mines qu'à leurs actionnaires.

L'auteur suggère que la question de la Nationalisation des services publics tels que les transports, l'énergie électrique et le charbon, ne peut pas être retardée bien longtemps. Il propose qu'un début dans cette direction pourrait et devrait être fait avec la production de l'énergie électrique dans les bassins houillers et la distribution de cette énergie aux centaines de petites stations électriques existantes, qui travaillent actuellement dans des conditions déplorables de rendement.

Des prix de revient de l'énergie électrique dans les petites stations sont donnés, et on fait remarquer qu'il y aurait un très grand avantage pécunier, pour les porteurs d'actions de ces entreprises, en prenant l'énergie électrique à des prix à forfait aux stations Centrales Nationales.

Dans ce développement général, des facilités importantes seraient offertes aux Compagnies de chemins de fer pour l'électrification systématique des lignes principales et des lignes suburbaines.

En raison des principes scientifiques et économiques, le traitement du charbon et la production d'énergie devraient commencer aux charbonnages, où une utilisation additionnelle peut, peut-être, être réalisée avec les gaz en surplus provenant des cornues de distillation, par la production d'un fertilisateur en partant des énormes déchets des mines de charbon.

Le but principal de ce rapport est de présenter à la discussion, des questions d'une importance Nationale considérable et de suggérer des moyens immédiats de réduire les prix de revient ; les frais de transport, les prix des commodités et de la nourriture ; moyens qui assisteront incidemment l'agriculture et la construction d'une grande quantité de machines pour les diverses branches de l'industrie ; et finalement l'absorption des chômeurs par des travaux de la plus grande importance Nationale.

Des tables de prix de revient et des plans d'installation sont donnés pour des usines de distillation, destinées à la production de combustibles sans fumée pour les usages domestiques et industriels.

LOW TEMPERATURE CARBONISATION

Dr. C. H. LANDER, D.Sc., M.I.Mech.E., Assoc.M.Inst.C.E., F.Inst.P.
Director of Fuel Research under the Department of Scientific and Industrial Research.

Although the question of the carbonisation of coal at lower temperatures than those at present practised has been before the public for almost twenty years, it cannot be claimed that a complete solution of the many problems involved has yet been obtained. The degree, however, of success varies according to whether the matter be viewed from the standpoint of the commercial utilisation of low grade or so called waste fuels, or whether it envisages the establishment of an industry on a national scale which would be capable of dealing with the tens of millions of tons of coal at present consumed in the raw state. In the former case the raw material could be debited to the plant at a low price and so render possible a margin for profitable working, which would not exist if the coal carbonised were of such a quality as to command a price commensurate with that which the public would be willing to pay for the smokeless fuel produced.

Broadly speaking, the history of the subject so far as this country is concerned may be divided into two periods, the first of which dates from Parker's proposals in 1906. The aims of the early pioneers had been in the direction of obtaining a fuel which would be smokeless when burnt under the conditions obtaining in the domestic grate and so alleviating the smoke nuisance of our large towns, although a certain amount of work had also been directed towards obtaining a fuel for use in gas producers of the ammonia recovery type in order to get rid of the trouble caused by the caking of raw coal when used in such plant. The second period commences some seven years later, when, as a result of the enquiries of the Royal Commission on Fuel and Engines for the Navy, under the chairmanship of Lord Fisher, low temperature carbonisation was recognised as affording a promising method of providing a home-produced fuel oil suitable for use by the Navy and Mercantile Marine. It was clearly brought out that, as only some six or seven per cent. by weight of the coal treated appeared as oil,

it would be necessary to find markets for the other products of carbonisation in order to render the proposition an economic one. Prior to the appointment of the Royal Commission, the crude oil obtained by the early experimenters had been regarded as comparatively unimportant, but very early in the enquiries of this Commission the possibility of using this oil for naval and marine purposes provided a new incentive to those who were at that time working on the problem. The subject was thus raised from one of comparatively small significance to one of national dimensions.

During the war the subject was brought into further prominence owing to the serious risk of shortage of supplies of fuel oil for the Navy and several emergency enquiries were conducted in order to find suitable methods of alleviating the grave situation which had arisen. The only practical steps which were feasible were the development to the utmost of the Scotch shale oil industry and the diversion of as much as possible of the tar produced in the gas and metallurgical coke industries to such uses as would set free a corresponding amount of imported oil for use at sea.

In this manner then it was brought home to the Government in 1916 that some measure of State aid was necessary to the solution of this and many other problems which present themselves in the direction of the better utilisation of our fuel resources, and it was decided by the Committee of the Privy Council for Scientific and Industrial Research in 1917 on the recommendation of their Advisory Council, to establish a Board which should be responsible for the promotion and co-ordination of research into fuel problems. It was, however, pointed out to the War Cabinet that, while the schemes of investigation proposed by this Board could have no possible effect in relieving the situation during the war, it was of paramount importance that the question of home produced supplies of oil for the Navy should be exhaustively studied " in order that a definite decision as to the possibility or impossibility of the proposals should once for all be arrived at."

Owing to the economic changes which have resulted from the war, the economic solution of the problem has proved much more difficult than was at first anticipated. Work of very great value has been done under the auspices of the Board and also by independent investigators, and accurate data on many doubtful points have been obtained. Much progress has been made towards a technical solution and the elements of uncertainty still remaining are mainly those of an economic nature.

Although the above remarks have been directed to the subject

of low temperature carbonisation of coal as a method whereby the smoke nuisance could be alleviated, and at the same time a considerable quantity of home produced oils obtained, the possibilities of development of the existing carbonising industries to this end should not be overlooked. Broadly speaking, there are two methods of carbonisation which have to be considered, *viz.*, the gas-works process in which carbonisation is carried out in externally heated horizontal or vertical retorts in which the temperatures of the heating chambers range from 1,000°C. to 1,300°C., and the coke-works process carried out in recovery ovens in which the temperatures of the heating chambers range from 1,200°C. to 1,300°C.

As these processes are practised to-day, the findings of the Fisher Commission are as true as they were when the Commission reported in 1913. The quantity of fuel oil suitable for industrial purposes which is produced is so small that it hardly needs serious consideration when dealing with the broad question of a home supply. In addition, regular and profitable outlets already exist for the whole of the tar product of both the industries concerned and it is certain that these outlets will continue to expand with the natural development of the industries.

The present trend of development in the gas industry is in the direction of obtaining the highest proportion of the potential heat units of the raw coal in the form of gas. Whilst no development of the gas industry *upon these lines* can help towards the production of sufficient quantities of fuel oil for our requirements, signs are not lacking that this progressive industry is beginning to realise more and more the possibilities which their position affords them of becoming the largest suppliers of forms of fuel other than gas. Great attention has been paid lately to the development of the sales of coke for domestic purposes and steps have been taken to overcome some of the disabilities of high temperature coke which may have rendered it in the past somewhat unpopular as a household fuel. Attention is also being paid by the gas industry to the possibilities which are presented by fine grinding, blending and briquetting as a preliminary to carbonisation with a view to obtaining a solid fuel which, whilst being produced at high temperatures will be more combustible than the ordinary type of gas coke and so more suitable for burning in an open grate.

The gas industry is also watching carefully the development of low temperature carbonisation from the point of view of the possibility of utilising the rich gas from carbonisation at 600°C. as an enriching agent for the raising of low grade gas to a higher standard

of calorific value. The calorific value of low temperature gas is about 1,000 B.Th.U. per cubic foot. Its high concentration would enable it to be stored in relatively small holders from which it could be accurately metered into the general supply system. For enrichment it possesses advantages over other gases and vapours frequently used for the purpose, inasmuch as it owes its high calorific value to its large content of methane and other saturated hydrocarbons, which will not settle out during storage and distribution. About 3,000 cubic feet per ton (or 30 therms) is available in a straight carbonisation process and the tentative value put upon this asset by the Fuel Research Board is fourpence per therm.

The amount of oil obtainable varies with the coal used and the process adopted. In experiments with various types of coal in a bench of horizontal externally heated steel retorts, the Fuel Research Board obtained yields of *dry* oil varying from about 13 to 20 gallons per ton. In this connection it is advisable to issue a note of warning against the high oil yields that are sometimes quoted. Such yields are often measured as wet tar and are therefore enhanced in direct proportion to the amounts of liquor present. In the opinion of the Fuel .Research Board it is not advisable, when considering the subject from the national point of view, to take a figure greatly exceeding 15 gallons of oil per ton of coal as the average obtainable from a wide selection of coals suitable for use in the process.

The characteristics of the oil vary considerably according to the type of coal used and the process adopted. Space does not permit of a full discussion of the properties of this oil, but the following characteristics may be expected in a process of straight low temperature carbonisation in which the oil has not been subjected to overheating.

1. That it will contain hydro-carbons chiefly of the paraffin, olefine and naphthene series and from 10-15 per cent of phenols.
2. That the quantity of benzene and its homologues will be small, but will be made up for by the presence of low boiling hydro-carbons of the above mentioned series.
3. That the higher phenols, such as cresol, will be more represented than phenol itself.
4. That the content of free carbon will be less than 2 per cent. and that of pitch will be 35-40 per cent.
5. That there will be up to 1 per cent. of basic nitrogenous substances including pyridine.

It is evident, therefore, that the oil possesses special properties not usually associated with natural fuel oil, and indeed these properties

have been reflected in the uses to which the comparatively small quantities made up to the present have been put, namely, as a raw material for the manufacture of disinfectants and for preservative paints. Several groups experimenting in processes of low temperature carbonisation have met with no difficulty in disposing of all of the oil which they have produced at a price of about 1/- per gallon at a time when foreign oil fuel could be obtained at a price in the neighbourhood of fourpence. So long as the process is conducted on a limited scale, an enhanced price may be obtainable for the oils, but such markets are not likely to be commensurate with the magnitude of an industry established on a scale sufficiently vast to meet our national requirements. As fuel the oil will have to meet the competition of natural oil, the price of which is mainly controlled by foreign suppliers. At the present time it is not safe to assume a stable value for the oil greatly in excess of 5d. per gallon.

For an oil to be suitable for naval or marine use, it is essential that it should possess the property of miscibility with natural petroleum. It is obvious that a ship must be in a position to take supplies from various sources and grave difficulty would be experienced in the blocking of pipes and valves if an oil taken aboard is liable to throw down a deposit when brought into contact with the residue of a previous supply. The adaptability of crude low temperature oil for mixture with natural oil has been investigated at H.M. Fuel Research Station. Seven oils were used from the following sources, Shale, American, Burman, Texas, Mexican, Persian and Trinidad. Two of these (American and Shale oils) were quite immiscible. Stable mixtures with Burmese and Texas oils were only obtained with less than 25 per cent. of the natural oil. With Trinidad oil only, was complete miscibility obtained and even then application of heat was necessary.

This disability is, however, being overcome by several processes which are being experimented upon at the present time, and the difficulty can also be surmounted by fractionating the oil.

Light spirits can be obtained, both from the oil and the gas which are suitable for use in internal combustion engines. The available yield of fine spirit from the tar amounts to 1·0 to 1·6 gallons per ton of coal, whilst that from the gas amounts to about 1·4 gallons giving a total yield of motor spirit of about 3 gallons per ton of coal. This spirit is miscible in all proportions with petrol and benzol of the British Standard specification.

The possibility of establishing a low temperature carbonisation industry on a national scale depends largely upon the recognition

by consumers of the superiority of the smokeless fuel over raw coal as fuel. To be effective from the commercial point of view, it is necessary that this recognition should take the practical form of its wide adoption by domestic users at a price somewhat in excess of that of the house coal which it would replace. From time to time small supplies of smokeless fuel have been placed upon the market from different sources and good prices obtained. Broadly speaking, there is a consensus of opinion amongst those who have used it that it forms an admirable domestic fuel. In the types usually made, it contains from 7 per cent. to 10 per cent. of volatile matter, which confers upon it the property of ready ignitability. When produced from suitable coals by modern methods it is sufficiently robust to stand transport without undue breakage.

Up to the present, small supplies of fuel have been disposed of at prices which were often considerably in excess of those of coal, but it must be remembered that such prices are not likely to be realised when fair supplies are obtainable and it is necessary to find customers other than those who are enthusiastic in support of any scheme which will tend to ammeliorate the smoke nuisance. The question still awaiting answer is—what extra price, if any, over raw coal, weight for weight, will customers be prepared to pay in consideration of its superiority?

The yield of coke per ton of coal by straight low temperature carbonisation amounts to about 14 cwt. on the average. It has been assumed in the computations which have been made in the past that the price obtainable for the coke, as a high-class domestic fuel, will be sufficient to meet the entire cost of the coal used. The possibility should not be neglected, however, that the smokeless fuel may only command a price equivalent to that of raw coal weight for weight. It will be seen, therefore, that in the latter case the price obtainable for the liquid and gaseous products of carbonisation must be sufficient to yield a profit after paying the cost of about 6 cwt. out of every ton of the raw coal treated, together with the entire costs of retorting. It is at the present time extremely difficult to draw up reliable estimates of the balance sheet, owing to lack of knowledge as to capital costs of plant, upkeep and cost working, but it is evident that the possibilities of many suggested processes turn upon the considerations mentioned above. In short, a process which might prove a commercial success under the conditions of the coke paying for the whole of the coal assumes a totally different aspect if the price obtainable is only equivalent to that of the raw coal weight for weight. Also under the latter

conditions and with the assumptions made above regarding the prices of oil and gas the greater the price of the coal the more is the process handicapped. Much harm has been done by the wild statements which have been issued from time to time and which have frequently exaggerated the yields of some of the more highly priced products by as much as 100 per cent.

Extravagant credits are often taken for the ammonia produced in low temperature carbonisation. In an average bituminous coal containing 5 per cent. moisture, the liquor yield would be approximately 10 gallons per ton from the coal itself and 11 gallons from the moisture, or say 21 gallons. For this liquor to be saleable it would have to be of at least 8 oz. strength or about 1·7 per cent. ammonia, which means that a recovery of about 14 lbs. per ton would be necessary in order that this strength should be reached. Otherwise, circulation of the collected primary liquid in a scrubber would be necessary to reach this strength, and it is likely that only a small proportion of the total liquor formed could be concentrated in this manner. In view, therefore, of the small possible yield, and the low prices obtainable at the present time, it is hardly worth while taking the ammonia into consideration in the balance sheet of a straight low temperature process. Of course, higher yields would be obtainable with processes in which some of the coke is completely gasified, as in the systems employing internal heating.

METHODS OF RETORTING.

In the broadest sense there are two distinct lines whereby the problem of low temperature carbonisation may be attacked, the differentiation being according to the method whereby heat is supplied to the coal under treatment.

1. " The coal may be distilled in a gas-tight retort in which the whole of the heat for carbonisation is passed through the iron or fireclay wall. The fuel, solid, liquid, or gaseous, is burnt either in a large chamber which almost completely surrounds the retort itself, or in a succession of smaller heating chambers built on the outside of the retort wall, *i.e.*, external heating."
2. " The coal may be exposed to the action of heat derived from the sensible heat of some substance which is mixed with the material to be carbonised. The substance forming the heating material is usually a large amount of producer gas, either generated within the retort itself, as in the Maclaurin type, or externally as in the Nielson retort. Proposals have, however, been made from time to time to use materials other

than producer gas for this purpose, these proposals including the use of superheated steam, heated low temperature coal gas, melted lead or hot sand, *i.e.*, internal heating."

Whilst the classification given above is on very broad lines it is obvious that many sub-divisions may be made within these two groups, one of the most important of these in its effect on the economics of the process relates to whether the coal is maintained in repose during the carbonisation period or whether it is turned over by the action of blades or conveyors. In the latter case the ingress of heat is facilitated and the time of carbonisation shortened, but the smokeless fuel produced is usually in such a form as to necessitate a process of briquetting before it could be disposed of as a household fuel.

Up to this point the discussion has tentatively assumed that carbonisation is being carried out according to the first of the two broad distinctions mentioned above. In this case, if the process is carried out in gas-tight retorts maintained uniformly at a suitable temperature, the quantities and qualities of the volatile products, gas and crude oil, will average out to about 3,000-3,500 cu. ft. of gas of calorific value 900-1,000 B.Th.U. per cubic foot and 12 to 17 gallons of crude oil. The physical and mechanical properties of the coke vary over wide limits, but if a raw material be supplied which is not too rich in fusible constituents and at the same time has sufficient binding material to cement the whole together into a robust coke, the solid product will be suitable for a domestic fuel. Space does not permit a full discussion of the various methods which have been tried in order to obtain such a raw material; it will be sufficient to mention the method of blending fusible and infusible coals in such proportions as will produce a mixture which contracts slightly on carbonisation at 600°C.

Several processes have been suggested from time to time whereby a part of the excess binding material present in certain types of coal, which swell strongly on carbonisation, is destroyed in order to produce a robust low temperature fuel. These methods are, of course, only applicable to those coals in which binding material is present in excess. The quantity of such coals is limited, and from the national point of view it would appear more desirable to utilise the excess binder to produce coke of good quality from materials which, while yielding considerable quantities of gas and oil, are deficient in this valuable constituent, and so do not by themselves produce hard smokeless fuel.

The proportions of the two coals to be used in the blending method

in order to produce a robust coke can be determined in a few hours by the method of low temperature assay developed by Gray and King at H.M. Fuel Research Station. In the same way the quantity and quality of the volatile products can be estimated in the laboratory with the full assurance that if suitable conversion factors be applied, the results will be reproduced upon a large scale.

When coal is carbonised according to the second method described above, entirely new considerations are introduced, the chief of which is the change in quality and quantity of the resulting gas.

In this case when considerable quantities of hot producer gas are used as the heating medium, this low grade gas is mixed with the richer gas given off by the carbonisation process. The resulting mixture as withdrawn from the retort or producer is therefore greatly increased in bulk and its calorific value is comparatively low. Typical figures for the yield per ton of this gas would be about 20,000 to 25,000 cubic feet of a calorific value of 230 B.Th.U. per cu. foot. As the increased volume of gas is usually derived from the combustion in steam and air of some of the coke there is a corresponding reduction in the amount of coke available for sale. The commercial success of the process therefore depends very largely upon the securing of a profitable outlet for this low grade gas and it is obvious that it is only suitable as a fuel gas for industrial purposes. The method is, however, exceedingly interesting and presents great possibilities owing to the low capital cost of the plant. In one process, where the principle of internal heating is adopted, a figure has been taken of 1·8 to 2·3 pence per therm, the former being its value for steam raising in comparison with coal at 20/- per ton. A most interesting development in this connection arises from the decision of the Glasgow Corporation to install a battery of five units of Maclaurin producers at Dalmarnock. Two objectives are aimed at: firstly, the production of smokeless fuel, and secondly, to prove whether or not the gas obtained by the process can be economically used for the firing of the boilers in the generating station.

A considerable amount of work is proceeding in various quarters on the effect of fine grinding and briquetting of coal as a preliminary to carbonisation. In the method of Sutcliffe and Evans a mixture of coking coal and coke, or of coking and non-coking coals, is ground finely and briquetted under heavy pressure without adding a binder. In this way it is possible to supply to any simple form of retort a material into which heat can be passed rapidly. The simplicity

of a Scottish shale vertical retort is a feature which appeals strongly to those who are working on the present problem and suggestions have often been made that carbonisation of bituminous coal might well be carried out in a similar type of apparatus. Unless, however, the retorts are made exceedingly narrow, in order to conform to the principle of treatment in thin layers there will be difficulty even with suitable blends of coal in transferring the heat to the interior with sufficient rapidity when the coal is fed to the retorts as a compact mass that will fuse together on carbonisation. In the case of the carbonisation of shale the material is fed to the retorts in pieces of fair size which do not tend to stick together on heating and the spent shale leaves the apparatus in approximately the same form as it enters. With such a material free convection can be set up, which considerably increases the speed at which heat can be driven in to the centre of the charge. A large charge can thus be dealt with and a fair degree of uniformity of carbonisation secured. The Sutcliffe-Evans process of pre-briquetting presents a material which in this respect is analogous to that of shale and therefore the subsequent retorting is reduced to the simplicity of the Scottish shale practice. In addition the fine grinding and intimate mixing plays an important part in securing the qualities of homogeneity and physical texture so desirable in any form of smokeless fuel intended for domestic use.

Experiments on a modification of the Sutcliffe-Evans process have been undertaken during the past eighteen months at H.M. Fuel Research Station with the object of using lower briquetting pressures than those adopted by Sutcliffe and Evans and also of obviating the necessity for fine grinding. A suitable blend of coal is passed through a disintegrator and then heated to a temperature at which incipient fusion takes place. The heated coal is then briquetted under a pressure of about two tons per square inch, the briquettes being then carbonised in simple cast-iron vertical retorts whose design is based on that of a shale retort. At the time of writing (April, 1924), the method has not been fully worked out, since difficulties have been experienced due to the excessive amount of dust produced in the retorts. These difficulties are, however, slowly being overcome and the staff of the Fuel Research Station is hopeful that a practical and economic process along the lines indicated will eventually be obtained.

In the present paper the author has confined himself to a consideration of the broader aspects of the problem as it is envisaged by the Fuel Research Board. Any attempt to discuss in detail

the various types of plant that have been proposed and tried, and the factors affecting the characteristics of the coke and oil, and the yields of the various products obtained, would extend this paper beyond permissible limits. Such a discussion is perhaps in any case unnecessary as several books have recently appeared on the subject, including one by the author, in which these questions are dealt with in far greater detail than is possible in a paper.

RÉSUMÉ.

Des travaux sur la carbonisation à basse température ont été effectués dans ce pays durant ces vingt dernières années. Le but des premiers investigateurs était d'obtenir un combustible sans fumée pour les usages domestiques. L'utilisation croissante de l'huile lourde pour la marine et de l'essence pour les transports terrestres et aériens, ont montré toute l'importance des goudrons et transformé la question en un problème d'importance Nationale. Des travaux importants ont été effectués et un combustible sans fumée, donnant satisfaction, a été obtenu en utilisant les types de charbon consommés principalement pour les usages domestiques et industriels ; ces résultats ont été réalisés par un traitement convenable et particulièrement en mélangeant intimement et dans des proportions convenables les charbons à coke et les charbons non-coké fiants.

Les huiles obtenues varient considérablement suivant le type de charbon utilisé et le procédé adopté et elles possèdent des propriétés que l'on ne rencontre habituellement pas dans les huiles lourdes naturelles. Elles ont notamment une valeur spéciale pour la fabrication des désinfectants et des peintures préservatrices. Quoique ces propriétés spéciales permettent d'obtenir un prix élévé pour de petites quantités, la demande ne serait pas suffisante pour maintenir le prix si l'industrie se développe sur une échelle nationale et les produits liquides peuvent seulement être considérés comme possédant la valeur de l'huile lourde. Les goudrons bruts obtenus ne se mélangent pas avec la plupart des pétroles naturels, ceci empêche leur utilisation sous cette forme pour l'approvisionnement des navires, mais cette difficulté peut être surmontée par fractionnement des huiles ou par d'autres procédés qui sont mis au point actuellement.

Les rendements moyens par tonne de charbon que l'on peut espérer obtenir en travaillant réellement sur une grande échelle sont :—

Combustible solide sans fumée, environ		14 cwt. (700 kg.)
Goudron *sec*	,,	15 gals. (67,5 litres).
Gaz	,,	30 Therms (757.000 cals.).

Le gaz obtenu par tonne de charbon à l'aide de cornues chauffées extérieurement sera d'environ 3.000 pieds cub. (86 mètres cub.) ayant une valeur calorifique d'environ 1.000 B.Th.U par pied cube (8.900 cals. per mètre cub.) ce gaz valant environ 4 pence par therm. Dans des Cornues chauffées intérieurement ce gaz est mélangé avec de grandes quantités de gaz de qualité inférieure et la production totale devient 20.000 pieds cub. (570 mètres cub.) ou plus ayant une valeur calorifique d'environ 230 B.Th.U et valant seulement environ 2 pence par therm.

Le procédé de carbonisation à basse température n'est commercialement possible sur une échelle nationale que si les frais généraux et de premier établissement peuvent être maintenus à un chiffre très bas et même dans ces conditions le succès dépendra largement de la possibilité de vendre ou non le combustible sans fumée à un prix par tonne supérieur à celui du charbon avec lequel il est obtenu.

THE GAS PRODUCER AS APPLIED TO LARGE SCALE POWER GENERATION

ARTHUR H. LYMN, LONDON

This paper, as its title indicates, is designed to describe the various methods of applying Gas Producer Plants to the generation of power on a large scale while at the same time showing the economics of the different systems as compared with each other and with the most modern direct fired steam practice.

It is not concerned with small gas power plants as used by private firms in their own undertakings, such as suction gas engine plants or the small so-called suction pressure plants, which are well known throughout the world.

The Gas Producer is known generally to the engineering public as an apparatus for producing poor grade fuel gas for the firing of metallurgical and other furnaces in which the gas is usually employed in the hot uncleaned condition exactly as it leaves the Producers; but gas in such a condition is unsuitable as the heating medium in any system of steam power plant which lays claim to thermal efficiency, and it is completely out of the question for internal combustion engines.

It is, of course, well known that excess gas from numerous industrial sources such as blast furnaces, coke ovens, etc., is used on a large scale in so-called waste heat power installations by the simple means of delivering it through large pipes direct to boiler furnaces and burning it in a more or less crude manner. This paper, however, will not concern itself with either of the above two sources of gas, since its object is not to show how waste or surplus gaseous fuel can be used, but rather to demonstrate how economically and efficiently power can be produced from coal or other fuel by means of its gasification in Gas Producers.

Gas Producers are so well known in the metallurgical, engineering and chemical industries generally that it seems almost redundant to describe the process, but for the benefit of the uninitiated who nevertheless are interested in economic power production a brief description is given.

In its simplest form Producer Gas is the product of the incomplete combustion of a solid fuel such as bituminous coal by means of a current of air passed through a column thereof. The gas from this simple type of Producer consists chiefly of carbon monoxide and nitrogen. Under these conditions the loss of heat in carrying through the Producer Gas Process which is exothermal is considerable, and the efficiency is consequently low.

In practice it is customary to introduce steam with the air blast, which reacts directly and indirectly with the carbon of the fuel, yielding hydrogen, carbon monoxide and carbon dioxide in different relative proportions according to the steam conditions obtaining. These reactions are endothermal and consequently absorb part of the heat resulting from the exothermal process above mentioned, reducing the working temperature and consequently the overall heat losses. The introduction of a proportion of steam enables the generation of a gas having considerably greater calorific value per unit volume than that from the steamless process.

The gas yielded by the Producer Process contains the following constituents, the percentages varying according to the operating conditions adopted and the type of Producer, viz. :—

Carbon monoxide.
Hydrogen.
Methane.
Carbon dioxide.
Nitrogen.

The gas as it leaves the Producer carries with it large quantities of tarry matter and dust, and must be passed through cooling and cleaning apparatus if required for the efficient generation of power.

Although it is unnecessary to go into a detailed description of the ordinary Gas Producer, it would appear desirable to explain what is meant by a Gas Producer Plant as a whole when applied to power production.

Gas Producer Plants which can be used for this purpose fall into two classes :—

A. Plants in which no by-products are recovered.
B. Plants in which the recovery of oil, tar, ammonia, etc., from the fuel is provided for.

These two classes of plant may be either completely non-mechanical with the exception of small running machines such as pumps and blowers, or they may be entirely mechanical, involving mechanical feeding of fuel to the Producers and discharging of

the ash, mechanical dust separators, mechanical gas washers and coolers, mechanical tar extractors, etc., etc.

It will be clear that many practical working types of Producer Gas Plant for power purposes can be designed, but efficient designs are strictly limited in number. A first desideratum is that the gas must be properly cleaned, and this applies to both types A and B. Moreover, so far as the gas cleaning itself is concerned the methods to be adopted are practically the same for both types. A plant for producing clean gas suitable for power purposes (without recovering by-products) is shown in Fig. 1.

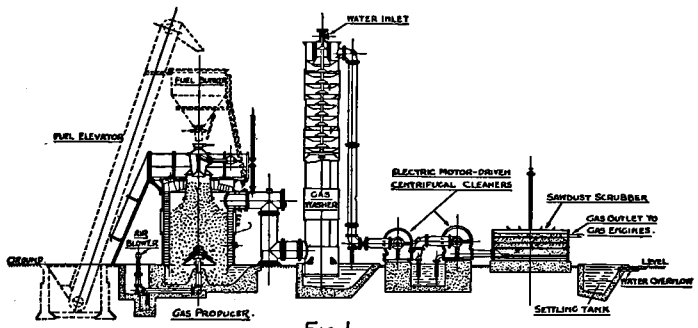


Fig. 1.

DIAGRAMMATIC ELEVATION OF NON-RECOVERY PRODUCER GAS PLANT FOR POWER PURPOSES

In this class of plant the gas from the Producers passes into the gas washer and thence to two centrifugal cleaning fans, where it is further washed, reducing the tar content to about 0.25 to 0.5 grammes per cubic metre. When utilised in internal combustion prime-movers it is passed from the cleaners through one or more dry scrubbers, charged with sawdust or equivalent material in which the last traces of tar are removed. For other purposes, however, the gas need not be cleaned so thoroughly, and the dry scrubber is then omitted.

This type of plant only comes into the sphere of practical politics for non-bituminous fuels such as anthracite, coke breeze, etc., or for bituminous fuels in those locations where they are cheap, or where there is insufficient market for by-products or where the necessary materials for their recovery are too costly. For example, a plant similar to Fig. 1 would be applicable for utilisation of bituminous fuels in the less industrially developed countries for locations situated near a colliery but far away from the coast.

It is nevertheless a fact that the fuels which are most widely available in the great majority of power consuming districts in the world are bituminous fuels, and it is clear that the proper use of such fuels is to obtain therefrom not merely a gas but also their valuable by-products—oils, tar and ammonia. Therefore, those plants which recover by-products will be more fully described together with their history, and here it should be pointed out that although the author has been associated with the development of the plants illustrated, and is consequently able to speak with full knowledge of their efficiencies and operation, they are introduced merely to enable the historical development to be clearly shown.

Following the early work of Young and Beilby, the By-product Gas Producer Plant was first brought out on a large industrial scale many years ago by the late Dr. Ludwig Mond, F.R.S., and the general design of this plant (illustrated in Fig. 2), as well as the later designs of Duff and Crossley, which were built more or less extensively in the early years of this century, were all founded upon the basic principle of fuel gasification by means of a superheated mixture of air and steam—the latter being much in excess of the quantity required for the actual gas-making process, but introduced in order to maintain the Producer in a cool condition and to protect the formed ammonia from decomposition.

Referring to Fig. 2, the Gas Producer A was blown by the superheated steam-air mixture, the steam reaching the very high quantity of 2½ lbs. per lb. of fuel gasified. The generated gas passed through the tubular Superheater B, in which the air-steam blast was superheated on its way to the Producer. The gas then passed through the Mechanical Washer C fitted with revolving dashers to the Ammonia Absorption Tower D for the recovery of the ammonia. This tower consisted of a lead shell supported by a timber framework and packed with earthenware ring tiles. The gas was here brought into contact with a solution (about 30 per cent.) of sulphate of ammonia containing a small quantity of free sulphuric acid to absorb the ammonia from the gas, which was subjected to further cooling and cleaning in Towers E and G. The hot water leaving Tower E was circulated through the Air Saturating Tower F where the bulk of its heat was given up to saturate the air blast. It will thus be seen that the Towers E and F constituted a closed steam recovery circuit.

Passing from G, the gas was now ready for firing furnaces, but for power purposes (internal combustion engines only were at that

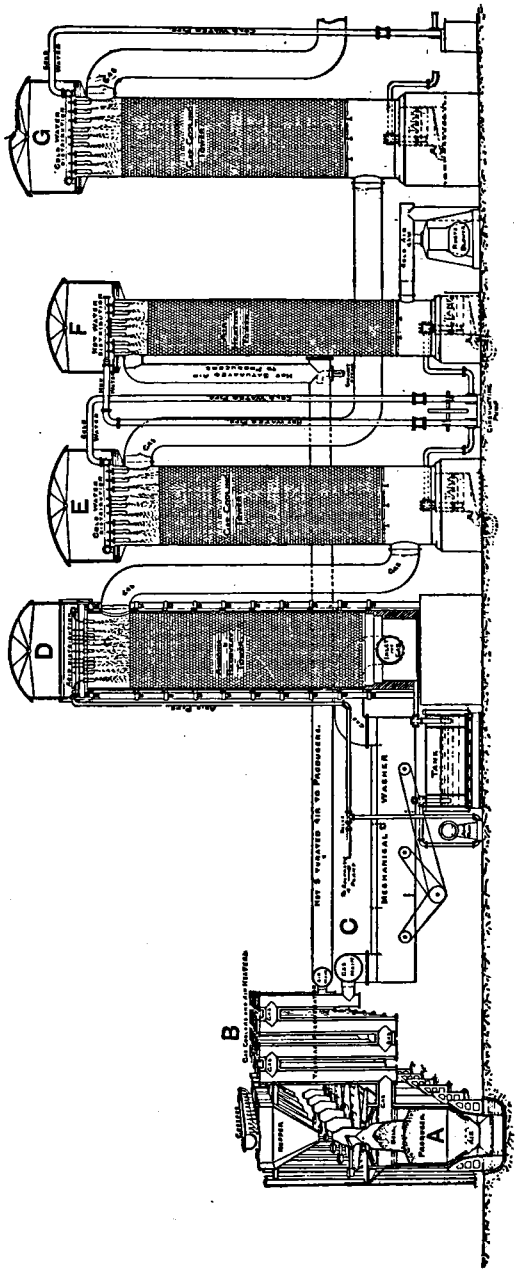


Fig. 2.

period profitably usable) it had to be further cleaned in centrifugal cleaning fans and sawdust scrubbers as illustrated in Fig. 1.

For the past ten years this by-product recovery process has been largely carried on in improved plants designed according to the Lymn patents and illustrated in Fig. 3.

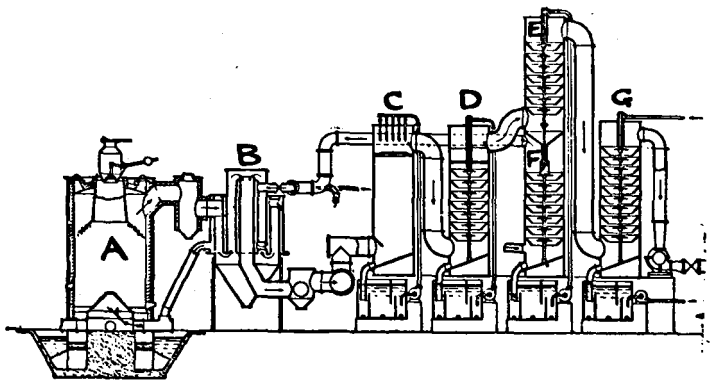


Fig. 3.

As a process, this is more or less similar to that of Mond, the main difference being in the design of cooling and cleaning apparatus as well as the steam and ammonia recovery systems from which all moving parts (except pumps) are eliminated. It will be seen from the illustration that this part of the plant comprises five static vertical cylindrical vessels, the first of which is empty, and here the gas is brought into contact with water sprayed through nozzles varying in number according to the diameter of washer.

The other vessels marked D, E, F, G are all of the same design, and consist each of a cylindrical steel vessel having a stationary shaft located centrally extending the full height. At suitable intervals on this shaft are fixed flat or shallow cones or distributors, and attached to the casing are corresponding inverted, truncated cones which serve as collectors. The design of these internal parts is varied to suit the requirements of the several operations.

It will be noticed that vessels E and F are superimposed the one on the other, thus economising in ground space and avoiding unnecessary loss of heat, as well as cutting out one pump. Attention is drawn to the fact that in this design of plants, steel apparatus is used for ammonium sulphate recovery.

In this plant the fuel depth was somewhat greater than in previous plants, and this fact, coupled with the points above mentioned, gave on the average better results as to products and by-products than those of the older Mond plants, while the process operation was decidedly simpler.

A further step was the modification of both of the above types of plants, going, say, half-way to the final modern design shown in Fig. 4. It would, however, be redundant to go into further details of this intermediate stage in the developments, since the final modern process and plant will be immediately considered.

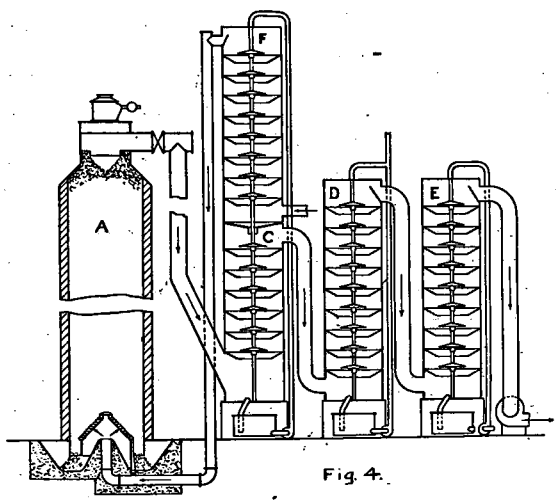


Fig. 4.

In order to show the extent of the latest developments it will perhaps be best to give at once a tabular comparison of the results of plants as they were operated up to, say, 10 years ago as compared with the present day, the improved results being the consequence of several years of technical experiment by the Power Gas Corporation, Ltd.—and involving the combination of the low temperature production of by-products (oil, pitch and ammonia) with the gasification process in one operation.

Practical results (long period averages) when using a Durham fuel of following composition :—

Moisture	5·7	per cent.
Ash	8·0	do.
Volatile matter	31·2	do.
Total Carbon	71·1	do.
Fixed Carbon	56·6	do.
Hydrogen	5·0	do.
Nitrogen	1·47	do.

on dry fuel.

Net calorific value B.Th.U.'s. per lb. 12,150

		Old Process.	*New Low Temp. Process.*
Gas Analysis.	CO_2	16·0 per cent.	8·3 per cent.
	CO	11·0 do.	21·0 do.
	H	25·0 do.	20·5 do.
	CH_4	2·5 do.	4·9 do.
	N	45·5 do.	45·3 do.
B.Th.Us. net cub. ft.		134	178
Gas Efficiency $\frac{\text{cal. val. of gas}}{\text{cal. val. of coal}}$		68 per cent.	80 per cent.
Average gas yield (cubic feet) per ton of dry fuel gasified		138,000	122,000
Average ammonium sulphate yield per ton of dry fuel gasified		95 lbs.	90 lbs.
Average yield of dry tar per ton of dry fuel gasified		Poor quality, Value negligible.	21 galls.
Steam into Producer per lb. of dry fuel		2½ lbs.	1 lb.

The tar produced by the new process can be readily dehydrated by mechanical treatment to less than 2 per cent. moisture content and on fractionisation yields high percentages of valuable oils and pitch. On the other hand, the tar produced in the old by-product recovery plants was most difficult to handle and of very low value.

The high yields of ammonium sulphate associated with the old plant are still obtained as formerly.

One important characteristic which distinguishes the operation of this new process is that there is little or no dust or soot produced. The much smaller volume of steam entering the Producer and the consequently lower temperature and volume of the crude gas leaving the Producer account for this circumstance.

As a direct consequence the cleaning and cooling plant is considerably reduced, as will be seen on reference to Fig. 4, which is lettered similarly to Figs. 2 and 3, while the superheater (B in Figs. 2 and 3) has been entirely eliminated, thus causing a large reduction in capital outlay for the plant and in the ground space occupied.

The distinctive feature of the latest process is to be found in the combination of the By-Product Recovery Producer Gas process with Low Temperature distillation in one and the same generator and in one operation.

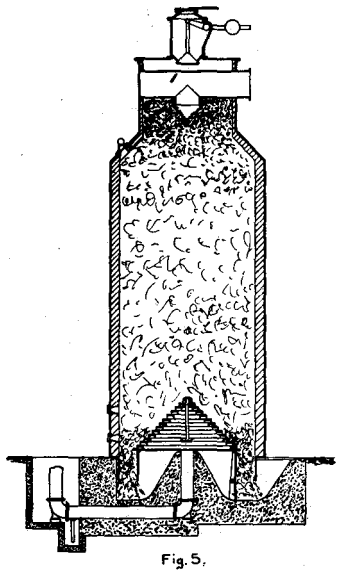


Fig. 5.

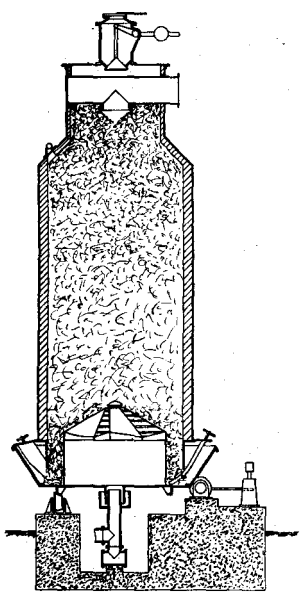


Fig. 6.

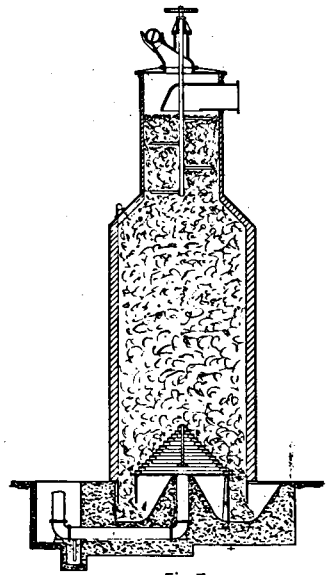


Fig. 7.

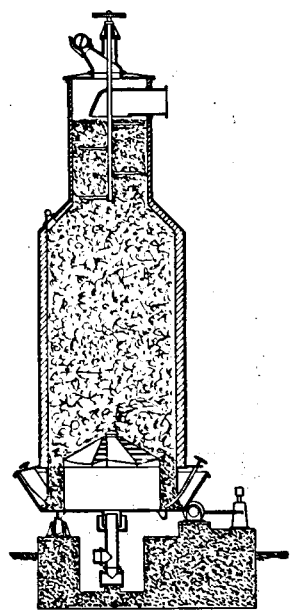


Fig. 8.

It should be explained here that the plant shown in Fig. 4 may embody producers of any of the types shown diagrammatically in Figs. 5, 6, 7 or 8. Any of these can be linked up with a gas purification plant in order that the gas may be made suitable for use in power plants, but it is a first condition of power gas production that the gas must be of good quality and of constant composition, towards which end the deep fuel bed is adopted.

Fig. 5 shows a simple static producer which is in place where a non-caking coal, coupled with reasonably cheap labour, is available.

Fig. 6 shows a producer fitted with mechanical ash removers for use where non-caking coals are available, but labour expensive.

Fig. 7 shows a producer fitted with static grate and mechanical anti-caking device. This type is called for where cheap labour is available, but where the coal is of a caking nature.

Fig. 8 shows a producer with both mechanical ash removers and mechanical anti-caking device, which combination is required where caking coals only are available and where labour is expensive.

Any of these four types may be fitted with mechanical coal feeding.

We now come to the main point of this paper, which is the application of the gas produced in apparatus as described above to the generation of power on a large scale, and in considering this problem we have to regard it in the light of several combinations.

1. Low temperature gas producer plant combined with reciprocating gas engines.
2. Low temperature gas producer plant combined with steam boilers and steam turbines (or reciprocating engines).

   The latter has to be divided up into two sub-sections, 2*a* representing those cases where steam is to be used entirely for power purposes and to its fullest extent; 2*b* those cases where steam is required for some process purpose simultaneously with the power.
3. Low temperature gas producer plant plus internal combustion turbines, which are only now becoming available as a commercial proposition.

Combination No. 1 really requires no description. It is old, it is well known, and has been in operation on a considerable scale in stations of sizes up to 10,000 KW. or more in numerous places. The reciprocating gas engine, however, although a mechanical construction of high merit, is nevertheless, when compared with the turbine, a cumbersome machine which does not appeal to many large power station engineers, and for power production in bulk would have to be installed in far too many units.

These engines are made in sizes up to 3,500 KW. in one machine, but for a station of 50,000 KW. it would be necessary for security in operation to install 20 units, allowing one spare to every four machines. The capital outlay for gas engine plant is extremely high, which fact is emphasised acutely when ample spares are included.

Combination No. 2: Both sub-sections under 2 above mentioned represent a combination to which careful attention is directed. Until the last few years it has always been considered uneconomical in most industrial regions to utilise a gas specially manufactured from coal or other fuel for firing boilers of steam plant, but the great advances and economies which are shown in the gas plant developments above described in combination with modern specially designed gas fired boilers have resulted in a combined thermal efficiency which is little short of those obtainable in the best direct coal-fired steam stations. Hand-in-hand with the advances in the Producer Gas plant great improvements have been achieved in the matter of gas-fired boilers specially constructed for efficient gas firing. Gas-fired boilers of all sizes up to 36,000 lbs. steam, from and at 212°F. per hour in a single drum, can now be obtained with a guaranteed 85 per cent. efficiency, and even 90 per cent. with air preheated, while the gas plant has an efficiency of 80 per cent. when by-product recovery is included, and 90 per cent. without by-product recovery. In the by-product recovery case, it should be pointed out that 10 per cent. of the carbon is in the form of recovered tar and oils, the mentioned 80 per cent. being the gas thermal efficiency.

A simple calculation shows that in the by-product recovery case a 72 per cent. overall thermal efficiency for the combination Gas Producer plant plus gas-fired boiler plant is practicable, while in the non-recovery case an 81 per cent. efficiency is possible.

I will not dwell further upon the non-by-product recovery plant for boiler firing because in most countries it is not practical politics

to use Gas Producers for boiler firing and at the same time to throw the valuable by-products away.

The boilers available for such highly efficient gas firing are so far mainly of the multi-firetube type, of which the best known is perhaps the Spencer-Bonecourt " Kirke " Patent Boiler illustrated in Fig. 9.

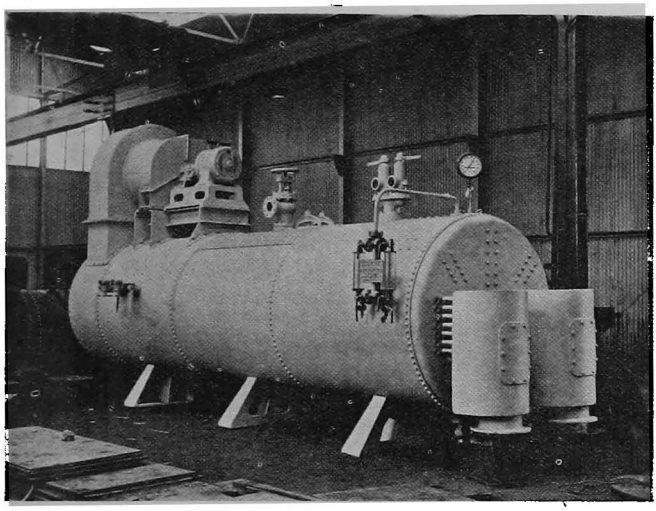


Fig. 9.

Points specially referred to by the patentees are that the gas is burnt in individual tubes by a special multiple-jet burner arrangement of high combustion efficiency. The absence of large combustion chambers cuts out all potential risk of explosion, and, furthermore, there is no brickwork of any sort required by these boilers, consequently no leaky settings, as each boiler is an entirely self-contained unit standing on its own cradle. Induced draft equipment is provided and high gas velocities are worked to, with corresponding high evaporations per unit of heating surface.

It is claimed that the gas is burnt with practically theoretical air volumes, the spent combustion gases leaving the boiler tubes at only a few degrees higher temperature than the steam. The superheater sections are generally similar to the boilers, and overall efficiencies of 85 per cent. gas to steam are guaranteed on these plants under ordinary running conditions, this guarantee figure

being increased to 90 per cent. if air pre-heaters are added to utilise the waste gases leaving the fans, no economisers being required under these circumstances.

The boiler system is simple in operation, extremely flexible, requires the minimum of attention, and is automatically controlled. Boilers of this type are in operation for working pressures as high as 750 lb. per square inch and superheat up to 800°F.

A further means of obtaining high gas thermal efficiencies with steam boilers not expressly designed for gas firing is to use one of the special burners for which practically perfect combustion is claimed. Such burners have given high thermal efficiencies and could be advantageously used in those cases where boilers already exist and a loss in thermal efficiency is of less importance than extra capital outlay. The use of the produced steam in efficient turbines requires no comment.

The above remarks concerning Combination No. 2a refer purely and simply to a straight power station in which the steam is utilised to its utmost limit by means of efficient condensation.

Combination No. 2b, however, is on quite another plane. It does not have reference to ordinary power stations at all, but is applicable to those many instances where private undertakings, such as paper mills or chemical works, require not only considerable power for the operation of their plant but also a large amount of steam for their processes.

It is highly economical to deliver the steam at high pressure into an extraction, pass-out or bleeder turbine discharging the whole or part of its steam at low pressure for process purposes, that part not so discharged being condensed in the ordinary way. A paper mill in this country which previously had a first-class boiler plant is now being equipped with such a combination, which is calculated

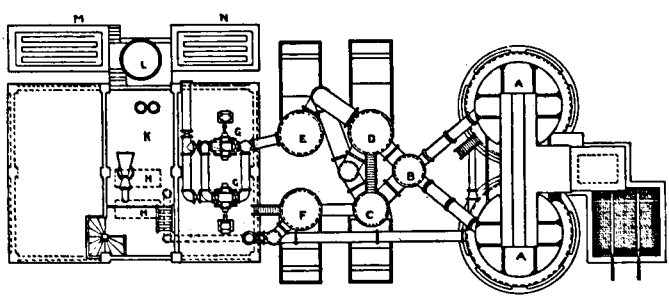


Fig. 10.

to produce cheaper power and process steam than any other concern of similar size in Great Britain. The By-Product Producer Plant utilised in this case is shown in plan in Fig. 10. It is practically the same as that shown in diagrammatic section in Fig. 4.

A, A are two Gas Producers with overhead coal storage bunkers. B is a dust catcher through which the gas passes on its way to the gas washer C. The gas passes thence through the ammonia absorber D and the final gas washer E to the two centrifugal gas cleaners G and from these it is taken direct to the boilers. F is the air saturator—it will be noticed here that F and C are separate vessels, not super-imposed one on the other. H, H are two electric-driven turbo-blowers; K is the ammonium sulphate house, where the sulphate liquor is evaporated and finally dried and bagged for sale. N is a tar sump where the tar from the whole plant is collected, and from which it is pumped to an overhead tar tank L and thence to a centrifugal tar dehydrator. The dehydrated tar is then ready for sale and is collected in the sump M.

Combination No. 3 brings into consideration a new prime mover, viz., the Internal Combustion Gas Turbine.

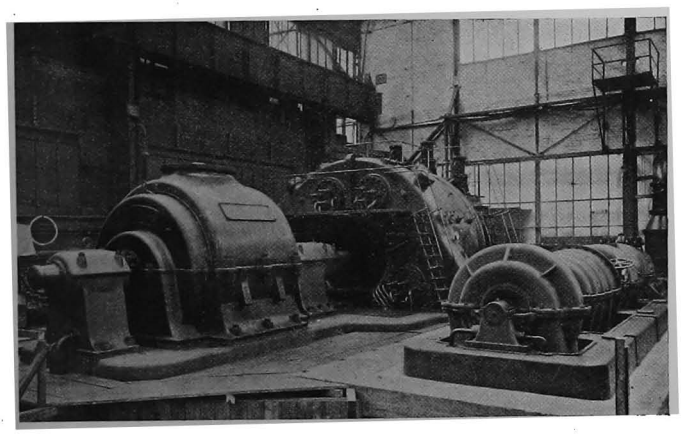


Fig. 11.

Figs. 11 and 12 show the Holzwarth Gas Turbine. As it is claimed that this turbine can now be built in large units for commercial purposes with all suitable guarantees, this paper would not be complete without some operative description of this new prime mover.

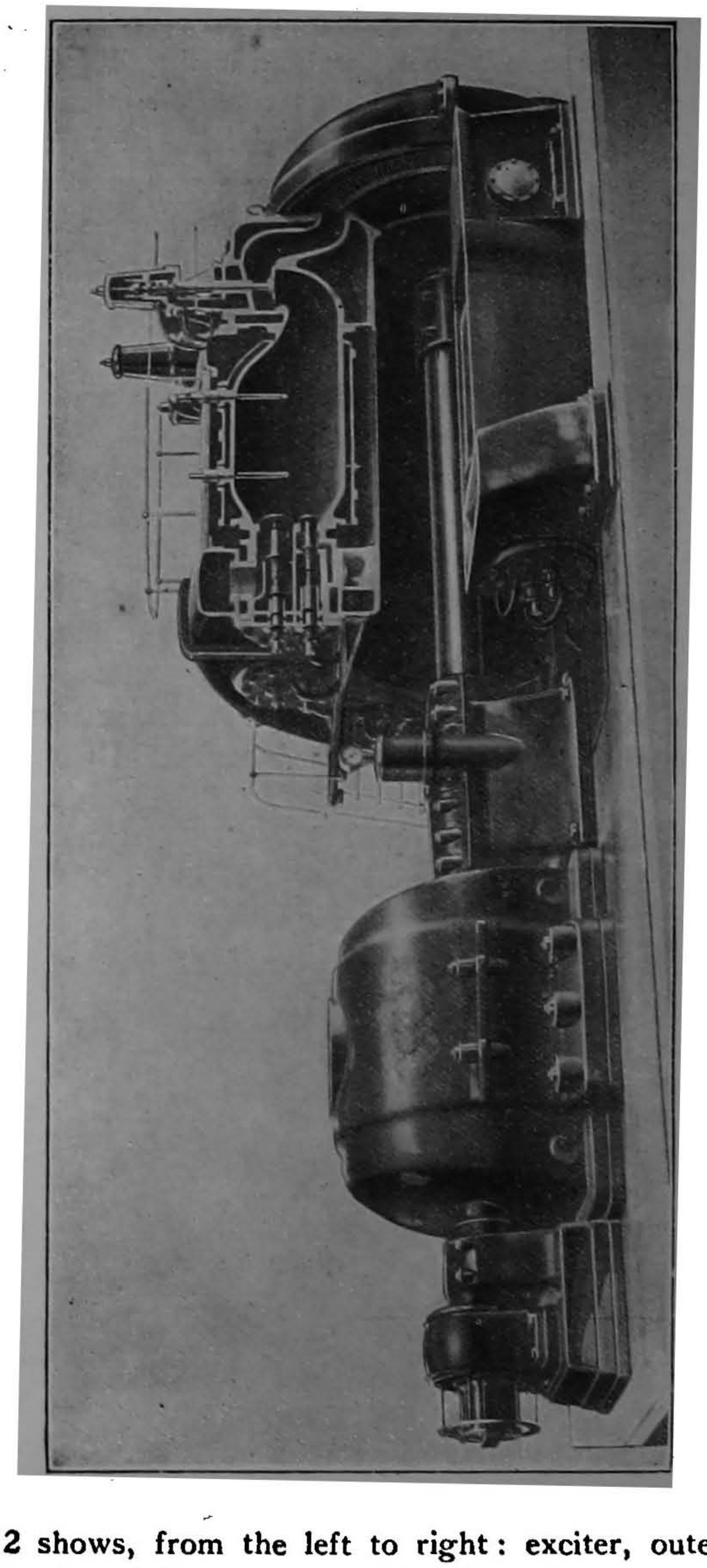


Fig. 12.

Fig. 12 shows, from the left to right: exciter, outer dynamo, double bearing, inlet manifold with inlet valves for gas and air, explosion chambers with ignition plugs, nozzle valves, nozzle segments, running wheel and cover over the exhaust gas chamber.

From the exhaust gas chamber, in which rotates the running wheel, the exhaust gases mixed with scavenging air flow through the steam superheater, the boiler, and the feed heater into the atmosphere.

Gas or liquid fuel and compressed air are forced into each explosion chamber of the series to a pressure of about 40 lbs. to 50lbs./sq. in. above atm. at a temperature of about 200°F. While this mixture is still in eddying motion it is ignited by means of high tension ignition plugs.

The combustion of the mixture takes place on the pure explosion principle, the whole mixture being burnt before the nozzle valve is opened. When combustion is complete, a pressure of about 250 lbs./sq. in. above atm. is reached at a temperature of about 2,500°F. At the moment of maximum pressure the nozzle valve is rapidly opened to its full extent by means of the initial explosion pressures, and the expansion period begins. The gases expand through de-Laval nozzles to the exhaust pressure of 15 lbs./sq. in. abs. and attain at the end of the nozzles a temperature of about 1,250°F. They immediately impinge upon the vanes of a two blade running wheel and leave the gas turbine by the exhaust pipe connecting with the waste-heat boiler plant.

This explosion and expansion cycle and impulse to the turbine wheel only last about two-tenths of a second. As soon as expansion is finished, air is scavenged through the explosion chamber, nozzle valve and nozzles, whereby the remainder of the explosion gases are swept out of the chamber and the ducts leading to the nozzles, all of which are thereby simultaneously cooled.

The explosion chambers are operated in rythmical succession, so that the resultant gases impinge consecutively upon the running wheel.

As a matter of fact—although the materials of the turbine nozzles are momentarily subjected to high temperatures—the average temperature is only 750°F. or 400°C., *i.e.*, no higher than that of the superheated steam used in modern steam turbine practice. Therefore, contrary to general ideas on this subject, the Holzwarth Gas Turbine has no more arduous conditions to withstand than many modern steam turbines, so that all fears in regard to durability of material become groundless.

ECONOMICS OF THE SEVERAL COMBINATIONS.

The value of Producer Gas as a means of power generation must be established not merely by comparing one method with another,

viz., 1, 2a, 2b and 3 above referred to, but also by comparing the best showing of those methods with that of other systems, such as :—

4. Straight coal-firing by the most modern means, and
5. Coal dust firing.

Therefore, in order to give a clear presentment, tabular comparisons of costs, etc., are given in Tables A, B and C.

Table A shows the three combinations above described under 1 2a and 3, in which Low Temperature Gas Producer Plant forms part, viz. :—

1. Low temperature gas producer plant and reciprocating gas engine generators.
2a. Low temperature gas producer plant, gas-fired boilers and steam turbo-generators.
3. Low temperature gas producer plant and gas turbo-generators.

These figures are on all fours as regards size of plant, load factor, etc., and are strictly comparable.

It will be noticed that under the conditions stated, and with coal @ 20s. per ton, the cheapest power on 70 per cent. load factor will be obtained from the gas turbo combination @ 0·172d. and a coal consumption of 1·67 lbs. per kilowatt-hour, with the gas-fired steam turbo set second @ 0·175d. and a coal consumption of 2·17 lbs. per kilowatt-hour, the gas engine combination being last @ 0·187d. and a coal consumption of 1·53 lbs. per kilowatt-hour.

The reader is here reminded that the value of the by-products from the coal nullifies the difference in cost of the coal per kilowatt-hour as between the gas turbo and steam turbo installations.

Simultaneously with these power costs the installation costs stand as follows : The gas turbo combination lowest @ £13·31, the gas-fired steam turbo combination second @ £14·7, and the gas engine combination third @ £18·8 per installed kilowatt.

On a 40 per cent. load factor the positions are changed, the gas-fired steam turbo combination with a 0·26d. per kilowatt-hour showing a slight advantage.

In fairness to the gas turbine development it should be pointed out that efficiencies taken in the calculations are those actually obtained, *i.e.*, while the machine is only in its initial stage of exploitation. It will, however, be clear that if the comparison were made upon the gas turbine with the steam turbine when it

also was in its initial stages of commercial exploitation, the advantage would be greatly on the side of the former. Similarly anticipating the developments which the gas turbine is likely to experience there would be a much greater advantage for the same.

A wide variation in the cost of power will, of course, be obtained according to local conditions, such as value of by-products, cost of labour and coal, etc., and though it would carry us too far to here consider the effect of these various fluctuating factors, the figures in the table are so given that adjustments can readily be made as required. The effect of the cost of coal is, however, clearly shown in Fig. 13, from which it will be seen that the decreased cost of coal has the greatest influence in combination 2a, due to the fact that the higher fuel consumption leads to a relatively greater advantage from the sale of by-products. This figure is based on a 70 per cent. load factor.

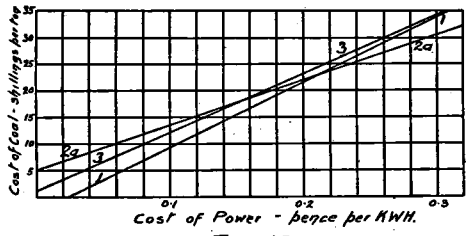


Fig. 13.

Table B. Combination 2b is especially applicable to private concerns (though equally realisable on a very large scale), and the figures for its operation are therefore given independently in this table, which it is necessary to explain at some length, as we have here a combination involving the simultaneous production of two commodities, viz., power and process steam, which are mutually interdependent, and whose respective costs of production may be envisaged as varying inversely and from nothing up to a maximum. The operation of this combination is based on the use of " pass out " Turbines, the steam passed out being variable from 0 per cent. up to 100 per cent. Since the steam consumption of a purely condensing turbine has been taken for these calculations at 13·2 lbs. per kilowatt-hour, and for a purely exhausting turbine at 30·9 lbs. per kilowatt-hour, it is obvious that the amount of power generated varies within wide limits according to the percentage of steam passed out. It is impossible within the scope of this paper to study the very extensive range of possibilities under these

conditions, and therefore four specific cases only have been calculated :—

I. For a gas plant gasifying 120 tons of coal per 24 hours and the steam turbine passing out the whole of the steam.

II. For the same size gas plant, but passing out only 30,000 lbs. steam per hour.

III. For a gas plant gasifying 60 tons of coal per 24 hours and the steam turbine passing out of the whole of the steam.

IV. For the same size gas plant, but passing out only 15,000 lbs. steam per hour.

It should be noted here that in all cases about 16 per cent. of the steam must be " passed out " to provide the requirements of the Gas Producer Plant.

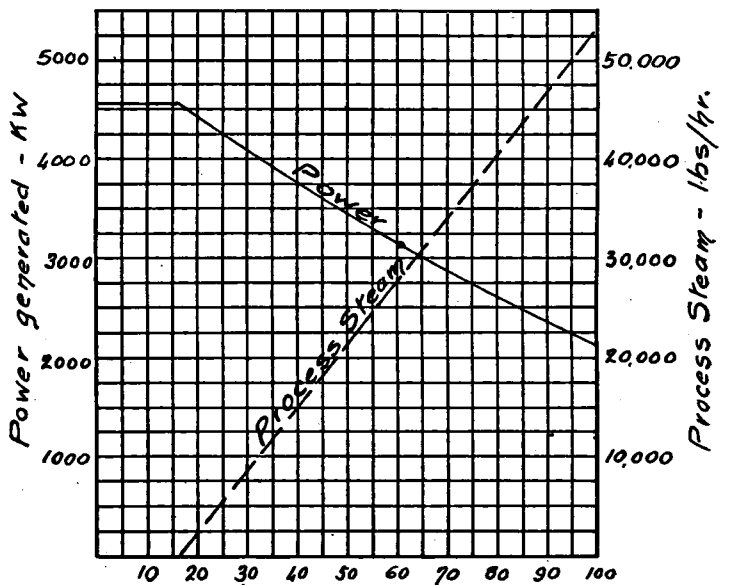


Fig. 14.

The possible ranges both with regard to power and the supply of process steam are clearly shown for the larger of the two plants under consideration in Fig. 14; for the smaller plant these figures may be halved.

At the end of Table B the unit costs of both power and process steam are scheduled. As stated above, these costs are mutually interdependent, and in order to determine the cost of one it is necessary to allocate an arbitrary value to the other. This has been done in the first line of these costs where steam has been valued at 1/9 per ton. In the second and third lines have been given the extreme costs under which in one case power is the main object, and steam is assumed to be produced gratis, while in the other the process steam is the main object, and power is assumed to be provided gratis. The full range of costs for all four cases is clearly set out in Fig. 15.

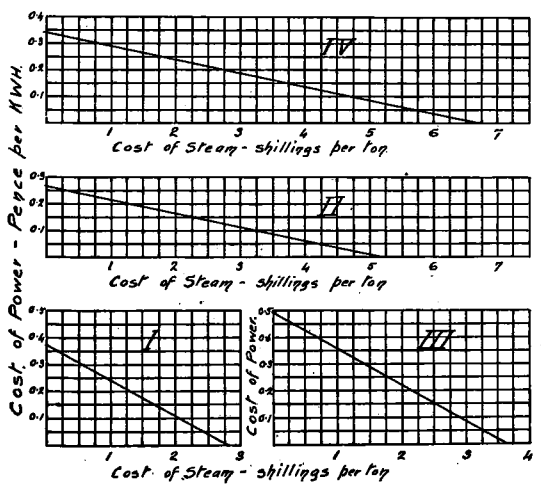


Fig. 15

Table B. is also arranged in such a way that modifications to suit local conditions can easily be made. It will be seen that in the cases 1 and 2 fuel at about 6/- to 7/- per ton, other conditions remaining unchanged, would enable both power and process steam to be provided without cost, the sale of by-products entirely meeting all expenses.

Table C. A further comparison is here given showing combination 2a above referred to (viz., producer gas plant, boiler and steam turbine) in comparison with a straight modern coal-fired steam turbo station, 4, and with the same operating on powdered fuel, 5.

For the first two cases, fuel has been taken at 20/- per ton as in Tables A and B, but since it is claimed that inferior grades of coal can be utilised in powdered fuel equipment a price of 17/- per ton, together with a lower calorific value, has been taken here. Fig. 16 has been prepared to show how the cost of power generation varies with the cost of coal (for 70 per cent. load factor), and it will be seen here that the gas producer plant–boiler–steam turbo combination shows a marked advantage over either of the two types of installation at both 40 per cent. and 70 per cent. load,

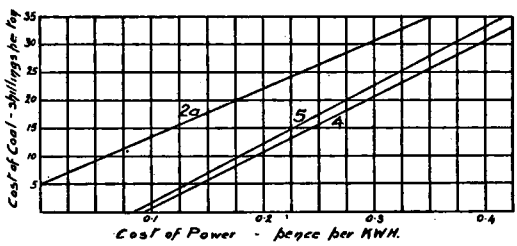


Fig. 16.

with a cost per kilowatt-hour @ 70 per cent. load factor of 0·175d. against 0·247d. per kilowatt-hour on the powdered fuel installation and 0·293d. on the water-tube boiler mechanical stoker installation.

As regards capital costs, here the powdered fuel installation stands first @ £12·3, with the mechanical stoker installation second @ £12·45, and the gas producer–steam turbine installation last @ £14·7 per installed kilowatt.

In conclusion the author desires to record his keen appreciation of the valuable assistance so willingly given by Mr. H. C. Rickwood in the preparation of this paper, and in making the many calculations connected therewith.

TABLE A.

COMPARISON OF CAPITAL AND OPERATING COST OF DIFFERENT METHODS OF POWER GENERATION USING GAS PRODUCER PLANT.

The installation comprises :—

1. Low temperature gas producer plant and reciprocating gas engine generators.

2a. Low temperature gas producer plant, gas-fired boilers and steam turbo-generators.

3. Low temperature gas producer plant and gas turbo-generators.

GENERAL CONDITIONS.

Alternatively (*a*) 40% load, and (*b*) 70% load for 24 hours daily and 365 days per annum.

Fuel used—bituminous coal having a calorific value of 11,400 B.Th.U. net per lb. dry fuel, and costing 20/- per ton containing 5% moisture.

Overall heat consumption of combined gas producer plant and gas engine-generator 16,625 B.Th.U. per kWh.

Overall heat consumption of combined gas producer plant and steam turbo-generator 23,500 B.Th.U. per kWh.

Overall heat consumption of combined gas producer plant and gas-turbo-generator 18,000 B.Th.U. per kWh.

BY-PRODUCTS.

Sulphate of ammonia 85 lbs. per ton of dry fuel. Value £14 per ton.
Dry tar 21 gallons per ton of dry fuel. Value 5d. per gallon.
Sulphuric acid (140°Tw) £3 per ton.

LABOUR.

Unskilled 1/- per hour—8 hour shifts.
Skilled 1/3 per hour. do.
Charge hands, £5 per week.

N.B.—It will be observed that the debit due to depreciation under combination 3 (Gas Turbine, etc.) is high when compared with the corresponding figure under I. This discrepancy is due to the fact that the latter is based on established English practice, while the former is based on German custom, no data being yet available from regular industrial operations. There is every reason, however, to believe that the Gas Turbine will in this respect prove equal to the steam turbine when working on highly superheated steam.

ANNUAL OPERATING COSTS.

	1.		2A.		3.	
	40 per cent Load.	70 per cent Load.	40 per cent Load.	70 per cent Load.	40 per cent Load.	70 per cent Load.
Installed Capacity	24,500 KW.	24,500 KW.	25,000 KW.	25,000 KW.	25,000 KW.	25,000 KW.
Full Load	20,000 KW.	20,000 KW.	20,000 KW.	20,000 KW.	20,000 KW.	20,000 KW.
Capital Cost—Plant	£358,000	£358,000	£319,000	£319,000	£281,880	£281,880
Do. Foundations, etc.	£102,800	£102,800	£48,150	£48,150	£50,600	£50,600
Total Capital Cost	£460,800	£460,800	£367,150	£367,150	£332,480	£332,480
Cost per Installed KW. Capacity	£18·8	£18·8	£14·7	£14·7	£13·31	£13·31
Annual Debit.	£	£	£	£	£	£
Fuel	47,950	84,000	67,850	118,700	51,950	91,000
Labour	17,600	18,930	15,965	15,965	17,620	17,620
Management	1,000	1,000	1,000	1,000	1,000	1,000
Repairs, Stores, Lighting, etc.	13,504	18,525	12,030	15,975	10,050	12,976
Sulphuric Acid	4,950	8,620	6,990	12,200	5,360	9,340
Depreciation—Plant	35,800	35,800	31,900	31,900	36,400	36,400
Do. Foundations, Buildings, etc.	6,168	6,168	2,889	2,889	3,024	3,024
	126,972	173,043	138,624	198,629	125,404	171,360
Annual Credit.						
Sulphate of Ammonia	24,290	42,420	34,300	59,800	26,300	45,920
Dry Tar	19,950	35,000	28,200	49,400	21,600	37,900
	44,240	77,420	62,500	109,200	47,900	83,820
Total Annual Cost	£82,732	£95,223	£76,124	£89,429	£77,504	£87,540
Total KWh. Generated	70,080,000	122,640,000	70,080,000	122,640,000	70,080,000	122,640,000
Cost per KWh.	0·283d.	0·187d.	0·26d.	0·175d.	0·265d.	0·1718d.

TABLE B.

COST OF POWER GENERATION IN CONJUNCTION WITH THE SUPPLY OF PROCESS STEAM.

The installation comprises :—

2b. Low temperature gas producer plant, gas-fired boilers and "pass-out" steam turbo-generators.

GENERAL CONDITIONS.

Continuous full load 132 hours per week and 50 weeks per annum. Full load assumed for standard of comparison.
Fuel used—bituminous coal having a calorific value of 11,400 B.Th.U. net per lb. dry fuel and costing 20s. per ton containing 5% moisture.
Steam pressure 300lbs./sq. in 675°F.
Steam consumption of condensing turbine 13·2 per KWh.
Steam consumption of turbine exhausting all steam at 20 lbs. pressure 30.9 lbs. per KWh.

BY-PRODUCTS.

Sulphate of ammonia 85 lbs. per ton of dry fuel, value £14 per ton
Dry tar 21 galls. per ton of dry fuel, value 5d. per gallon.
Sulphuric acid (140°Tw) £3 per ton.

LABOUR.

Unskilled 1/- per hour—8-hour shifts.
Skilled 1/3 per hour do.
Charge Hands £5 per week.

ALTERNATIVE CONDITIONS OF OPERATION.

I. Gasifying 120 tons of coal per 24 hours generating 2120 KW. and providing 53,080 lbs. of steam per hour for process.

II. Gasifying 120 tons of coal per 24 hours generating 3120 KW. and providing 30,000 lbs. steam per hour for process.

III. Gasifying 60 tons of coal per 24 hours generating 1060 K.W. and providing 26,540 lbs. steam per hour for process.

IV. Gasifying 60 tons of coal per 24 hours generating 1560 KW. and providing 15,000 lbs. steam per hour for process.

	I.	II.	III.	IV.
Full load capacity—				
Power	2,120 KW.	3,120 KW.	1,060 KW.	1,560 KW.
Do. Steam per hour...	53,080 lbs.	30,000 lbs.	26,540 lbs.	15,000 lbs.
Capital Cost—Plant	£56,720	£62,720	£34,060	£37,060
Do. Foundations, etc.	£7,050	£8,300	£4,095	£4,720
Total Capital Cost.....	£63,770	£71,020	£38,155	£41,780
Cost per installed KW. capacity	£30·1	£22·8	£36	£26·8
Annual Debit.	£	£	£	£
Fuel	34,800	34,800	17,400	17,000
Labour	5,780	5,780	5,120	5,120
Management	750	750	750	750
Repairs, Stores, Lighting, etc.	3,067	3,354	1,718	1,857
Sulphuric Acid	3,600	3,600	1,800	1,800
Depreciation—Plant	5,672	6,272	3,406	3,706
Do. Foundations, Buildings, etc.	423	498	245	283
	54,092	55,054	30,439	30,916
Annual Credit.				
Sulphate of Ammonia	17,620	17,620	8,810	8,810
Dry Tar	14,500	14,500	7,250	7,250
	32,120	32,120	16,060	16,060
Total Annual Cost.....	£21,972	£22,934	£14,379	£14,856
	I.	II.	III.	IV.
Cost of Power, taking steam at 1/9 per ton	0·143d. per KWh.	0·177d. per KWh.	0·259d. per KWh.	0·256d. per KWh.
Cost of Power while regarding steam as a costless by-product.	0·377d. per KWh.	0·268d. per KWh.	0·492d. per KWh.	0·347d. per KWh.
Cost of steam while regarding power as a costless by-product.	2/10 per ton.	5/2 per ton.	3/8 per ton.	6/9 per ton.

TABLE C.

COMPARISON OF CAPITAL AND OPERATING COSTS OF POWER GENERATION.

The installation comprises:—

2a. By-product recovery gas producer plant, gas-fired boilers and steam turbo-generators.

4. Water tube boilers fitted with mechanical stokers and steam turbo-generators.

5. Water tube boilers with pulverised fuel equipment and steam turbo-generators.

GENERAL CONDITIONS.

Alternatively (*a*) 40% load, and (*b*) 70% load for twenty-four hours daily and 365 days per annum.

Fuel used for 2a and 4, bituminous coal having a calorific value of 11,400 B.Th.U. net per lb. dry fuel, and costing 20/- per ton containing 5 per cent. moisture; for 5, rough Midland slack having a calorific value of 10,000 B.Th.U. net and costing 17/- per ton.

Overall heat consumption of steam turbo-generators with direct coal firing 18,000 B.Th.U. per kWh.

BY-PRODUCTS.

Sulphate of ammonia 85 lbs. per ton of dry fuel, value £14 per ton.
Dry tar 21 gallons per ton of dry fuel, value 5d. per gallon.
Sulphuric acid (140°Tw.) £3 per ton.

LABOUR.

Unskilled 1/- per hour—8-hour shifts.
Skilled 1/3 per hour do.
Charge hands, £5 per week.

ANNUAL OPERATING COSTS.

	2A.		4.		5.	
	40 per cent Load.	70 per cent Load.	40 per cent Load.	70 per cent Load.	40 per cent Load.	70 per cent Load.
Installed Capacity	25,000 KW.	25,000 KW.	25,000 KW.	25,000 KW.	25,000 KW.	25,000 KW.
Full Load	20,000 KW.	20,000 KW.	20,000 KW.	20,000 KW.	20,000 KW.	20,000 KW.
Capital Cost—Plant	£319,000	£319,000	£240,000	£240,000	£236,000	£236,000
Do. Foundations, Buildings, etc.	£48,150	£48,150	£71,250	£71,250	£71,250	£71,250
Total Capital Cost	£367,150	£367,150	£311,250	£311,250	£307,250	£307,250
Cost per Installed KW. Capacity	£14·7	£14·7	£12·45	£12·45	£12·3	£12·3
Annual Debit.	£	£	£	£	£	£
Fuel	67,850	118,700	58,200	101,850	45,800	80,300
Labour	15,965	15,965	6,570	6,570	6,570	6,570
Management	1,000	1,000	500	500	500	500
Repairs, Stores, Lighting, etc.	12,030	15,975	9,300	12,450	7,670	10,800
Sulphuric Acid	6,990	12,200	—	—	—	—
Depreciation—Plant	31,900	31,900	24,000	24,000	23,600	23,600
Do. Foundations, Buildings, etc	2,889	2,889	4,275	4,275	4,275	4,275
	138,624	198,629	102,845	149,645	88,415	126,045
Annual Credit.						
Sulphate of Ammonia	34,300	59,800				
Tar Oils	28,200	49,400				
	62,500	109,000				
Total Annual Cost	£76,124	£89,429	£102,845	£149,645	£88,415	£126,045
Total KWh. Generated	70,080,000	122,640,000	70,080,000	122,640,000	70,080,000	122,640,000
Cost per KWh.	0·26d.	0·175d.	0·35d.	0·293d.	0·303d.	0·247d.

RÉSUMÉ.

Ce rapport, comme son titre l'indique, a pour but de décrire les différentes méthodes permettant d'appliquer les gazogènes à la production de la force motrice sur une grande échelle, tout en montrant le rendement économique des différents systèmes comparés l'un avec l'autre ainsi qu'avec l'installation à vapeur la plus moderne.

Ce rapport n'examine pas les petites installations de gaz pauvre telles qu'elles sont utilisées par des firmes privées pour leurs besoins propres, telles qu'installations de moteurs à gaz par aspiration ou encore les petites installations à gaz sous pression qui sont très connues dans le monde entier.

L'auteur passe en revue le développement du gazogène depuis son début jusqu'au tout dernier perfectionnement actuel, c'est-à-dire la combinaison du procédé de production du gaz avec récupération des sous produits à l'aide de la distillation à basse température, dans un même gazogène et en une seule opération.

Le sujet principal du rapport est l'application du gaz produit dans les appareils décrits, à la production de la force motrice sur une grande échelle et ce problème est considéré en utilisant différentes combinaisons.

(1) Installation de production de gaz à basse température, combinée avec des mouteurs à gaz à pistons.

(2) Installation de production de gaz à basse température, combinée avec des chaudières à vapeur et des turbines (ou des machines à vapeur à pistons). Il faut en réalité diviser le cas en deux sous sections, 2a représentant le cas où la vapeur est entièrement utilisée pour la production de la force motrice et jusqu'à sa plus grande limite; 2b le cas où la vapeur est nécessaire pour un but déterminé ainsi que pour la production de force motrice.

(3). Installation de production de gaz à basse température et utilisation de ce gaz dans des turbines à combustion interne qui sont depuis peu utilisables commercialement.

Des chiffres sont donnés montrant l'aspect économique des trois combinaisons examinées, on remarquera que dans les conditions indiquées et avec du charbon à 20/- la tonne, la force motrice la moins chère avec un facteur de charge de 70 pour cent, sera celle obtenue par la combinaison de la turbine à gaz à 0,172 pence et une consommation de charbon de 1,67 livre anglaise par KW.-heure, l'installation avec chaudière chauffé au gaz et groupe turbo-générateur arrive en second avec 0,175 pence et une consommation de charbon de 2,17 livre anglaise par KW.-heure, la combinaison avec moteur à gaz arrivant la dernière avec 0,197 pence et une consommation de charbon de 1,53 livre anglaise par KW.-heure.

Une comparaison est également donnée montrant la combinaison 2a (c.a.d. l'installation de gazogène, chaudière et turbine à vapeur) comparée avec une installation moderne de chaudières chauffées au charbon avec turbo, également la même installation fonctionnant au charbon

pulvérisé, d'où il résulte que la combinaison, installation gazogène-chaudière-turbo-generateur indique un avantage marqué sur l'une quelconque des deux autres types d'installation, à la fois avec 40 pour cent et 70 pour cent de charge. Le prix par KW.-heure à 70 pour cent de charge est de 0,175 pence alors qu'il est de 0,247 pence par KW.-heure avec l'installation au charbon pulvérisé et de 0,293 pence avec une installation de chaudières multitubulaires avec chargeurs mécaniques.

PREPARATION OF FUELS IN SWEDEN

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GENERAL REMARKS.

Most of the power consumed in Sweden is generated by water power plants, in the form of hydro-electric energy, the total consumption of electric energy per year approaching 3,000,000,000 kWh. This quantity would represent, if generated by steam, a coal consumption of about 5,000,000 tons. Steam-generated energy is produced only to a rather limited extent in auxiliary condensing steam plants, interlinked with the big distributing systems, or in individual industrial plants, the low pressure steam being used for heating purposes. The fuel needed for this production, and also for other kinds of heat generation in industry and household, is calculated to be the equivalent of 11,000,000 tons of coal. As a matter of fact, only half this quantity per year was imported as coal before the war and the rest was provided by the national resources of fuel, in the first line by wood and to some extent by domestic coal and peat. Under the war conditions, especially the blockade, the importation of coal was extremely reduced, and as a consequence the national resources had to be resorted to in a much greater proportion than before. As a result of the necessary readjustment of fuel provision and heating methods during this time the importation of coal has decreased permanently to an average of 2,500,000 tons per year since the war.

COAL AND COAL FUELS.

Coal is found in Sweden only in the southern part, in the province of Skåne, the deposits being estimated at about 300,000,000 tons. The annual output varies about 400,000 tons. The coal, being of the mesozoic type, contains generally a rather high percentage of ash, is of a poor coking quality and is not suitable for distillation. The relatively high grade qualities are used by the railways and in local steam plants. The poorer qualities are used at the pit for

firing kilns of earthenware and refractories and to some extent for direct reduction of iron ore to iron sponge.

Distillation of imported gas coal is carried out mainly in municipal plants for gas generation. Before the war about 260,000 tons of coal were distilled, producing 90,000,000 cu. m. gas and 150,000 tons of coke. The coke produced is consumed in house heating systems. Coking of coal for industrial purposes is only to be noted in one case, in the new coke and iron works at Oxelösund. Coke is also imported to some extent (about 500,000 tons a year).

The most modern gasworks are those of Stockholm, using horizontal chamber ovens of the Koppers type and being equipped with full sets of apparatus for collecting the various by-products.

Pulverized coal is used in this country only in the furnaces of the portland cement industry.

WOOD AND WOOD DISTILLATION.

As mentioned above, wood plays a very prominent part in the fuel economy of Sweden. This is easily understood, when it is realised that some 54 per cent. of the total area of the country or 240,000 sq. km. is covered by forests. The annual output is estimated at 40 to 45,000,000 cu. m. The main part of this is consumed as raw material of the lumber, wood pulp and paper industries, but rather big quantities of wood—the equivalent of about 5,000,000 tons of coal—are used for fuel purposes in several industries and for domestic heating. In the above named industries waste wood and sawdust are reclaimed and used for boiler firing. The generally adopted method of wood firing is the attachment of a separate semi-gas producer close to the grate of the boiler, a separate inlet of secondary air being provided. The working conditions of this arrangement have been thoroughly studied. It was found that a constant value of moisture content in the wood is an important factor in securing a good fuel economy. Several devices have been tried with the object of drying the wood fuel artificially by using the waste heat.

The old Swedish iron industry is based upon the use of charcoal as a reducing agent in the blast furnaces, thus securing the well-known purity and high quality of the Swedish iron and steel products.

Under normal conditions the consumption of charcoal amounts to an equivalent of about 700,000 tons of coal. The charcoal is produced partly in open-air heaps, partly by distillation in retort kilns, this method allowing recovery of by-products such as tar, methylalcohol, aceton, acetic acid and turpentine oils.

The heap method, long in use in this country, is still frequently used in large districts. The raw material, small wood from the forests or waste wood from the saw mills, is piled together in heaps

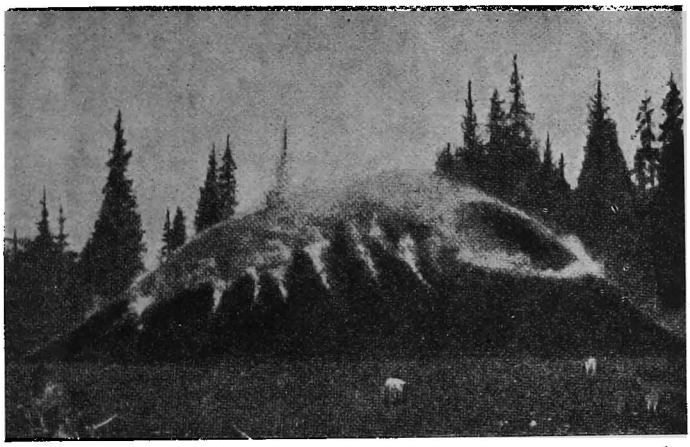


FIG. 1.

in the open air and covered with a layer of earth. After ignition the mass is left to burn through slowly in the course of about three weeks (Figs. 1 and 2).

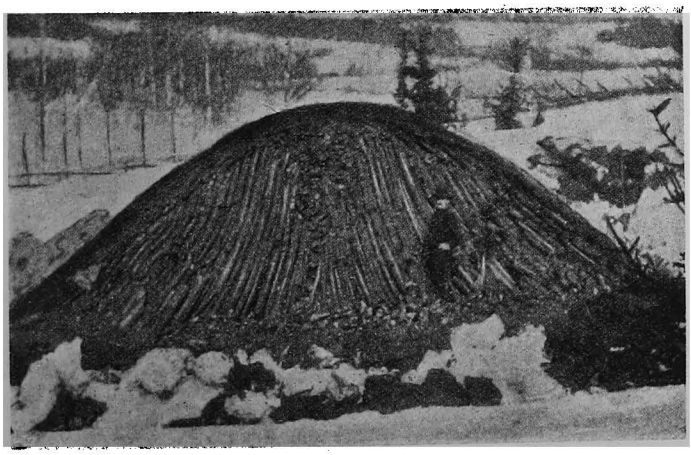


FIG. 2.

The kilns used are of different types and construction. The shaft type is shown in Fig. 3. The raw material is cut into suitable pieces, piled into the top chamber, and dried here with the aid of the waste heat from the flue gases. Through a gap, the dried wood falls into the retort heated from the furnace, and from there the coal passes through another gap to the cooling chamber down below.

Another type is illustrated by Fig. 4. The raw wood is packed into waggons and placed in a kiln heated by a system of tube elements. The distilling process completed, the waggons pass to the cooling chamber. In the most modern plants of this type the hot gases

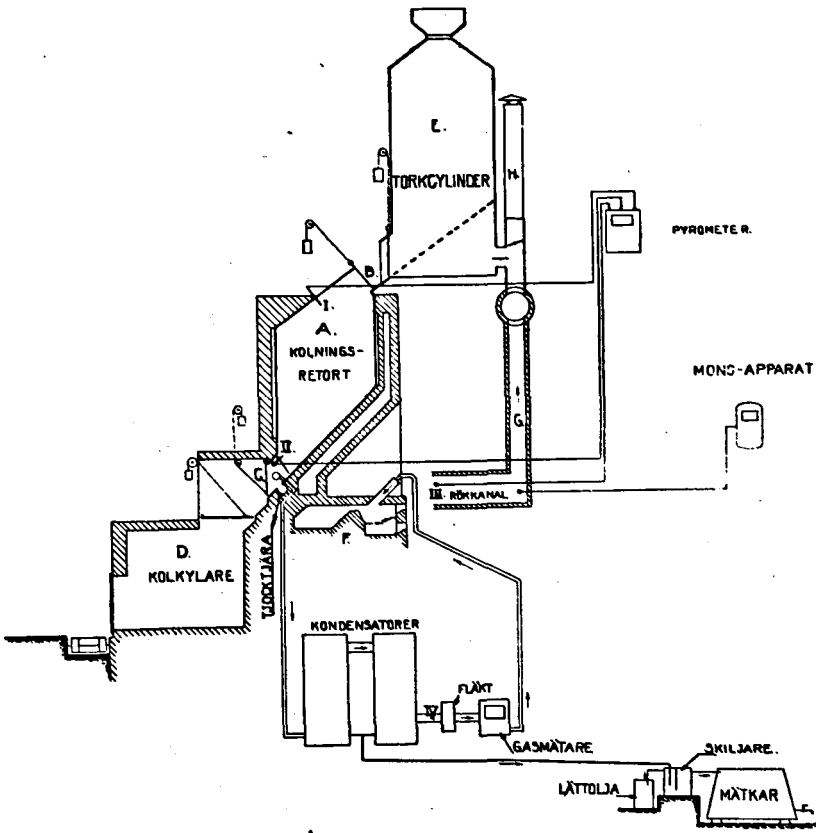
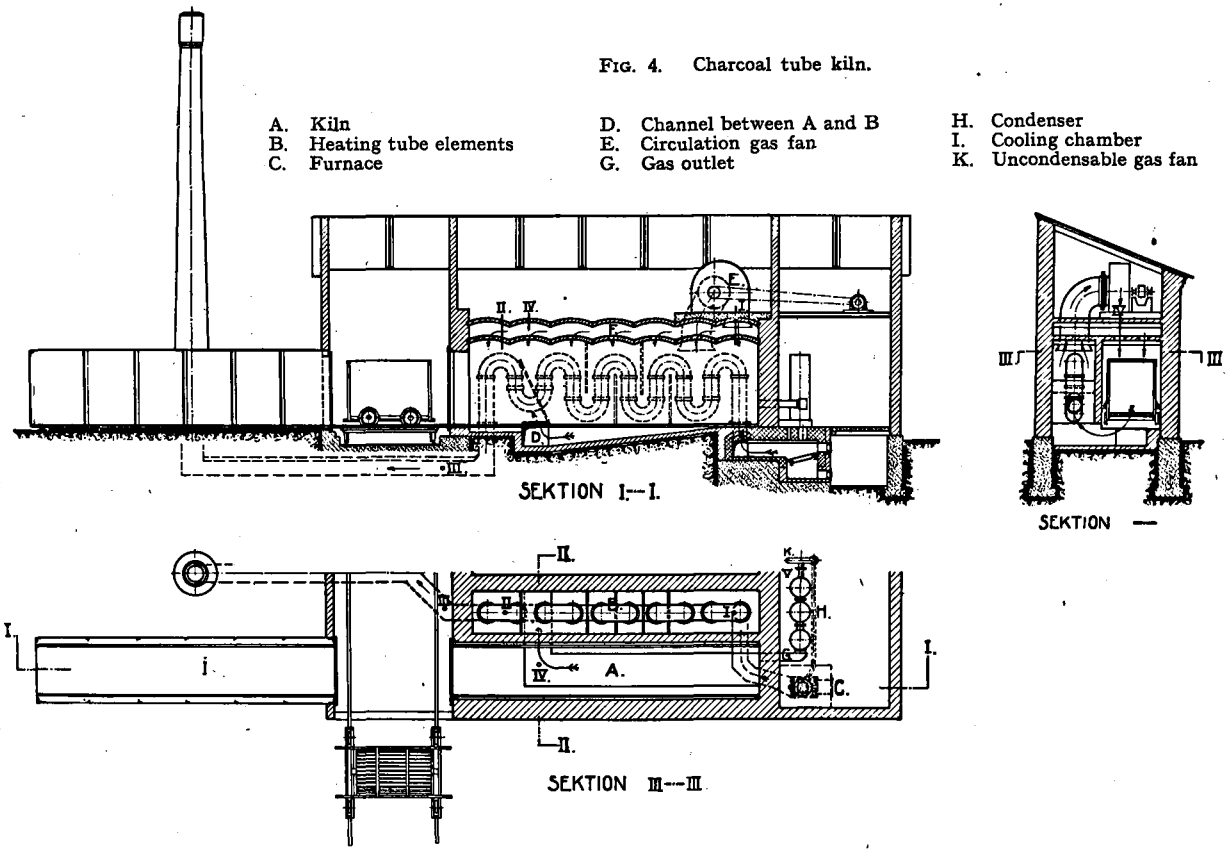


FIG. 3. Charcoal shaft kiln.

A. Retort
B. C. Gaps
D. Cooling chamber
E. Drying chamber.
F. Furnace
G. Fuel gas channel

FIG. 4. Charcoal tube kiln.

A. Kiln
B. Heating tube elements
C. Furnace
D. Channel between A and B
E. Circulation gas fan
G. Gas outlet
H. Condenser
I. Cooling chamber
K. Uncondensable gas fan



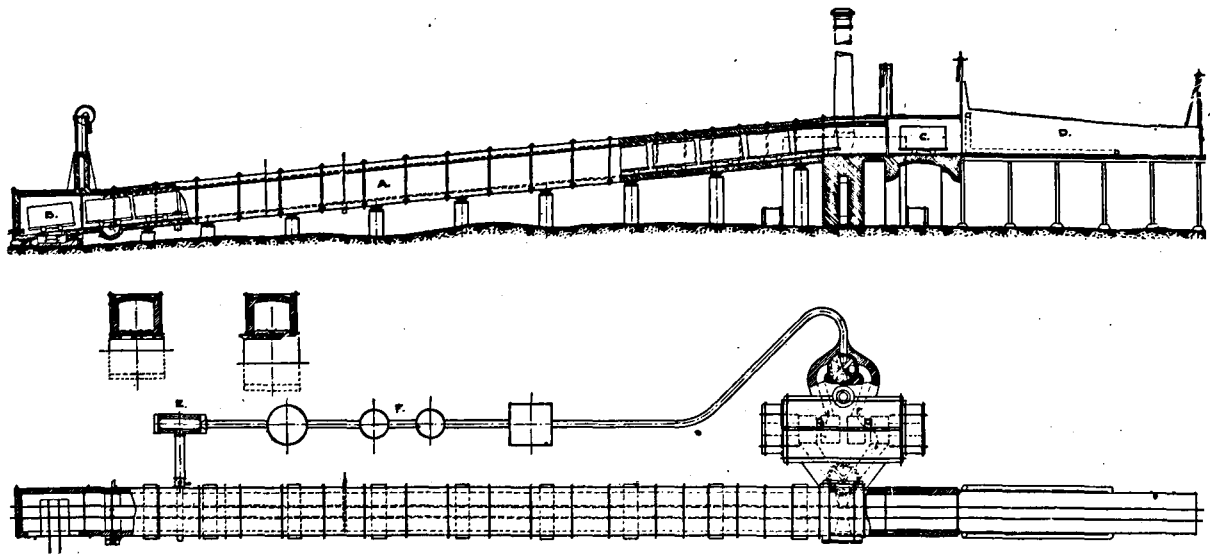


FIG. 5. Charcoal Aminoff channel kiln.

A. Kiln
B. Waggon entrance
C. Sluice
D. Cooling chamber
E. Circulation gas fan
F. Condenser
G. Regenerators

within the kiln are circulated by the aid of a fan, thus securing an improved heat transmission and a high degree of fuel economy.

A third type is the Aminoff Kiln, shown in Fig. 5. Here the waggons pass slowly through a channel oven heated by circulating gases. The material is successively heated until it enters the distilling zone. From here the cars are sluiced into the cooling part of the channel. The cars move continuously. The fuel economy of this arrangement is favourable but the output of by-products is not so complete as from the tube kiln type described in Fig. 4.

The condensing gases from the distilling process are collected in condensers. The tar is separated and the acid water refined in

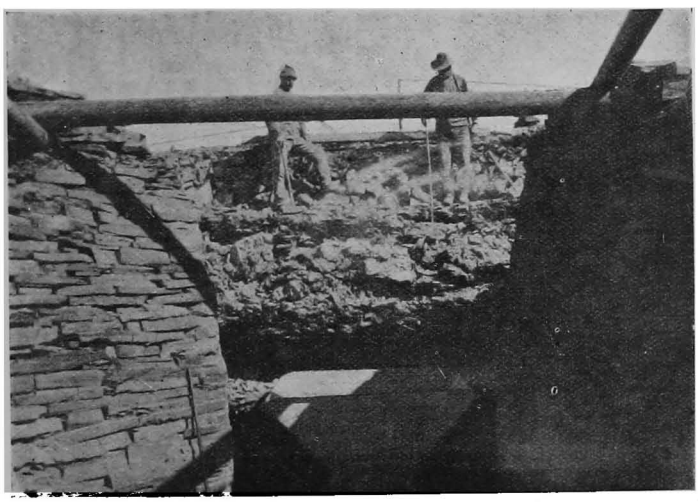


FIG. 6.

several processes. The uncondensable gases from the process—*viz.*, the surplus of the circulation—are used as a fuel in the heating furnace. The wood distilling processes have been intensively studied in Sweden, and there is no doubt that they have been brought to a high standard of perfection.

DISTILLATION OF SHALES.

Oil shales occur abundantly in the midland part of Sweden. The amount of the shale deposits has not been fully investigated, but several estimates made deal with some billions of tons. However, the oil content is low, only 5—8 per cent. in the best shales, and on

the other hand the content of sulphur is generally considerable. On account of these drawbacks the utilisation of the Swedish oil shales has proceeded very slowly.

The shales have for long been used as a fuel for lime production in open-air built-up kilns, the limestone and the shale being piled in consecutive layers one upon the other. After ignition the mass is left to burn through in the course of 6—8 weeks. Of course, no oil can be collected when this method is used (Fig. 6).

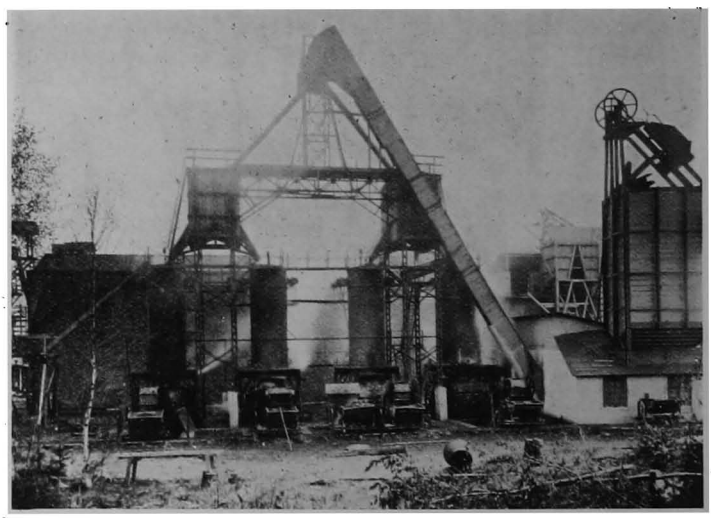
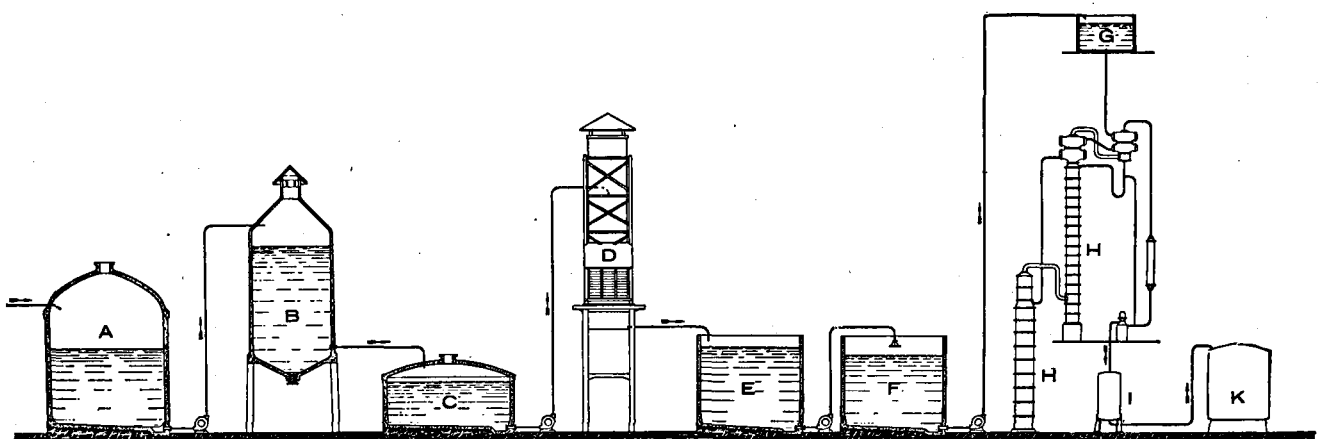


FIG. 7.

Several experiments have been made in order to design a distilling plant suitable for working the Swedish shales. However, complete economic success has not so far been achieved, the cost of construction generally being prohibitive, at least so far as concerns retort methods.

A producer method has been used for several years at the Lanna works of the Svenska Skifferverken, up to the last period of general economic depression. In Fig. 7 a general view of the plant is shown. The gas producers are about 2 metres in height. The gas produced is used as fuel in lime furnaces after passing through condensers which extract the oil. The annual output of oil has been only about 3,000 tons.

However, during the last years comprehensive researches have been carried out in order to gain a thorough knowledge of the



A. Samlingscistern för lut
B. Neutraliseringstorn
C. Klarningsbinge
D. Kyltorn
E. Jäskar
F. Förrådskar
G. Mäskbehållare
H. Kolonnapparat med kylare och eprouvett
I. Mätcistern
K. Legerbehållare

FIG. 8. Sulphite liquor alcohol plant.

A. Waste liquor tank
B. Neutralisation vessel
C. Tank for cleaning
D. Cooling tower
E. Fermentation tank
F. G. Mash tanks
H. Still
I. Meter
K. Reservoir

Swedish shales, their constitution and the best distilling conditions of the material. Investigation in the laboratory[1] have given some valuable hints as to the technical side of the problem. Quite recently a new retort design, due to Messrs. Bergh and Larsson, has been tried on a semi-industrial scale. The distillation was carried out on a low temperature basis. The experiments so far have given good technical results as to yield and quality of oil, heat economy of the process, etc., and the construction costs being apparently moderate, the economic aspect seems to be rather promising.

The shale oils produced from Swedish shale have been used unrefined as fuel oil. Oil refining plants for indigenous or imported oils have not been built in this country, except on a small experimental scale.

PEAT AND PEAT FUEL.

In Sweden no lignites are found, but peat is found in great quantities throughout the whole country. A close inspection of the peat deposits was started by the government, but is not yet completed. Estimates of the peat resources by several geological scientists vary considerably, but the probable value seems to be some billions of tons. Generally, the peat areas are split up into a multitude of relatively small parcels; this forms a serious obstacle to economic utilisation on a large scale. The quality of the peat also varies widely according to the prevailing vegetation and the degree of humidity. A great many of the bogs contain tree roots. Thus, from the point of view of peat as a fuel, the efficient peat resources are not so large.

Peat has for long been obtained from the bogs by hand cutting and air drying and used as a fuel for domestic purposes. This method is still used by the peasants in districts short of timber. However, during the years of increasing coal cost the interest in the winning of peat on an industrial scale was substantially stimulated and a series of improved peat cutting machines have been constructed and put into operation. To some extent such plants are still at work. The Anrep and Svedala machines for this purpose are well known. The annual pre-war production of peat fuel for industrial use amounted to 50 to 75,000 tons. During the war the production increased to about 400,000 tons a year, but has decreased again considerably during recent years. The amount of peat used for domestic purposes is not exactly known.

The industrial peat fuel is generally used for boiler firing in stationary plants or in railway locomotives. In the iron industry the peat

[1] B. Holmberg, I.V.A.: Handlingar No. 6 and 16.

is sometimes used in gas producers, providing heat for the Martin furnaces. A regular distillation of peat in retorts in connection with the utilisation of by-products has not yet been practised, except for experimental purposes.

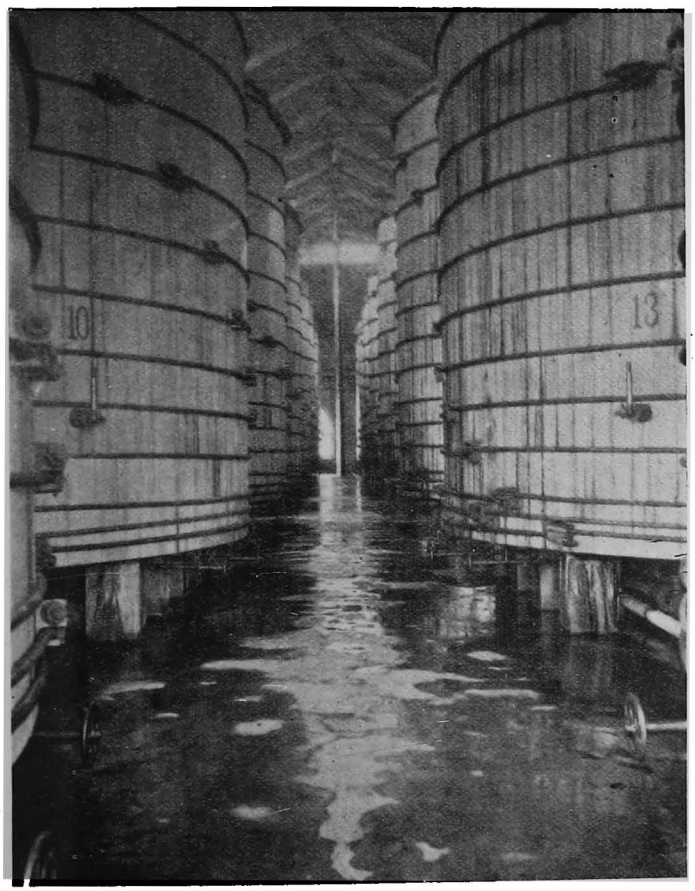


FIG. 9.

Much work has been devoted in Sweden to experiments on the production of a refined peat fuel, but without any economic success. Wet carbonising was tried amongst other methods by de Laval, and a rather big plant was built. The only practically successful proposition has been that of producing pulverised peat, which has been

used for several years as a locomotive fuel in some districts of the country. The air-dried peat is ground to an extremely fine dust and, after that, again dried artificially to a moisture content of only 12 to 15 per cent. The powder is stoked automatically, and has proved advantageous in locomotive service. Careful precautions must, of course, be taken in order to save the fire-box from burning out.

LIQUID FUELS.

Native mineral oils are not found in Sweden, the main bulk of oil fuel used being imported. On account of the steady growth of the use of automobiles the importation of petrol has substantially increased during the last years, the annual import at present amounting to some 90,000 tons. The consumption of kerosene, on the other hand, has decreased substantially on account of the electrification of the country. The total importation of petroleum oils amounts to about 220,000 tons a year.

As, during the war, especially due to the blockade, the importation of motor oils was almost completely stopped, it became necessary to resort to an indigenous motor fuel. The cellulose factories, therefore, took up the fermentation of the sulphite liquors, and installations were made with a total capacity of not less than 20,000,000 litres of 95 per cent. alcohol a year. Carburetted by some content of benzene, this motor fuel gave very good service. However, since the war the notable revolution in oil prices on the one hand, and on the other a very restrictive State policy have for the present reduced the use and production of alcohol to only a small percentage of the factory working capacity. But suitable means being under discussion for the removal of the obstacles, it is to be supposed that the national power alcohol will again secure its position in the market.

Fig. 8 gives a schematic view of a sulphite liquor alcohol plant according to the method of Aktiebolaget Ethyl, used by the Swedish factories. The Ethyl Company mentioned, holds a series of patents concerning apparatus and details of construction. The yield amounts to 50 litres 100 per cent. alcohol per ton of pulp produced. Fig. 9 shows a view from the fermentation room of one of the first plants in Sweden—the Storvik sulphite pulp mill.

After the fermentation and extraction of alcohol the sulphite liquors could deliver considerable quantities of light and heavy oils if treated in a special manner. Such oils could also be obtained from the tar. Research work along these lines is going on.

GAS FUEL.

As mentioned above, some 90,000,000 cu. m. of coal gas is produced per year in the municipal gasworks. This gas is used mainly for domestic heating purposes. Another gas fuel of some importance is produced by the blast furnaces of the iron industry. Big quantities of this gas fuel could not be recovered economically, but an annual quantity, equivalent to some 45,000 tons of coal, has been made useful, to some extent for power production in gas motors, but mainly for the heating of furnaces. In the special gas producers of the iron industry, gas is produced from coal as well as from wood and, to some extent, from peat. During war time, of course, the wood and peat-generated gas played a rather prominent part in both industrial and municipal gas production. At the Ljusne works an interesting gas plant has been successfully installed, the sawdust and waste wood being gasified in suction gas producers, supplying a gas engine driven electric power station. Experiments are also proceeding in order to adopt small suction gas producers to ordinary motor car engines.

Although of no importance for power production, acetylene gas may be mentioned as a fuel for special lighting purposes. Sweden produces per year about 30,000 tons of calcium carbide, the raw material for acetylene gas production.

RÉSUMÉ.

La Suède consomme annuellement en énergie hydro-électrique près de 3.000 millions de kW-h., équivalent à une dépense de charbon de 5.000.000 tonnes environ. De plus, il est consommé en combustibles une quantité équivalente à 11 millions de tonnes, évaluée en charbon. Sur ce chiffre on en importait avant la guerre à peu près la moitié en charbon ; le reste était fourni par les ressources de combustibles nationaux : le bois, la houille et la tourbe. La houille n'est distillée que dans les usines à gaz municipales et dans une usine métallurgique. Les houilles du pays ne se prêtent pas à la carbonisation. Le bois est distillé en grand pour la production du charbon de bois, dont l'industrie métallurgique a besoin, cette carbonisation est réalisée d'une part dans des charbonnières (ouvertes) et de l'autre dans des fours spéciaux, dont les trois types principaux sont décrits. La distillation des schistes bitumineux n'a réussi, en exploitation pratique, que dans des gazogènes, il existe un nouveau procédé à cornue sur une échelle réduite. La tourbe est employée, le plus souvent, séchée à l'air de la manière habituelle. Parmi les combustibles de tourbe transformée la fabrication de la poudre de tourbe seule a réussi en pratique. En combustibles liquides, on fabrique dans le pays, outre une certaine quantité d'huile de schiste, un certain tonnage d'alcool provenant des lessives de fabriques de sulfite. Des usines à alcool ont été établies avec une capacité totale de 20 millions de litres. Parmi les combustibles gazeu on signale le gaz de haut-fourneau qui est utilisé sur une certaine échelle.

PREPARATION AND COMBUSTION OF FUEL

C. F. HIRSHFELD

A.A.I.E.E., M.A.S.M.E., M.A.I.M.M.E., Chief of Research Department, The Detroit Edison Company.

I. COAL

By far the greater part of all the power generated in the United States is produced by burning coal. The varieties of coal available are so numerous and so diverse in their characteristics that no correct picture of the utilisation of coal in this country can be formed until the significance of this fact is appreciated. These coals vary all the way from a graphitic anthracite, which is almost too graphitic for use as a fuel, through the true anthracites, bituminous coals and lignites to the youngest peats.

It would seem that a country with so wide a range of choice would have little difficulty in obtaining that fuel best suited by nature to any particular purpose in any given locality. However, this is not the case. The country is very large and, although several of the coal fields are quite extensive when measured in terms of the areas occupied by many of the European countries, each field occupies a relatively small part of the total area of the United States. As a result, many of the coals that are best suited to the needs of a given community or industry are located at distances measured in hundreds and even thousands of miles.

It is not uncommon to find an industry using coal on which it pays more for freight than the cost of the coal at the mine, but there is a growing tendency to learn how to burn efficiently that coal which is nearest geographically, and much progress is being made in this direction. The indications are that each community will ultimately utilise, in its natural state or in a modified form, that variety of coal which is nearest to it, thus diminishing the burden now put upon the transportation systems, as well as conserving the better and more valuable varieties to a corresponding extent.

It is probably simplest to treat separately each of the major varieties of coal available, pointing out its characteristics and peculiarities and the methods available for its utilisation. For this reason such a treatment has been adopted in what follows.

A. ANTHRACITE COAL.

Excepting the Rhode Island graphitic anthracite, because it has as yet no significance as a fuel, there may be said to be three deposits of anthracite in the United States. One of these occurs in the eastern part of Pennsylvania, a state which touches the Atlantic seaboard. This deposit has an area of about 480 square miles (1243 square kilometres). The second deposit occurs in Colorada and New Mexico, and has an area of only about 29 square miles (75 square kilometres), so that it is comparatively insignificant. The third deposit occurs in Alaska, and it is also of comparatively small extent. The Pennsylvania deposits have been extensively developed and commercialised, and coal from these deposits is commonly understood when anthracite is spoken of in the United States.

Anthracite, which is also known in common speech as hard coal, has a deep black colour and a semi-metallic lustre. The combustible contains from 92.5 to 97 per cent. Fixed Carbon and from 3 to 7.5 per cent. Volatile. The calorific value varies from 14,600 to about 15,500 British thermal units per pound (8,100 to 8,600 kg. cal. per kg.) of combustible. This is the "high" value, that is, it is not corrected for heat bound up in water vapour formed during combustion and irrecoverable under most commercial conditions.

The earthy material in anthracite as marketed varies greatly with the characteristics of the particular vein mined, the care used in mining, and the extent to which ash is removed by washing, sorting or jigging before marketing. In general, the ash runs from about 10 to 15 per cent. in the larger sizes of well prepared anthracite and from about 17 to 25 per cent. in the very small sizes. The sulphur content is generally low, ranging from 0.5 to about 1.25 per cent. The ash varies in character with location and seam, but is usually very refractory. Softening temperatures of the ash frequently run as high as 3,000° F. (1,650° C.) and most anthracite ash does not soften below 2,200° to 2,400° F. (1,200° to 1320° C.).

Anthracite coal is broken during or after mining to such an extent that the largest piece will pass through a circular ring or hole with a diameter of 4½ inches (114 mm.). It is quite generally prepared for market by sizing and by some treatment to remove earthy or stony inclusions that would raise the ash content to an undesirable extent. In the larger sizes the removal of such earthy material is frequently effected by hand-picking, that is, by removing it manually as the coal passes along in a thin stream on a conveyor belt. The smaller sizes are quite commonly subjected to some sort of washing or jigging or similar concentrating process.

Sizing and refining of product before marketing is carried to a greater extent in the anthracite fields than in any other coal fields in this country. The larger sizes are used practically exclusively for domestic heating and form an almost ideal fuel for such purpose because of the cleanliness of handling and of burning. This fuel is smokeless under the most adverse conditions. The smaller sizes are known as Steam Sizes because they are used almost exclusively for generating steam in industrial and public utility plants.

There is no sharp line of demarcation between domestic sizes and steam sizes, but in a general way all sizes above Pea, which passes through a ⅞ in. (22.23 mm.) round opening and is rejected by a ⅝ in. (15.88 mm.) round opening, are known as domestic. Pea and smaller are therefore considered as Steam Sizes. There is now a marked tendency to include pea coal with the domestic sizes, as a result of the development of domestic furnaces so arranged as to burn pea coal successfully. The steam sizes and their designations are shown in the following table. It should be noted that the screen sizes here given are not rigidly adhered to by all producers.

TABLE I.

STEAM SIZES, ANTHRACITE COAL.

Designation.	Round Mesh Screen. Diameter of Holes, Inches. Passes Through		Rejected By	
Pea (Buckwheat)	7/8	(22.23 mm.)	5/8	(15.88 mm.)
No. 1 Buckwheat (Rice) ...	5/8	(15.88 mm.)	3/8	(9.525 mm.)
No. 2 Buckwheat (Barley)	3/8	(9.525 mm.)	3/16	(4.763 mm.)
No. 3 Buckwheat (Birdseye)	3/16	(4.763 mm.)	3/32	(2.381 mm.)
No. 4 Buckwheat	3/32	(2.381 mm.)		

Designation.	Square Mesh Screen. Side of Hole, Inches. Passes Through		Rejected By	
Pea (Buckwheat)	3/4	(19.05 mm.)	1/2	(12.70 mm.)
No. 1 Buckwheat (Rice) ...	1/2	(12.70 mm.)	1/4	(6.350 mm.)
No. 2 Buckwheat (Barley)	1/4	(6.350 mm.)	1/8	(3.175 mm.)
No. 3 Buckwheat (Birdseye)	1/8	(3.175 mm.)	1/16	(1.588 mm.)
No. 4 Buckwheat	1/16	(1.588 mm.)		

Number 3 Buckwheat is the most commonly used of these steam sizes. It is estimated that about 10,000,000 long tons (10,160,000 metric tons) of this material are produced annually. Of this quantity about 7,000,000 tons (7,112,000 metric tons) are used at the mines for power production and about 3,000,000 tons (3,048,000 metric tons) are sold to various industries. There is a rapidly growing tendency for the mines to use central station power and this tendency is causing a shifting of the relative proportions here given.

At the present time about twelve central stations are using Number 3 Buckwheat and other small sizes under boilers aggregating about 1,000,000 square feet (92,900 sq.m.) of boiler surface In addition to this about 4,000,000 square feet (371,600 sq. m.) of boiler surface in industrial plants are fired with this material.

The steam sizes were originally burned on hand-fired grates and quite frequently with forced draft, that is, with air forced under the grates by means of a fan discharging into the ash pit. Within the past fifteen years chain-grate stokers have been developed for burning this material. These have been so successful that the useable minimum size has gradually been decreased until now material that may be described as coarse dust can be burned with fair efficiency.

This has made it possible to recover much material previously wasted. The old "culm piles" or piles of washery waste obtained when sizing the grades previously marketable are now being worked over to recover all useable material. Such coal is also being recovered by dredging the rivers and streams that flow through the anthracite regions and which accumulate in their beds great quantities of the finer sizes which are discharged into them with mine water and washery water, or are washed out of culm piles and waste banks by rain water. Coal recovered from streams in this way is known as river coal.

The characteristics of river coal vary with the original size,

character and origin of the coal, the kind of river bed, the kind of water-shed drained, the care used in dredging and the extent to which the dredged material is washed and sized before marketing. River coal is not usually considered as good as that coming direct from the mine or culm pile, but in some cases it is as good and in others it is actually better. Much depends upon the care exercised in preparation for the market.

The total quantity of coal recovered from the water courses in the anthracite region varies greatly with the condition of the coal market. The maximum recovery is about 600,000 to 700,000 long tons (609,600 to 711,200 metric tons) per year.

The chain grate stoker used for burning small sizes of anthracite is arranged with very small air spaces which are so shaped as to prevent to the maximum possible extent the sifting through of the very small particles. The total area of air openings is also small, about 5 to 7 per cent., so that the air passes through the grate in a great number of very small streams moving at high velocity. A fan delivers air to the space between the upper and lower runs of the chain and is constructed to deliver the maximum quantity of air at a pressure between 2 and 4 inches (51 and 102 mm.) of water, depending upon the size of coal used, the ratio of boiler heating surface to grate surface and the rating at which the boiler is to be operated. The space into which the discharge duct of the fan delivers is divided into from four to six open topped boxes running transversely with respect to stoker travel. The air enters each box or compartment through a hand-controlled damper so that the pressures in the different boxes can be adjusted independently of each other and of the fan delivery pressure. Ordinarily fairly high pressures are maintained in the boxes under the entrance end or front end of the stoker and the pressure tapers off toward the discharge or rear end, as may be required to burn out all carbon without passing excessive quantities of air through the end of the fire.

An arch is always used over these stokers to ignite the fuel and to assist in combustion by preventing too rapid cooling of the fire by excessive direct radiation to cold or cooler surfaces. This arch is located over the front end of the stoker and is quite similar in general shape to the arches used with chain grates in Europe.

Recently an arch at the rear end of the stoker has come into use. This is known as a reversed arch and is used in addition to the arch described above. It may be regarded as a forward extension of the upper part of the bridge wall. Its function is really three-fold. It throws back upon the fire a great quantity of fine coal that was previously blown over the discharge end of the stoker and into the ash pit. It reflects back on the fire a certain amount of heat which would otherwise be radiated, and thus tends to maintain a higher fuel bed temperature. It deflects air which passes through the discharge end of the stoker and air that leaks upward from the ash pit in such a way as to mix it with the gases rising from the front part of the stoker, and thus greatly improves the combustion.

The grate area provided in any case depends upon the character of the coal and the maximum steam output required. Combustion rates with the smallest steam sizes vary from about 20 pounds per square foot of grate an hour to about 50 or 55 pounds (98 to 244 or 268 kg. per sq. m.) as the present upper limit. The best results are commonly obtained when burning about 30 to 35 pounds per square foot (146 to 171 kg. per sq. m.). In a general way, about one square foot of grate surface is installed per 40 square feet of boiler heating surface when moderate steam outputs are set as a maximum desired performance, say, about 5,000 to 7,000 British thermal units per square foot (13,600 to 19,000 kg. cal. per sq. m.) of heating surface, and hour. This ratio changes to about 1 to 37 or even 1 to 35 for outputs of 8,000 to 10,000 British thermal units per square foot (21,700 to 27,100 kg. cal. per sq. m.) and hour.

In modern practice, boilers equipped with chain grate stokers for burning the small sizes of anthracite are set so that the tubes are 16 to 18 feet (4.9 to 5.5 m.) above the surface of the grate. Combustion chambers for furnaces are so proportioned that from 25,000 to 60,000 British thermal units are liberated per cubic foot (222,500 to 534,000 kg. cal. per cu. m.) and hour when operating at maximum output. The variation is due to different types of design, different characters of coal and different ideas of designers.

The efficiencies obtained in daily operation with such stokers using the smaller sizes and with boilers not equipped with economisers vary from 55 per cent. in the older and in the more poorly

operated installations to a maximum which may possibly be as high as 70 per cent. in the newest installations working under the most favourable conditions. Efficiencies of some 75 or 76 per cent. have been obtained on test with the newest installations, but many of the equipments now in use are not capable of giving more than 60 to 65 per cent. efficiency under test conditions. All of these efficiency figures are based on the "high heating value" of the fuel; that is, the heating value obtained in a calorimeter of the bomb type in which the products of combustion are cooled to approximately initial conditions with condensation of the water vapour. No allowance is made for inability of the boiler to recover latent heat of vaporisation of water vapour in the flue gases.

Within the past few years several industrial plants have installed pulverised fuel equipment for use with anthracite coal. It has been demonstrated that this material can be burned satisfactorily in pulverised form in spite of its low volatile content, and it looks as though even the poorest grades with high ash contents can be burned in this way. It is as yet too early to say that this method is going to prove commercially successful on a wide scale because it has not been used for a sufficient length of time or in enough different localities to make available any adequate data on preparation and maintenance costs. The indications are favourable and some of the larger utilities that use the small sizes of anthracite are considering experimental installations.

B. BITUMINOUS COAL.

By far the most important coal in the United States is that classified as bituminous. This does not mean that this tremendous quantity of coal, estimated at at least 1,000,000,000,000 tons of 2,000 pounds each (907,200,000,000 metric tons) has like characteristics throughout. It occurs in five principal fields with a total area of about 200,000 square miles (518,000 square kilometres). There are other small fields scattered about in different parts of the country, but they are comparatively insignificant.

The five fields referred to are:—

1. The Appalachian Field with an area of about 70,000 square miles (181,300 sq. km.) extending in a general southwesterly direction from the western end of Pennsylvania through Ohio,

West Virginia, Eastern Kentucky, Tennessee and Northern Alabama. The extreme eastern edge of this field in Pennsylvania, West Virginia and Kentucky contains coal known as semi-bituminous, which is a very high grade coal that will be referred to later.

2. The Northern Interior Field, located within the state of Michigan and having an area of about 11,000 square miles (28,490 sq. km.).

3. The Eastern Interior Field, running in a south-easterly direction through Illinois, South-western Indiana and Western Kentucky.

4. The Western Interior Field, running in a southerly direction from Iowa, through Eastern Kansas, Western Missouri, Eastern Oklahoma and Western Arkansas.

5. The South-western Interior, which reaches in a south-westerly direction across the State of Texas, starting in the southern part of Oklahoma.

In a very general way the bituminous coals of the United States are poorer as one travels from the East toward the West. The semi-bituminous coals referred to above as lying on the eastern edge of the Appalachian Field contain fixed carbon, ranging from 87.5 to 75 per cent. of the dry combustible, with 12.5 to 25 per cent. of volatile matter. They burn freely, with little tendency to form smoke and generally are low in moisture, ash and sulphur. Their characteristics are such that they command a very good price under normal conditions, and are not as extensively used for steam production as are the more plentiful and more widely distributed coals of the lower order designated simply as bituminous.

The bituminous coals of the Appalachian Field, with the exception of the semi-bituminous described above, are generally designated as eastern bituminous. They contain from 75 to 60 per cent. of fixed carbon per pound of combustible, with about 25 to 40 per cent. of volatile.

The Western bituminous coals run about 65 to 50 per cent. fixed carbon and 35 to 50 per cent. volatile per pound of combustible.

In a general way the Eastern bituminous coals contain less ash and sulphur and less moisture than the Western bituminous coals,

although this is more nearly true of the coals from the centre of length of the Appalachian Field than from the coals at the ends of that field. The better Appalachian bituminous coals contain from 0.5 to 1.5 per cent. sulphur and not over 4 to 5 per cent. moisture. In fact, moisture sometimes runs as low as 2.5 per cent. The ash content is often below 4 per cent. and seldom higher than 9 or 10 per cent. In contrast, the Western bituminous coals commonly contain from 2 to 5 per cent. sulphur and 10 to 16 per cent. of moisture, with ash running at 10 per cent., or higher.

These facts are all reflected in the heating values of the coals. The best grades of Eastern bituminous give heating values varying from about 13,500 to 14,500 British thermal units per pound (7,500 to 8,000 kg. cal. per kg.) as received, depending upon characteristics of the coal, care used in mining and preparation, and the content of accidental moisture. In contrast, the Western bituminous coals of the better grades run from about 10,500 to about 12,200 British thermal units per pound (5,800 to 6,800 kg. cal. per kg.) as received, and the poorer grades have heating values as low as 8,000 British thermal units per pound (4,400 kg. cal. per kg.).

With coal fields extending over such tremendous areas and possessing such different characteristics, one would naturally expect to find great variation in the characteristics of the ash, and this is found to be the case. In a very general way the ash content not only rises as one travels from the East toward the West, but the ash also becomes less refractory. Thus some few of the Eastern bituminous coals have ash which softens in the neighbourhood of 3,000° F. (1,650° C.), while many give fusing temperatures of from 2,300 to as high as 2,500° F. (1,260° to 1,370° C.). In contrast to this, the ash of most Western bituminous coals softens at values between 2,000° and 2,300° F. (1,090° and 1,260° C.) and some of these Western coals contain ash fusing as low as 1,900° F. (1,040° C.).

Bituminous coal is not, in general, prepared as carefully as anthracite before marketing. Much of it is marketed just as it comes from the mine, and is known as " Run of Mine." This contains all sizes from the largest lump that can be carried in the mine cars, or other handling equipment, to the finest dust that is formed in mining and handling.

In other cases, the finest sizes, such as those passing through a 1-inch (25 mm.) or a 2-inch (50 mm.) screen, are removed and sold as screenings or slack, while the part remaining on the screen is sold as lump. In still other cases, a fairly complete breaking and sizing operation is customary.

The extent to which sizing is used depends upon the market demands. Large sizes of lump are often called for when the coal is to be transported long distances or stored in large quantities for a long time. When this is the case, screening must be resorted to and screenings or slack coal result. These are commonly sold for steam-boiler firing at a price below that charged for the larger lumps. In other cases, domestic users demand certain prepared sizes, and material passing through the smallest size screen used in preparing coal to meet this domestic demand becomes available as screenings and is generally sold at a reduced price for steaming purposes.

The American Society of Mechanical Engineers has recommended certain standardised practices in the sizing and naming of bituminous coals as prepared for market. These reflect to a certain extent the practices existing in the different fields to which they refer, but they have not been generally adopted by the trade and are not in universal use. These recommended practices are as follows:—

For Eastern Bituminous Coal.

(a) Run of Mine designates unscreened coal as it comes from the mine.

(b) Lump designates coal passing over a bar screen having a clear space of 1¼ inches (32 mm.) between adjacent bars.

(c) Nut designates coal passing through a 1¼-inch (32 mm.) mesh bar screen and over a bar screen having a clear space of ¾ inch (19 mm.) between adjacent bars.

(d) Slack designates everything that passes through a bar screen having a clear space of ¾ inch (19 mm.) between bars.

For Western Bituminous Coal.

(a) Lump coal designates certain definite sizes which are named as 6 inch (152 mm.), 3 inch (76 mm.) and 1¼ inch (32 mm.) respectively. In each case they represent the coal that passes over a screen containing circular openings with diameter equal to the size designation. Or the lump may be designated as 6 by 3 inch (152 by 76 mm.) and 3 by 1¼ inch (76 by 32 mm.),

in which case the coal shall pass through a hole of the larger size and be rejected by a hole of the smaller size.

(b) Steam nut designates 3 by 1¼ inch (76 by 32 mm.) lump. Nut combined with a numeral, as 1¼ inch (32 mm.) nut, passes through the screen designated by the numeral and is rejected by a screen of the next lower size. Thus there are 1¼ inch (32 mm.) nut and ¾ inch (19 mm.) nut. The latter is rejected by a ⅝ inch (16 mm.) circular opening.

(c) Coal screenings designates anything that passes through a 1¼-inch (32 mm.) round hole.

It would seem that in a country in which coal is hauled for very long distances and in which the freight charges quite frequently equal or exceed the cost of coal at the mine, preparation at the mine would include some sort of washing or jigging or air cleaning process to reduce the quantity of ash hauled uselessly and necessarily disposed of in some way after burning the coal. There is, however, no widespread use of such processes in the bituminous fields, probably less than 4 per cent. of all bituminous coal mined being subjected to any sort of cleaning process.

Many investigations have shown that such cleaning processes can be utilised to commercial advantage in many cases, but in spite of this fact coal is still mined and sold and hauled very much as it was before these investigations were made. The reasons behind this obvious failure to take advantage of improved methods are very complex and need not be discussed here in detail. They are deeply rooted in the facts that the country as a whole is still buying coal in a very unscientific manner and that about twice the necessary mine capacity is developed and operated, much of it on a distinctly "hand to mouth" basis. It seems quite probable that the next decade or two will bring about such changes in production and purchasing as to concentrate attention on more perfect preparation, and that as a result there will be much less hauling of useless material around the country, first as ash in coal and later as boiler room refuse.

Bituminous coals are fired under boilers in five different ways; namely, by hand firing, by means of inclined or overfeed stokers, underfeed stokers and chain grate stokers, and as pulverised fuel.

Hand firing is rapidly passing out of use because of its recognised inefficiency as ordinarily conducted, because of the increasing difficulty experienced in getting intelligent men to do such

work, and because of the increasing tendency to drive boilers to rates of output not commercially attainable with hand firing.

Various types of inclined, overfeed stokers are still manufactured and sold for use with bituminous coals, but they appear to have definite limitations which are rapidly restricting them to use in small installations operating at easy ratings and with fairly constant rates of output. They operate best with coals containing ash of high fusing temperature and which have such physical and chemical characteristics that the individual lumps do not tend to coalesce excessively during the combustion process. They therefore give their best performance with a comparatively limited number of available bituminous coals.

Underfeed stokers vary all the way from a single plunger combined with a single retort to the multiple retort stokers which have reached an exceedingly high state of development in the United States and are the outstanding feature of a great many public utility and other boiler rooms in this country at the present time. These stokers, in their earlier forms, were limited to fuels containing ash of high fusing temperature, preferably as high as 2,400° F. (1,320° C.) and therefore in general to the better grades of bituminous fuel. Gradual development over a period of twenty years and particularly during the past decade has extended their field, until now they can handle commercially substantially all marketable grades of bituminous coal. They may be said to be the country's standard equipment at the present time for burning the better grades of Appalachian coal and they are standard equipment with many of the larger companies that are required to burn Western bituminous coals.

These multiple retort stokers have always been noted for their extreme flexibility; that is, the speed and ease with which they respond to great changes in demand for steam, and this led to their early adoption by public utility plants having an irregular load curve with sharp peaks. It became evident that they offered a means of burning large quantities of coal in a given furnace area and this led to the high rates of steaming now common in many plants in this country. Such high rates of steaming were first obtained by placing two stokers opposite each other under a single boiler, but within the past few years the development of stokers of more than twice the length of the original designs has made this complicated arrangement unnecessary. At the

present time it is possible to obtain a 16 retort stoker of such dimensions that it can be placed under a single boiler and can burn about 3,000 pounds (1,360 kg.) or more, per retort and hour, when using the better grades of bituminous coal. This is equivalent to burning about 24 tons (2,000 pounds each) (21.8 metric tons) under a single boiler in an hour. Under favourable conditions this would correspond to 400,000,000 or more British thermal units (100,800,000 kg. cal.) per hour actually passed to water and steam in a single boiler unit. The boiler room efficiency that would correspond to driving at such a rate, combined with water rates now easily attainable, would enable a single boiler unit thus equipped to supply about 28,000 to 30,000 kilowatts of generating capacity with a proportionate share of all auxiliaries.

As ordinarily installed in central stations, these stokers and the boilers over them are so proportioned that the boiler can be driven at from 250 to 300 per cent. of builders' rating; that is, up to heat transfers of from 8,400 to 10,000 British thermal units per square foot (22,800 to 27,100 kg. cal. per sq. m.) of boiler surface and hour. Arches over the stoker are not required with any of the fuels used, so that the furnace is comparatively simple.

The underfeed stoker as now marketed consists in most cases of three essential parts. The first of these is the feeding mechanism and underfeed section. In this section coal is fed into the furnace beneath that already within the furnace, is forwarded slowly toward the discharge end and burned by air passing through tuyeres near or at the tops of the retort sides. This is the section responsible for distillation and combustion of volatiles, ignition of the solid fuel and part of the combustion of the solid fuel. The next section may be described as an overfeed section.

The incandescent and burning carbon from the first section is forwarded over this second section together with any ash and clinker already formed. Air is supplied under separate control from below and most of the remaining carbon is expected to burn on this section. Beyond this comes the means for ash disposal. Some combustion practically always occurs in this third section excepting at the very lowest rates of firing, and much of the economy of any given stoker depends upon the skill used in designing and operating this section so as to reduce combustible in the refuse to a minimum value.

Two distinctly different types of ash disposal mechanism are in use. One may be designated as the ash dump. It takes the form of a shelf hinged at one edge. The ash and clinker collect on this shelf until enough has accumulated to justify "dumping" by dropping of the dump plates. These dumps are operated by hand in some cases and by power in others. In some designs provision is made for rotation of the dump through an angle above the horizontal as well as below for the purpose of sheering off clinker adhering to the bridge wall or other parts.

The other type of ash disposal device is known as the clinker grinder. This consists of a single, toothed roll or of two such rolls located at the bottom of a deep pit. The material forwarded by the stoker ultimately arrives at this pit, and when the mechanism is operated properly, it flows over a mass of comparatively cool refuse already contained in the clinker grinder pit. The completion of combustion occurs on top of this mass of refuse as the whole pile is gradually worked downward by the continuous operation of the clinker grinder rolls at the bottom of the pit.

The clinker grinder is generally considered to require a higher grade of intelligence for its operation than does the dump plate. If unintelligently operated it is quite common to find it very short lived, because of frequent grinding through of burning coal with rapid destruction of the grinding rolls and their bearings. On the other hand, if intelligently operated, it permits the attainment of a higher thermal efficiency because of the more nearly complete elimination of combustible from the refuse. With dump plates, combustible in the refuse will ordinarily run from about 18 to 25 per cent., or higher, with the better grades of coal, whereas with the clinker grinded, values of about half these sizes are obtainable in practice.

Many ingenious devices are used with these stokers for the protection of refractory furnace walls and bridge walls where the burning fuel or hot clinker and ash come into intimate contact with them. In the case of the bridge wall, water-cooled devices have been used to some extent. These are known as water-backs and take the form of castings or tubes through which water is circulated so as to prevent the metal from attaining too high a temperature.

In the case of the side walls, air-cooled metal structures have been most common. In some cases these take the form of

hollow boxes through which air passes on its way to the stoker tuyeres. Such boxes are frequently further protected by plates which are ribbed on the outside to catch and hold small cold particles of clinker and ash, so that the hot coal and hot clinker do not come into actual contact with the metal. In other cases, cast iron plates which are pierced with holes are built into the side walls so as to form the fireside of a box through which air is fed. This air passes into the furnace through the perforated plates which are called side-wall tuyeres for this reason.

There are also available blocks of refractory material which can be built into bridge wall or side wall in the place of ordinary fire brick. These blocks are hollow and are perforated on the side facing the fire. Air passes through them and into the furnace, thus keeping the blocks cool and chilling molten ash that is blown against them so as to reduce the chances of adhesion or of fusing to the wall.

Bricks made of carborundum have proved efficacious in some cases in preventing the excessive adhesion of clinker and the rapid deterioration of the wall. They are used as a facing at the so-called clinker line. Success in the use of such bricks depends to a great extent upon the binder used to hold the carborundum crystals together, and also upon the character of the ash. At the present time some of the air-cooled refractory blocks mentioned above are being made of carborundum for use under the most severe conditions.

The underfeed stoker may be said to be principally responsible for the use of very large boiler furnaces in the United States. It made possible the operation of boilers at very high ratings, *i.e.*, 6 to 12 pounds of water per square foot (29 to 58 kg. per sq. m.) of boiler surface and hour. Under such conditions it was necessary to enlarge the furnace both in area and in height for the purpose of preventing excessive maintenance charges and in order to permit approximate completion of combustion before the gases came in contact with boiler-heating surfaces.

Boilers equipped for operation at high ratings with such stokers are now being set so that the minimum distance from stoker to tubes is from 10 to 15 feet (3.0 to 4.6 m.) and occasionally much greater, and the furnace is so proportioned that from 25,000 to about 35,000 or more British thermal units are liberated per cubic foot (222,000 to 311,000 kg. cal. per cu. m.) and hour when operating at maximum rating. Under these conditions coal is burned at

the rate of 50 to 60 pounds an hour per square foot (240 to 290 kg. an hour per sq. m) of horizontal area within the furnace walls. Calling this horizontal area the grate area, about one square foot of grate area is provided for 40 to 50 square feet of boiler-heating surface, depending upon the character of the coal and the boiler rating desired, characteristics of load, etc. Coal has been burned experimentally at a rate of about 100 pounds an hour per square foot (490 kg. an hour per sq. m.) of horizontal furnace area.

Test efficiencies of such boilers and stokers, exclusive of economisers, generally run at about 81 to 83 per cent. at the best point and with the best fuels. They drop to between 68 and 74 per cent. at maximum rating, depending upon the ratio of heating surface to stoker area. The average boiler room operating efficiency over long periods of time runs about 70 to 75 per cent., exclusive of economisers, and in the best designed and best operated stations using the better grades of bituminous coal.

When using the poorer grades of Western bituminous coal with underfeed stokers built for use with such coals, the best efficiency, exclusive of economisers, will ordinarily be found to be about 72 to 75 per cent. at the best point, falling to values as low as 60 per cent. at maximum rating. The average boiler room operating efficiency is seldom much above 65 or 66 per cent.

The modern chain grate stokers which are used for burning bituminous coals have been developed from the earlier "natural draft" equipment by arranging them so that a "forced draft" fan can deliver air under the grate surface at a pressure above that of the atmosphere. Provision has also been made for the better control of the coal feed and of the stoker speed. Arches are always used over these stokers and much ingenuity has been shown in the design of such arches. At present most of the newer installations are using what are known as suspended arches. In these, each individual block is separately suspended from an external metal framework, so that each block is theoretically independent of all the others.

In general, these chain grate stokers are very similar to those described as used with small sizes of anthracite. They have the same multiple wind box so that air pressure can be controlled

separately for different sections of the grate. The air spaces in the grate are of larger dimensions and form a greater proportion of the grate surface.

These chain grate stokers are frequently provided with water-cooled devices for protecting the side wall and bridge wall. The side wall protection consists of a steel box or tube of rectangular section or of one or more tubes of circular section. These are located just above the edges of the grate and are connected into the boiler circulation.

The bridge wall protection or "water back" usually consists of two or more steel tubes of circular section and of fairly large diameter, such as 6 or 8 inches (150 or 200 mm.). In the later designs these are located so as to support the face of the bridge wall, the whole structure overhanging the discharge end of the grate, that is the stoker runs under the bridge wall.

These stokers are known as forced draft chain grates, or by other similar designation. Until quite recently they have been the standard equipment for burning the Western bituminous coals with high volatile and high ash contents and with ash fusing at a low temperature. The development of the underfeed stoker referred to above is now threatening their supremacy. The forced draft chain grate is not well adapted to handle fuels with low ash, say below about 7 per cent., nor coal that cakes to any great extent during combustion.

Such stokers have been developed very rapidly in recent years in an effort to keep pace with the increasing size and refinement of the underfeed. A number of chain grates are now in use which measure 24 feet (7.3 m.) across and 18 feet (5.5 m.) or more from front to back. Such a stoker can burn sufficient coal of about 10,000 British thermal units per pound (5,560 kg. cal. per kg.) to drive a boiler of about 15,000 square feet (1,400 sq. m.) of surface to about 300 per cent. of builders' rating; that is, to an average heat transfer of about 10,000 British thermal units per square foot (27,100 kg. cal. per sq. m.) and hour. The best modern installations have the distance between stoker and heating surface about the same as the values given above for underfeed stokers, although there is a tendency toward making this distance even greater with the chain grates using Western coals because of the greater quantity of volatile per pound of combustible and the tendency to form a correspondingly longer

flame. The furnace volume is proportioned so that the ratio of heating surface to furnace volume is about the same as with underfeeds. Because of the poorer quality of the coals used this often results in a slightly higher rate of combustion in terms of pounds of coal per cubic foot of furnace volume at a given boiler rating, although the liberation of heat per cubic foot is about the same as with the other stokers. The rate of combustion per square foot of grate surface varies from about 40 to 55 pounds (195 to 269 kg. per sq. m.) an hour.

The low fusing temperature of the ash in most Western bituminous coal leads to the collection of ash on the lower tubes of boilers when operating at high ratings, and ultimately makes necessary complete shut down for cleaning unless definite provisions are made to minimise such collection. This is done by using very high settings and by arranging the lower tubes to form a "slag screen." This is accomplished by wider spacing of the lower tubes so that the velocity of gases is decreased and molten ash is given an opportunity to settle out or to cool by radiation to the tubes before entering narrow passages between closely spaced tubes. Similar slag screens are now being used even with the better grades of coal when very high ratings are to be used. This is true for underfeed stokers as well as for chain grates.

Boiler and furnace test efficiencies as high as 75 to 77 per cent. can be obtained with the very best installations of forced draft chain grates using the best grades of Western bituminous coals when operating at the most advantageous ratings. These figures are exclusive of economiser performance. However, the average good installation ordinarily shows efficiencies a few points lower. Operating efficiencies of boiler rooms equipped with such stokers and exclusive of economisers generally run from about 65 per cent. for the average good installation to about 70 per cent. for the best, when working under the most advantageous conditions.

During the several years just past, the use of pulverised fuel in boiler plants has increased at a tremendous rate. Starting about ten years ago with practically no boilers fired with pulverised fuel, this method has come rapidly to the front until at the present time, the total boiler surface in operation with pulverised fuel, or under construction for such operation, amounts to about 2,000,000 square feet (185,800 sq. m.). Most of this development has, in fact, occurred in the past two years. By far

the greater part of this surface is fired or is to be fired with bituminous coal, and it is for this reason that pulverised fuel firing is treated under this head.

The use of pulverised fuel in recent large undertakings has been advertised so widely that one not entirely familiar with the actual facts might easily get the idea that this method is completely supplanting the use of stokers. This is certainly not the case, as is evidenced by the fact that a number of large plants now under construction are being fitted with stokers, and that this action is being taken after exhaustive studies of the relative costs and advantages of the two methods of firing.

Any fair statement must admit that the evidence so far available does not make an unanswerable argument for the use of pulverised fuel. Further, it must be admitted that the stoker has not yet been given many of the advantages accorded to pulverised fuel in those cases in which high performance records have been established with the latter method of firing. It still remains to be seen what modern stokers using previously dried coal, supplied with preheated air and fitted to furnaces with air-cooled or water and steam-cooled walls are capable of, both with respect to thermal performance and to maintenance. It will not be possible to draw final conclusions until such figures are available for extended periods of time, and until pulverised fuel has been used on an extensive scale and in many different localities for a few years.

Many of the recent decisions in favour of pulverised fuel have been dictated largely by the belief that this method of firing would give greater flexibility in the choice of coal, or that it is better adapted to the utilisation of a particular variety of coal that has not worked well with stokers now available, or by other similar considerations of a rather intangible and, in many cases, unproven but nevertheless very important character.

All of these facts must be born in mind if a complete and unbiased picture of the situation is to be obtained.

The author has no desire to disparage the pulverised fuel method. In fact, he has recommended it for several installations and looks forward to its wide and successful use. On the other hand, he feels it necessary to indicate that the whole story of the stoker has not yet been heard, and that pulverised fuel has not yet been proven a universal panacea.

The pulverised fuel method, as applied to large boiler rooms, has been developed so rapidly and so recently that it is not possible to describe any equipment as standard. Everything is in a state of flux, and huge sums are being expended in development work. At present, most installations of magnitude are designed with what may be called separate coal preparation to distinguish it from the self-contained units which consist of a combination of fan and pulveriser, and which receive crushed coal, pulverise it and deliver it to the furnace with the necessary air. While this is the case, many engineers feel that it is only a temporary condition and that some modification of the self-contained unit will ultimately triumph.

The separate coal preparation equipment usually consists of magnetic separators, drying devices, pulverising mills and means for delivering the pulverised fuel to the storage hoppers above the feeders supplying the burners.

Magnetic separators are required for the purpose of removing "tramp iron" received with the coal, *i.e.*, lost mine tools, railway spikes and tie plates, car couplings, pins, etc. Such iron would cause serious trouble if permitted to enter the pulverising mills.

Drying in the earlier modern installations was done by means of separately fired rotary driers, but more recently driers utilising flue gases or steam bled from the lower stages of turbines, or other forms of low grade or waste heat have come into use. These so-called waste heat driers can hardly be said to be out of the experimental stage, but they give great promise.

Drying is to a certain extent a misnomer, since the coal is practically never dried completely, in the sense that all the water is driven off. It seems necessary to drive off all or nearly all superficial moisture if the best results are to be obtained, and in some cases it is also necessary to drive off some of what has been called the inherent moisture. Experience has shown what percentage of moisture may be permitted to remain in the coal as it enters the pulveriser, and this varies from 2 or 3 per cent. in the case of the best bituminous coals to as high as 7 or 8 per cent. with the poorer bituminous coals which have higher inherent moisture content.

Two distinctly different types of pulverising mills are in use. In one, the coal being pulverised is thrown against screens built

into the mill and that which is fine enough passes through. These mills are referred to as screen mills. In the other type, air is drawn through the mill, and coal that is fine enough is "floated" out by the air current. These devices are generally spoken of as air mills. Each type has its advocates and the experience to date has not shown definitely that either is so far superior as to justify exclusive use. The pulverising mills now in use generally give outputs of 5 to 10 tons (4.5 to 9.1 metric tons) per hour, capacities which require the installation of many mills in a large boiler plant. Many new forms of mill are being experimented with, and several capable of grinding 20 tons (18.1 metric tons) per hour or more, with comparatively low lubrication, attendance and maintenance charges, are giving much promise of success.

It is customary to refer to the performance of fuel pulverising mills in terms of the total percentage of their output that will pass through a 200 mesh screen. This is apt to give an erroneous impression unless its real significance is understood. It is necessary to have sufficient fine material in the product to insure proper ignition and flame propagation, but it is equally important not to have an excessively large quantity of material so coarse that it cannot be burned completely within the space and time period available.

The permissible sizing varies with the character of the coal, the type of mill, the rating at which the installation is to operate, the shape of furnace, the temperature of combustion air and other considerations. In each case it is possible to determine that percentage passing through 200 mesh which corresponds to proper sizing, that is, to absence of more than the permissible quantity of coarse material. As this is a convenient method, it has come to be more or less customary to refer to the results of the pulverising operation in terms of percentage through 200 mesh.

The failure of the unit system in its simplest form to find favour in the case of large installations is partly traceable to the necessity of having properly sized product if high efficiency in burning and economy in preparation are to be obtained. All of these mills so far experimented with appear to wear rapidly so that the percentage of coarse material increases beyond the value for best efficiency within a period of a day or two. In addition, the proper control of air supply is more difficult than where a separate

preparation room is used because flotation of the coal and supply of combustion air are more intimately tied together.

When an air mill is used a cyclone separator is installed to separate the coal dust from the air and collect it in compact form in a suitable container.

The early plants transported the coal dust from screen mill or cyclone by means of screw conveyors. The more recent designs have almost universally used a compressed air transportation system. Several varieties are available, but that which is most widely used feeds the dust continuously into a stream of air so that the mixture flows through a pipe to the bin into which the dust is to be delivered. In this bin the dust settles out and the air passes off. One of these air transport systems has experimentally carried coal through a pipe line about one mile (1.6 km.) in length.

Many varieties of burning equipment have been developed but by far the greater part of the installed capacity is using devices in which the dust is fed into the furnace with a small amount of "primary" air, say about 15 to 20 per cent. of that required for combustion. The remainder enters around this jet and through ports or openings in the furnace walls nearest the flame.

Most furnaces are constructed with hollow walls arranged so that air passes through ducts formed in the walls on its way to the ports or openings referred to above. In this way the refractory lining is prevented from reaching a prohibitively high temperature and the air is preheated with resultant improvement of the combustion process. In some cases the walls have been further protected by the use of superheating surface located on the furnace side of the wall, such devices being known as radiant heat superheaters. In other cases, boiler tubes connected into the circulation of the boiler and located on the fireside of the wall have been used to keep the temperature of the refractories down to moderate values.

Experience has shown that in most cases provision must be made to prevent the ash from fusing on the hearth or bottom of the furnace and forming a clinker which it is very difficult to remove. In some cases this is done by admitting comparatively cold air at the bottom of the furnace so that the small molten particles of ash drop through this layer of air and are chilled and solidified before reaching the hearth. In other cases, a water

screen composed of boiler tubes connected into the boiler circulation is used to achieve the same result and to keep the ash below the fusing temperature after it reaches the hearth.

There is now obvious a movement toward the use of completely water and steam-cooled walls, but as yet no installation has gone to this extreme. There is also developing a feeling that furnaces with walls protected in this way can be made smaller with equally good results provided the air is adequately preheated and intimately mixed with the coal dust before entrance to the furnace.

The furnaces now used with pulverised fuel are very large, but it is believed that the size will be decreased if the development mentioned above continues. At the present time furnace volumes vary from about 0.2 to about 0.7 cubic foot per square foot (0.06 to 0.21 cu. m. per sq. m.) of boiler heating surface. The smaller values represent early practice and generally limit the boilers to comparatively low ratings. Most of the more recent designs have used about 0.5 to 0.7 cubic feet per square foot (0.15 to 0.21 cu. m. per sq. m.). With fuels containing refractory ash and burned in properly shaped furnaces it appears to be safe to figure on liberating 20,000 to 25,000 British thermal units per cubic foot (178,000 to 222,000 kg. cal. per cu. m.) of furnace volume, whereas fuels with ash fusing at low temperatures appear to give the best results when not more than 15,000 to 20,000 British thermal units are liberated per cubic foot (133,000 to 178,000 kg. cal. per cu. m.) of furnace volume an hour.

The efficiencies attainable with pulverised fuel are not yet well established for many grades of coal, but authentic tests on several different coals are available. These indicate that under suitable conditions pulverised fuel equipment is capable of giving test efficiencies from 3 to 5 points higher than those now attained with the best stokers using the same fuels. The monthly or yearly operating efficiencies show a greater margin in favour of pulverised fuel, apparently because it is easier to approximate test conditions during regular steaming periods and because of decreased banking losses.

Much has been said and written about the explosion hazard associated with the use of pulverised fuel. Those who urge this hazard as an argument against the adoption of pulverised fuel for boiler firing, point to the disastrous explosions occurring from

time to time in cement-making plants and metallurgical plants in which pulverised fuel is used.

The existence of such a hazard cannot be denied, but analysis of the explosions which have occurred indicates that all such catastrophes are avoidable. It remains to be seen whether they can actually be avoided in pulverised fuel boiler rooms.

The facts seem to be about as follows :—Disastrous explosions, that is, explosions of great magniture and involving any appreciable amount of equipment and building are nearly always secondary. They are initiated by a minor explosion, which is of itself practically harmless in so far as destruction of property is concerned. This minor explosion creates sufficient disturbance to shake down quantities of fine, dry coal dust from walls, beams and other resting places. If, when this occurs, an explosive mixture happens to be formed and if a source of ignition happens to exist, a violent explosion is almost certain to occur.

The obvious means of preventing such occurrences are to prevent the initiating explosion or to observe such scrupulous cleanliness that no dust is available to form the mixture required for the secondary explosion. Most modern equipment is so designed that an explosive mixture does not exist within any part of the equipment during normal operation, so that the chances of an initiating explosion are greatly reduced. However, it is practically impossible so to arrange equipment that a combustible or explosive mixture is not formed during starting and stopping. For this reason every precaution is taken to prevent the occurrence of means of ignition. The principal precaution is to provide for complete cleaning out of all pulverised fuel when shutting down. This minimises the chance of spontaneous combustion of a small collection of such fuel within the equipment during idle periods to serve as a means of ignition when the equipment resumes operation. Also, very complete provision is made for the elimination of all iron and steel from the coal entering the mills to prevent the striking of sparks which might serve as sources of ignition. In addition, the maximum temperature reached by the coal during drying is very carefully watched, and by this means the temperature reached during milling and later storage is controlled and as far as possible, is held below a dangerous value.

Beyond these precautions nothing can be done except to observe scrupulous cleanliness and to guard against the existence of possible sources of ignition outside the pulverising and handling

equipment. Such things as sparking commutators, arcing contactors and the like should always be eliminated or screened if elimination is impossible.

C. LIGNITES.

Lignitic coals are very plentiful in the United States, probably exceeding in quantity the bituminous coals already described. The lignite fields are well scattered over the entire western half of the country with the largest deposits lying east of the Rocky Mountains.

These lignitic coals are markedly different from the bituminous coals both in physical and chemical characteristics. In general, the dry combustible contains less than 50 per cent. of fixed carbon and over 50 per cent. of volatile. The moisture in the coal as mined is commonly very high, running from about 20 to 45 per cent., and occasionally as high as 50 per cent. The high heat value of the dry combustible varies between 11,000 and about 13,500 British thermal units (6,100 and 7,500 kg. cal. per kg.), but the high heat value of the coal as mined generally falls between 6,000 and 8,000 (3,300 and 4,400 kg. cal. per kg.) because of the high moisture and frequently the high ash content. These coals are practically all brownish in colour and often show a woody fracture. There are, however, many coals closely allied to them and of slightly better quality which are known as black lignites because of their black colour.

Many of the plants that are reported as burning lignites are really burning black lignite or very low grades of bituminous coal. However, a few plants are actually using true lignites. Most of these are of small size and are burning lump lignite on hand-fired grates. The boilers in such plants are generally operated at or below what is known as builders' rating, which is a heat transfer of about 3,350 British thermal units per square foot (9,100 kg. cal. per sq. m.) of boiler surface and hour.

Both natural and forced draft chain grates and underfeed stokers are used in burning lignite. Within the past few years it has also been burned in pulverised form. With properly designed stokers and furnaces it is possible to operate boilers using lignitic fuels at two to two-and-one-half times builders' rating over long periods of time, but very few plants are now operated under such favourable conditions.

Test efficiencies for stoker, furnace and boiler of the order of

70 per cent. at the best point are obtainable with the better grades, and about 65 to 67 per cent. with poorer grades of black and brown lignites. The operating results are naturally lower, frequently as low as 50 to 55 per cent. over long periods.

II. COAL PREPARATION AND STORAGE AT CONSUMING PLANT.

The steam sizes of anthracite are sufficiently uniform and of such small size that they can be used as received. Therefore no preparation is necessary. Such coal can be stored successfully in bins or stock piles up to any height found convenient for handling in and out of storage, and it can be handled with any kind of digging and transporting machinery. It therefore presents no serious problems, and almost as many different systems of storage and handling are in use as there are plants using this fuel.

Bituminous coals, on the other hand, present many peculiar problems and the possible solutions frequently differ with locality, character of coal and operating methods.

Most plants using bituminous coal have some sort of outdoor storage in addition to bunker storage capacity inside the boiler room structure. The problem faced by the designer, therefore, generally consists of all of the following parts :—

1. Means for unloading coal as received.

2. Means for putting this coal into the plant or into storage as may be necessary.

3. Means for crushing that part of the coal put into the plant which is above the size desired.

4. Means for recovering from storage and placing in the plant bunkers with or without crushing as may be necessary.

It is not possible to consider in a paper of this size all of the varieties of equipment and the various combinations thereof which are used in solving these problems. The best that can be done is to point out a few high spots in an endeavour to give a sort of bird's-eye view of the solutions.

Tide water plants and those located on navigable rivers very close to tide water, as well as certain plants in the Great Lakes Region receive most if not all of their coal by water. In such cases, the coal is usually received in barges and is customarily removed by a clam shell grab bucket and hoist. Distribution into

storage piles in these cases is often accomplished by belt conveyors fed from hoppers filled by the coal hoist, and in a few recent installations by a drag scraper which will be described later. That coal destined for immediate entry into the plant is either dropped into hoppers that feed on to belts or into cars that run over the boiler-room bunkers, or into an inside hopper or bunker from which a travelling boiler-room larry can be supplied. Where crushing is necessary the crusher is installed between the unloading and the distributing equipment.

When the plant receives all or part of its coal by rail, the type of unloading devices used depends upon the type of car to be expected. In most cases, provision is now made for the receipt of bottom dump or of side dump cars, but even then it is usually necessary to provide means for unloading cars not provided with dumping equipment. In a very general way, three systems for unloading cars are in use. These are:—

1. Track hoppers, in which the car runs over a hopper into which its contents can be dropped if it is provided with dumping gates or doors. The use of a trestle permitting dumping to ground at a lower level is really only an elementary form of the track hopper method.

2. Car dumpers, which are devices adapted to receive and hold the car while it is rotated about a longitudinal axis until its contents are spilled out. These dumpers are ordinarily located over hoppers similar to those just referred to.

3. Digging devices, such as locomotive cranes fitted with clam shell buckets.

When track hoppers or car dumpers are used, provision is generally made for removing the coal automatically through an opening in the bottom of the hopper and passing it to stocking devices or to the equipment which is to place it in the station bunkers, after crushing if necessary. Two distinctly different types of bunker storage are in use.

In one, the coal is elevated to bunkers located opposite each boiler and gravitates from these bunkers to the stoker hoppers as necessary. In such cases coal weights must be obtained from car weights or by using some sort of weighing device in the equipment conveying the coal to the overhead bunkers. Several such weighing devices are available. A few plants have

attempted to obtain coal weights by means of weighing devices or meters incorporated in the spouts leading from bunkers to stoker hoppers. Some of these are claimed by the users to be operating satisfactorily, but they have not received any wide spread recognition, at least in the larger plants.

In the other type of arrangement the coal is elevated to overhead bunkers occupying any convenient position and flows from these bunkers to travelling weigh larries which are arranged to travel the full length of the firing aisle. These larries deliver weighed quantities of coal to each stoker hopper and thus make it possible to keep a running check on the efficiency of each boiler unit.

The mechanisms used for elevating coal from ground or track hopper discharge to overhead bunkers are of three sorts; rope hoists, pivoted bucket conveyors and belt conveyors. The rope hoists generally take the form of automatic skips which load, hoist and discharge automatically and continuously until stopped by hand. The pivoted bucket conveyors generally load, hoist and discharge automatically and continuously, the point of dumping in some cases being arranged for hand control so that it may be changed from time to time to fill different bunkers. Such bucket conveyors are frequently used only for elevating the coal, dumping on to belt conveyors which distribute to the different bunkers. Belt conveyors used as elevators are comparatively rare because of the excessively long run required to reach elevations of the magnitude generally under consideration.

Reference has been made to the possibility of having to incorporate coal crushing devices in the coal handling equipment.

Screenings and slack coal can be used on stokers as received so that no preparation is required, except when the coal is received in frozen condition at a plant in which the necessary thawing cannot occur in boiler room bunkers. Run of mine or lump coal must first be reduced to smaller sizes. The crushing devices are generally specified to reduce all coal so that it will pass through a 1 inch (25 mm.) ring or a 1¼ inch (32 mm.) ring or a 1½ inch (38 mm.) ring, depending upon the character of the stoker and the ideas of the designer and operator.

Various types of crushing devices are in use, but practice is gradually settling down toward three principal types. These are the four and two roll crusher, the flail or hammer type crusher and the tumbling barrel type.

In the four roll crusher, the rolls are arranged in groups of two. One group is spaced fairly wide and effects the first rough crushing. The material leaving these rolls falls to the second group which is more closely spaced and produces the finished product. The roll bearings are backed up with springs so that the rolls can move apart to accommodate anything that they cannot crush.

The flail or hammer type contains a horizontal, rotating shaft to which are fastened steel members in such a way that they swing out when the shaft is rotated. This device is contained in a cylindrical casing so arranged that coal can be fed into it at the side and near the top. This coal is struck by the revolving flails or equivalent and thus broken to smaller size. It finds its way out through gratings on the lower part of the casing when reduced to sufficiently small size. If a flail strikes an obstruction which it cannot crush it is forced back toward the shaft and clears the obstruction.

The tumbling barrel type breaks the coal by dropping it. The lump material is fed into one end of a large rotating metal cylinder with perforated walls. The cylinder is usually about 12 feet (3.7 m.) in diameter and its interior surface carries projections which serve to pick up the coal and then drop it across the vertical diameter of the cylinder. These or other projections also forward the coal toward the discharge end. All the material that is reduced to the desired size passes out through the perforated walls while that which is too large to pass through leaves at the discharge end and is returned to the head end for further tumbling. Also, any iron or wood which is mixed with the coal as received and which is of such size that it cannot pass through the perforations in the cylinder is discharged with the unbroken lumps.

Coal storage at the plant or on property within easy reach of the plant has always been common practice with plants located at a distance from the coal fields. This was necessary to insure the required supply when normal transportation was impeded by storms, wrecks and other unpreventable or unpredictable causes. More recently strikes, car shortage and study of seasonal variations in coal demand have done much to increase such storage at the point of consumption. Stocks of coal running from a value of a few hundred thousand to several million dollars at or near the point of consumption are now regarded as necessary by

the larger coal burning utility companies. The quantities stocked frequently represent a three months supply and occasionally provide for six months.

The problem of stocking and recovering from stock has received much study, and the recent increase in the size and value of storage piles has served to concentrate attention on these features.

The locomotive crane fitted with a fairly long boom and a clam shell bucket is by far the most common equipment for stocking and recovering from stock. It digs out of the car and deposits in a pile for stocking and digs out of the pile and deposits in the car when recovering. Many schemes have been developed for utilizing available ground area to the best advantage, but the most common method of storing is in long, wedge shaped piles lying between coal yard tracks. When more is to be stored on a given area than this arrangement permits, the crane simply covers up tracks as it withdraws so that it leaves behind a more or less flat topped pile of greater width and with sloping sides.

The next most common device is probably the travelling bridge crane. This may travel on parallel tracks in such a way as to build up a flat topped, rectangular pile or it may rotate about one support with the other support travelling on a circular track so as to build up a flat topped, circular pile. In either case the sides of the pile naturally slope. Such cranes are fitted with clam shell buckets.

There has been introduced recently a drag scraper stocking and recovering device which is rapidly gaining in favor. It consists of a large, flat bottomed scoop fitted with a bail and so connected to cables that it can be used to spread coal deposited in a pile at a given point or to collect coal spread over an area and deliver it at a certain point. It gives a flat topped pile of any desired shape and of uniform depth.

The height to which coal can be stored depends partly upon the character of the coal and partly upon the method used in building up the pile and the ultimate shape of the pile. In a very general way the danger of spontaneous ignition is least with coals from the Eastern Bituminous Fields and gets greater as one travels westward. A few of the Western Bituminous and Sub-bituminous coals will ignite spontaneously, even if not piled, that is, if spread in what one would call a comparatively thin layer.

The better grades of coal can be stored safely in piles 18 or 20 feet (5.5 or 6.1 m.) high without any particular attention to method of placing, to sizing or to shape of pile. Others can be stocked safely in piles of this height provided proper care is taken. Certain of the western coals are best limited to piles not over 10 to 12 feet (3.1 to 3.7 m.) in height and certain others to heights not in excess of 4 feet (1.2 m.).

The phenomenon of spontaneous combustion is not yet completely understood but such evidence as is available points toward the following conclusions. Any arrangement which permits poor circulation in parts of the pile and good circulation in adjacent parts will ultimately lead to firing if the coal is of such a character that it tends to heat up in storage. For this reason any method of storing which will tend to build up piles with uniform dispersion or distribution of all sizes present will give the best results. This can be achieved by maintaining flat tops on all piles as they are being built up instead of building them in peaked form from the very bottom. Rolling of flat topped piles by passing tractors over them also tends to improve conditions.

Those companies that stock coal of such character that it tends to heat up excessively in the pile quite frequently drive pipes into the coal at regular intervals over the extent of the pile. These pipes are closed at the lower end and serve as means of introducing temperature measuring devices to the depths of the pile. Measurements of temperature are made at regular intervals of time and in this way dangerous spots and incipient fires are discovered and dug out before the condition becomes serious.

In some cases in which storage over excessively long periods of time is contemplated and in others in which easily ignitable coal is to be stored, under-water storage has been used. Under ordinary conditions this is considered too expensive for adoption.

III. LOW TEMPERATURE DISTILLATION OF COAL.

The processing of coal for the purpose of obtaining valuable distillates and salts before burning has not made much progress in the United States. Many individuals and a few of the larger public utility corporations have devoted time and study to the subject and quite a bit of experimental work has been done. But, there is not yet available conclusive evidence that any of the

suggested processes can be economically combined with steam production for power purposes.

One large industry has recently installed a low temperature distillation process on a rather extensive scale and the fact has been widely advertised. It must be understood that this is installed under very peculiar, in fact almost unique conditions, and that even though it should prove technically and economically successful that fact can not be made the sole basis of an argument for its success under the conditions that generally surround power production in this country.

It is probably correct to say that the present attitude of the engineers and executives of this country with respect to low temperature distillation as an adjunct to power production from fuel is hopeful but not over-enthusiastic. The promises made are very enticing and the modicum of success already achieved is encouraging but there is as yet no real evidence of successful commercialisation.

One point in this connection seems to deserve special mention. Any wide-spread use of such processes would bring into the market tar oils and other by-products in quantities not yet dreamed of, and it is only reasonable to suppose that the result would be a marked drop in prices. Therefore, it would seem that any calculations made for the purpose of proving the wide-spread applicability of such processes must assume selling prices for by-products materially lower than those now prevalent. Most calculations made to date seem gracefully to ignore such a possibility.

IV. FUEL OIL.

Petroleum Oil deposits are very plentiful in the United States and are well scattered over a large part of the country. The principal fields thus far developed are in Pennsylvania and states immediately south and west of it along the Appalachian range, in Oklahoma and adjacent states to the south and west, and in California.

The oils from the Appalachian fields are of the paraffin base type and similar oils are found in some of the fields further west. The oils found in California and Texas and in some of the other western fields are of an asphaltic base type.

At the present time the paraffin base oils are considered the more valuable, as lubricants made from such oils are believed to have better characteristics than those made from asphaltic

base oils. Further, practically all of the paraffin base oils contain greater quantities of the more volatile constituents than do the others.

As a result of these facts, very little crude oil of paraffin base is available for fuel purposes and comparatively little of the residuum left after the distillation of the more volatile constituents which are used for cleaning fluids, motor fuel and other purposes. On the other hand, much of the asphaltic base oil has been used as fuel in its crude form and by far the larger part of all fuel oil consumed in the country is either this crude oil or the residuum resulting from fractional distillation for the recovery of motor fuels and other distillates. The Mexican oil fields which are principally asphaltic have also contributed largely to the fuel oil supply of the United States.

Oil is the principal steam boiler fuel in California, in fact it is almost the only fuel used for such purposes in the southern half of the state. It is very generally burned throughout Texas, Oklahoma and other western and south-western states. It is also used to a certain extent along the Atlantic Coast. At best however, its use is fairly definitely confined to well demarked areas and even some of these are never certain of a continous supply. In all, about 110,000,000 barrels, 42 United States gallons (159 l.) each, are consumed per year as fuel in stationary steam power plants.

Fuel oil is purchased by volume, the common unit being the barrel of 42 United States gallons (159 l.). As the density varies rapidly with temperature, there is a well defined tendency to purchase in terms of barrels at a given temperature, generally 60° F. (15.6° C.). Correction factors are then used to make adjustments when delivery is made at a different temperature.

In a general way the users of fuel oil attempt to obtain a fuel sufficiently fluid to handle without excessive heating and at the same time containing no volatiles which will reduce its flash point to a dangerously low value. Many specifications have been proposed and used but there is, as yet, no standard specification applicable throughout the country. This will probably continue to be the case because of the many different sources and the natural variations from field to field, the unavoidable results of different methods of storage and of transportation and the ever varing characteristics of residuum resulting from the

application of different cracking processes for the production of ever increasing quantities of motor fuel.

The specific gravity of oils commonly sold for steam boiler fuel varies between about 11° Baumé and 18° Baumé although most of it now probably falls between about 11° and 14°. In terms of specific gravity with respect to water as unity 11° Baumé is equivalent to O.9929+, 14° to 0.9722+ and 18° to 0.9459+. In a very general way the viscosity at normal temperatures increases as the specific gravity increases so that the heavier oils must be heated to facilitate handling. This necessity for heating brings the flash point of the oils into the picture, flash point being defined as the minimum temperature at which the oil gives off appreciable quantities of inflammable vapour.

The better specifications state a minimum permissible flash point and also co-ordinate viscosity and flash point so that in effect they call for an oil which will have a flash point above that temperature to which the oil will have to be heated to make it flow properly in handling equipment. The minimum permissible flash point is generally given at 140° F. or 150° F. (60° C. or 66° C.) and refers to flash point determined with a closed cup tester.

Specifications practically always limit the water content and sometimes sulphur and earthy material. Water is generally limited to 1 or 2 per cent. and the specification frequently calls for adjustment of volume so that water is not paid for. Sulphur is sometimes set at 1 per cent. maximum, although it often runs close to 3 per cent. in available oils, and earthy material is limited to a trace.

The calorific values of fuel oil vary widely, but the greater part of it as marketed probably runs between 18,000 and 19,000 British thermal units per pound (10,000 and 10,600 kg. cal. per kg.) with the average close to 18,500 British thermal units per pound (10,300 kg. cal. per kg.) of oil. This is the high value.

Fuel oil is generally delivered to steam boiler plants in tank cars or tank vessels and must be pumped from these to the storage tanks on the power plant property. Tank vessels are equipped with steam heating coils for heating the oil to handling temperature but tank cars are often not so equipped. It is therefore necessary to provide at the plant steam coils which can be inserted into tank cars and steam connections for these coils.

The oil is stored on the power plant property in steel tanks

above ground or in concrete tanks which may be below or partly below ground.

Steel tanks are generally built in either 55,000, 37,500 or 25,000 barrel (8,740, 5,960 or 3,970 kl.) sizes. The 55,000 barrel (8,740 kl.) tank has a diameter of 114 feet, 6 inches (34.9 m.) and a height of 30 feet (9.1 m.). Many power plants are so constructed or located that such large tanks can not be accommodated and they have to install tanks of the smaller capacities.

The better tanks are equipped with large manholes and stairways for ready access to the interior, with sludge lines for draining or cleaning, explosion hatches, vent pipes and vacuum relief valves, steam heating coils and steam lines to furnish a blanket over the oil surface in case of fire. Some of them are also shielded against electrical discharges.

The pipe lines leading from the dock or from the railroad siding are in northern latitudes laid in the ground below frost line, and provision is made for heating them by steam lines laid alongside or by running one line within the other. Pipe lines from the tank to the pumping equipment are similarly treated. All lines are preferably sloped so that they drain completely when out of service.

It is quite common to divide the tankage into two or more parts, both for the purpose of insuring flexibility and safety and facility for cleaning as well as for the purpose of getting the necessary tankage on the available site. Frequently a so-called service tank is used as distinguished from the storage tanks. The service tank is the immediate source of supply for the boiler room and is filled as required from the storage tanks. When such tanks are used the oil piping is generally arranged so that storage tanks can be used as service tanks in emergency and so that all tanks are completely or almost completely interchangeable with respect to method of functioning.

Fuel is handled in many ways between service or storage tank and burner, but the most common method is about as follows. Oil is heated to about 90 to 100° F. (32.2 to 37.8° C.) at the tank, and is maintained at that temperature as it flows through the lines and into the pumps on its way to the burners. After it passes through the pumps, its temperature is further increased in a heater, and from there it passes to the plant piping which leads it to the burners. The temperature attained in the heater varies with the type of installation. For steam atomising systems

the final temperature runs between 130 and 160 or 170° F. (54 and 71 or 77° C.). For the mechanical atomising systems temperatures as high as 200 to 280° F. (93 to 138° C.) are used at the burner.

The pumping of the oil has usually been done with steam driven, direct acting pumps fitted with large air chambers to damp pressure variations. The exhaust steam from the pumps is used for heating the oil. Rotary pumps are now coming into favour and these are driven either by steam or electric motor. Pumps are installed in duplicate or triplicate and heaters are similarly duplicated. Provision is then made in the piping so that any one or two can be disconnected or by-passed in case of breakage or to permit maintenance work.

The oil is now ordinarily supplied to the boiler plant by a ring header so arranged that flow through it is normally continuous irrespective of the way in which burners are operating. In some cases this header discharges back into the service tank, but it is considered preferable to have it discharge back into the suction of the pumps so that the highly heated oil is not put back into the tank.

Strainers are always used and are frequently so arranged as to strain all oil leaving tanks and all oil passing from pumps to station header and from header to burner. The more important strainers are installed in duplicate with piping so arranged that one or the other can be cut out for cleaning without interrupting the flow of oil.

Meters of the disc type and also of the positive displacement or reciprocating type are commonly installed at critical points in the system. Their indications are sufficiently accurate in the case of the better makes to permit of their being used for operating guidance, but variations of calibration with temperature and with viscosity are so great that final operating results are generally checked back against tank gauging.

Fuel oil burners are conveniently classified on the basis of the means used for atomising the oil. On this basis, three varieties are in use in stationary plants, air burners, steam burners and mechanical burners.

The air burner uses compressed air to atomise the oil. It is rapidly passing out of use because it has been found that investment and maintenance charges combined with energy charges for

compressing the air run higher than in the case of steam atomisation.

Steam burners are divisible into two different types as Inside and Outside Mixers, depending on whether oil and steam meet inside the burner and emerge together from a single orifice or whether oil and steam emerge separately from adjacent orifices and meet outside the burner. There are a great many different designs of each type but practically all of them depend primarily on a tearing apart or "atomization" of the oil by the mechanical action of steam blowing across an oil surface. In addition there is of course the partial vaporisation of the oil by the hot steam with which it is brought into contact. The better designs are capable of using comparatively low pressure steam, say 20 to 30 pounds per square inch (1.4 to 2.1 kg. per sq. cm.) gauge pressure although the different types vary greatly with respect to both steam and oil pressure required.

The steam consumption of steam atomising burners is a very serious consideration, particularly in large plants in which high efficiencies are sought and in plants in which make-up water is expensive or requires expensive preparation. Under test conditions the best steam atomising burners consume about 1 per cent. of the boiler output at high ratings and a higher percentage at lower ratings. Very well operated plants commonly use about 2 to 2.5 per cent. as a yearly average and many good plants use as much as 4 per cent. on the same basis. Figures as high as 10 per cent. are not unknown. The steam used for pumping and heating must be added to that used for atomising to get the total.

Burners of this type are practically always arranged to give a flat flame, that is, a flame spreading horizontally. Air is usually admitted below the burner or flame and preferably through a checkerwork of brick which both preheats the air and reflects heat to the underside of the stream of atomised oil. The maximum capacity of each burner is definitely limited by the fact that atomisation is too coarse for good results when the burner is forced above a certain quantity of oil and by the further fact that the thickness of the sheet of atomised oil becomes so great at high rates of discharge that proper admixture of air becomes impossible. The maximum number of burners that can be used in a given furnace is determined by its width, as the burners must be located in a single horizontal row, if best results are

desired, and they must be so spaced that the flames do not overlap appreciably at maximum oil consumption.

The earlier steam atomising installations were limited to boiler ratings of about 150 to 175 per cent. of builders' rating, that is, a transfer of about 5,000 to 5,900 British thermal units per square foot (13,600 to 16,000 kg. cal. per sq. m.) of boiler heating surface, and hour. Later installations, built after extensive technical study and much practical experience, have been able to operate at higher ratings, running for long periods at 250 per cent. of builders' rating, that is, transferring about 8,400 British thermal units per square foot (22,800 kg. cal. per sq. m.) and hour. The combined boiler and furnace efficiency generally falls off rapidly at high ratings with steam atomising burners, and boiler tubes near the furnace generally have very short life when such burners are forced for any length of time.

The excessive use of steam by burners of this type combined with definite limitations with respect to efficiency and tube and furnace life at high ratings has caused the rapid development of the mechanical burner during recent years. Several burners of this type are available but those that are now most favoured atomise the oil by forcing it through atomising nozzles at high pressure. Oil pressures varing from 100 pounds to about 250 pounds per square inch (7.0 to 17.6 kg. per sq. cm.) are used. The oil is generally well heated before entering the burner, oil temperatures running as high as 200 to 250° F. (93 to 121° C.) and occasionally 280° F. (138° C.).

These burners generally produce a spray in the shape of a very flat cone and provide for air admission through a circular opening surrounding the oil spraying device. The air is in some cases given a rotary or helical motion so that it adds to the turbulent condition of the burning oil as it mixes with it.

Properly designed and operated mechanical burners give a remarkably high efficiency, both gross and net, and a very uniform efficiency over a wide range of boiler ratings. Boilers equipped with such burners are operated for long periods at boiler outputs equivalent to 250 per cent. of builders' rating, that is, a transfer of about 8,400 British thermal units per square foot (22,800 kg. cal. per sq. m.) of boiler surface and hour.

Exact comparisons between the efficiencies obtainable with steam atomising burners and with mechanical burners are difficult to obtain because it is seldom possible to find tests of the two types

which have been made under conditions equally favourable to each. However, such a comparison may be put in general terms as follows.

At or below boiler outputs approximating builders' ratings the gross efficiency of the two types is approximately the same and gross boiler and furnace efficiency, exclusive of economisers, may be expected to be somewhere between 80 and 83 per cent. In the case of the steam atomiser the combined efficiency may be expected to drop about 6 or 7 points on the efficiency scale by the time an output equal to twice builders' rating is obtained, while with the mechanical burner double this range can be obtained with only half as great a loss of efficiency.

Many of the mechanical burners may be operated with forced draft, that is, air is supplied them under pressure. This feature assists greatly in maintaining high efficiency as well as in extending the range of boiler output attainable. Forced draft has probably never been successfully applied to steam atomisers in stationary practice.

Furnaces equipped with steam atomising burners are provided with furnace volumes varying from about 1.25 cubic feet to 2.5 cubic feet (0.035 to 0.071 cu. m.) per rated boiler horse power, that is per 3,354 British thermal units per square foot (9,098 kg. cal. per sq. m.) of boiler heating surface and hour. The exact volume that should be provided depends upon the efficiency desired, the character of feed water and the rating to be obtained. In general it may be said that a liberation of not more than 20,000 British thermal units per cubic foot (178,000 kg. cal. per cu. m.) gives the best results with respect to efficiency and maintenance provided the shape of the furnace is such that the flames do not impinge on tubes or refractories. Such furnaces may be driven to a liberation of about 30,000 British thermal units per cubic foot (267,000 kg. cal. per cu. m.) for long periods and to 40,000 or more British thermal units per cubic foot (356,000 kg. cal. per cu. m.) for periods of an hour or so.

Mechanical burners do not require as large furnace volume as steam atomisers. Installations now operating satisfactorily are proportioned to liberate about 50,000 British thermal units per cubic foot (445,000 kg. cal. per cu. m.) for long periods and have been driven satisfactorily to 80,000 British thermal units per cubic foot (712,000 kg. cal. per cu. m.). It is frequently found

commercially best to take advantage of this large liberating capacity for the purpose of driving the boilers at high rates instead of economising on furnace volume.

Thus modern installations of this sort have been given about 2.5 cubic feet (0.071 cu. m.) of furnace volume per unit of boiler rating and can be driven continuously at three to three-and-a-half times builders' rating with high efficiency throughout.

The actual operating efficiencies of oil fired boiler rooms are in general more easily maintained close to test values than are stoker fired installations. This is particularly true in the case of mechanical burners. Much of the success attained depends upon the character of the personnel and supervision, and the instruments supplied, but it is much easier to check the departure from best conditions in oil fired than in stoker fired equipment and the result of improved adjustments is almost instantaneous. The better oil fired boiler rooms operate over long periods at gross boiler room efficiencies at from 94 to 96 per cent. of test values at corresponding ratings.

V. GAS.

The only gases which are used to any extent in the United States for steam boiler firing are Natural Gas and Blast Furnace Gas.

Natural gas is a very comprehensive name which is used to designate all combustible gases obtained from wells drilled in the earth's surface. These gases vary from a typical "dry gas," consisting almost entirely of Methane (CH_4), to "casing head gas," which is really a collection of the most volatile constituents of petroleum oils.

Natural gas is produced in about twenty-three of the States at the present time, but the greater part of the entire output comes from West Virginia, Oklahoma, Pennsylvania, Ohio, California, Louisiana, Kansas and Texas. The quantities produced by the different states vary from a maximum of about 39 per cent. of the country's production in West Virginia, through the states in the order named down to about 2 per cent. of the country's production in Texas. The total annual output of the country is about 795,000,000 thousand cubic feet (22,514,400 thousand cu. m.). In heat value this is equivalent to about 30,000,000 tons (27,216,000 metric tons) of good bituminous coal. It is probable that much less than one third of this total quantity is used for

steam production so that it is apparent that this fuel is not responsible for any great part of the country's steam development.

As indicated above, the composition of natural gas varies widely from well to well and from field to field. At one extreme is a gas containing more than 99 per cent. of Methane mixed with small quantities of such gases as Ethane, Carbon Dioxide and Nitrogen. The high heat value of such gases is about 1,000 British thermal units per cubic foot (8,900 kg. cal. per cu. m.) measured at 60° F. (15.6° C.). The density is about 0.57 referred to air as unity. Other gases are much poorer in Methane but very rich in Ethane, containing roughly 40 per cent. of Methane and 60 per cent. of Ethane Such gases have a high heat value of about 1,500 British thermal units per cubic foot at 60° F. (13,000 kg. cal. per cu. m. at 15.6° C.) and a density of about 0.86 referred to air as unity. Other natural gases contain comparatively large quantities of Nitrogen, some running as high as 8 to 9 per cent. The high heat value of these gases is usually found to be in the neighbourhood of 950 British thermal units per cubic foot at 60° F. (8,500 kg. cal. per cu. m. at 15.6° C.).

Many natural gases as they come from the well contain small quantities of the higher members of the various hydrocarbon series, members which would be volatile liquids at normal temperature and pressure if existing alone. Such constituents are now frequently separated by combined compressing and cooling and made available for sale as solvents, cleaning fluids, and as volatile blends for motor fuels. The result is the sale of a poorer gas to the ultimate gas consumer.

The standard method of transmission of natural gas is by pipe line and many of these lines are of great length, as producing field and market are widely separated. The gas is highly compressed both for the purpose of supplying the necessary pressure differential to cause flow and for the purpose of decreasing to a minimum the size of line required for transportation. It was the condensation of certain volatile constituents in connection with such compression and transmission that first called attention to the possibility of recovering valuable liquid hydrocarbons from such gases.

When the supply of gas is adequate and the line is not overloaded the gas generally arrives at destination with a pressure between 50 and 100 pounds per square inch gauge (3.52 and 7.0 kg. per sq. cm.). It is ordinarily reduced to some lower pressure,

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say 20 pounds per square inch (1.4 kg. per sq. cm.), for metering and then to a pressure of a few ounces for burning.

Metering of large quantities is usually effected with a pitot tube device or by means of an orifice in a thin plate. The necessary corrections must be made for temperature and pressure variation when substantial accuracy is desired.

Natural gas is such an ideal fuel for domestic use and for industrial heating of various sorts that such uses are given the preference, only the surplus above such demands being ordinarily available for steam production on a commercial scale. In many locations domestic heating requirements actually exceed the available supplies during the winter months, so that gas is available for steam generation only during the warmer months of the year.

In most places where natural gas is used extensively for steam generation its supply is more or less uncertain, due to such seasonal limitations or to the exhaustion of wells or to the development of higher priced markets. As a result many gas fired boilers are equipped for burning two fuels, such as gas and oil or gas and coal.

The comparatively small number of installations combined with the uncertainty of supply and the consequent unwillingness to spend large sums in the development of equipment has resulted in a rather heterogeneous practice. Almost every user or district has experimented independently with burning equipment and has had to solve his or its own problems.

Some of the solutions represent developments of oil burners or blast furnace gas burners while others are nothing more than elaborations of the ordinary laboratory type of Bunsen burner. Many burners have used blasts of air at high pressure and some have even used steam for mixing the gas and air. Others have used air and gas at pressures obtainable with high speed fans, depending on high jetting velocity for adequate mixing. Many installations have directed the jets of air and gas against piles of fire brick arranged in checker work formation, with the idea that this would serve both as a mixing and an igniting device. Experience has demonstrated that proper size and shape of furnace, combined with proper burners, makes the use of such refractory targets entirely unnecessary.

At the present time there are in successful use two radically different methods of firing with natural gas. In one the necessary number of burners is inserted through the front or rear wall

of the furnace as in the case of oil burners, and the general direction of gas travel is horizontal as it leaves the burner and enters the furnace. In the other the burning equipment is placed at the bottom of the furnace, lying on the furnace floor or hearth, and the general direction of gas flow is upward from the burner into the furnace.

Two distinctly different varieties of burners for installation in front or back wall are available and are in use. One of these may be called the single mixer device. It takes many different mechanical forms but its essential characteristics are that one gas supply tube and one air supply tube are combined to form a single mixing tube and single burner. These burners are commonly designed to burn a maximum of about 1,800 to 2,000 cubic feet (51.0 to 56.6 cu. m.) of gas per hour but operate best when burning not more than 1,200 to 1,500 cubic feet (34.0 to 42.5 cu. m.). Much depends on the shape of furnace, distance from burner to tubes and area of hot refractory walls as compared with exposed area of cold tubes.

These burners generally require a gas pressure of from 8 to 15 inches (203 to 381 mm.) of water and give a blow pipe type of flame when operating at high ratings. They ordinarily take the form of an air tube within which is contained a gas tube, the latter being arranged to admit many small jets of gas into the stream of air so that gas and air are well mixed before entering the furnace. The draught within the furnace is depended on for air flow, the quantity of air being controlled by shutters or dampers on the air tube. The gas flow is regulated by a cock in the gas line.

The other type of burner used in front and back walls may be called the multiple mixer device. It is so designed that each complete burner consists of a collection of very small burners. The underlying idea is to obtain most perfect mixing before entrance to the furnace so as to burn with a very short flame. Burners of this sort when properly operated give the desired "soft flame" which is much less destructive of refractories and tubes. Such units operate on comparatively low gas pressures, say 2 to 8 inches (51 to 203 mm.) of water. Single units now in use are capable of burning satisfactorily from seven to ten times as much gas as the larger, single mixer device already described. The multiple mixer type is also more flexible than the other, as good results can be obtained over a much wider

range by adjustment of gas pressure and air shutters or dampers.

Burning arrangements located on the hearth take the form of a number of parallel pipes connected at one end into a gas header and projecting into the furnace near the floor or hearth. They are supported a short distance above the hearth and provision is made for entrance of air below them so that during operation they are bathed in air which later supports combustion. These gas pipes carry small lateral or vertical extensions, each of which is perforated and forms the gas supply for an individual burner. Over each extension is placed a short iron or fire clay tube which corresponds in function to the tube of an ordinary laboratory type of Bunsen burner. This tube has air holes or slots at its lower end and gas and air mix on their way upward in the tube. A floor of brick or tile is supported above the hearth, and at such a level that these tubes just project through it.

With burners that give a soft flame and with furnaces designed to give adequate distances from walls and tubes it is possible to operate continuously with a liberation of from 35,000 to 40,000 British thermal units per cubic foot (311,000 to 356,000 kg. cal. per cu. m.) of furnace volume. Boiler and furnace efficiencies, exclusive of economiser, vary between about 75 and 80 per cent. under test conditions with the best equipment, and with good attendance these values can be very closely approximated in daily operation. However, much gas burning equipment is in use that is not capable of giving better than 65 to 70 per cent. on test, and operating results are frequently of the order of 50 per cent.

Most boiler installations burning natural gas are limited to comparatively low rates of output because of insufficient furnace volume or imperfect burners or burner installation. It is possible to obtain economically, rates of heat transfer equal to about 9,000 to 10,000 British thermal units per square foot (24,400 to 27,100 kg. cal per sq. m.) of boiler heating surface and hour, but most existing installations are probably limited to about half of this figure.

Nearly every operator who has used natural gas has experienced trouble from pulsations within the furnace. At times these are so severe as to suggest disruption of the furnace walls. It has been shown conclusively that such pulsations result from improper combustion which is generally caused by imperfect mixing of gas and air. They are in the nature of explosions resulting from a mass of hot gas coming suddenly into contact with an adequate

air supply. An operator naturally tries to use the minimum possible quantity of excess air and the nearer such conditions are approached the more perfect must be the mixing if pulsations are to be avoided.

Combination furnaces were referred to above. When oil and gas are to be used interchangeably it is generally simplest to arrange for removal of one set of burners and installation of the others when a change is to be made. This makes it unnecessary to protect idle burners from the heat of the furnace. However, some combination burners are in use. These are arranged to feed either oil or gas as desired, the combustion air sweeping over and cooling the parts not in use. When gas and stoker firing are to be combined the gas burners are usually installed in the bridge wall or rear wall of the furnace. They may then be removed and the openings bricked up when it is desired to use the stokers. When gas is to be burned the stoker is protected by proper covering, as with a layer of ash covered with steel plates which are in turn protected with a covering of fire brick.

The generation of steam with blast furnace gas is restricted to plants producing such gas, and to immediately adjacent properties. Much of the gas is still burned very inefficiently by admitting it to the furnace through a single, wide, rectangular nozzle and depending upon mixture with air in the furnace. This naturally gives an excessively long flame and inefficient combustion. Boiler ratings are generally low and the efficiency attained with such devices seldom exceeds 50 per cent.

Many better forms of burner are in use, some of them being copied from European practice. In some of these better burners a certain amount of air is mixed with the gas in the burner itself, and a secondary supply is admitted around the jet as it enters the furnace. In some, both primary and secondary air are induced by gas velocity or furnace draught, while in others air is supplied under a positive pressure. In a few types all or practically all the air is supplied as primary air under pressure. Such burners contain an explosive mixture and in many cases they are provided with screens to prevent flash back. With the newer and better burners, boiler efficiencies of the order of 70 per cent. are attainable.

Practice differs with respect to cleaning and cooling of the gas. Practically all of the earlier installations used raw gas and conserved the sensible heat, but there is now a marked tendency to-

ward cleaning and cooling because of the better results obtained with the more complicated burners now in use and because of the resultant greater degree of cleanliness of the boiler.

VI. COMBUSTION CONTROL.

The engineers of the United States have made rapid strides in the past decade in the development of combustion control equipment. Two decades ago most boiler rooms were supposed to be completely equipped when they contained steam gauges and water gauges. A few operated by engineers with advanced ideas contained draft gauges, and occasionally a feed water thermometer. Now the array of instruments deemed necessary for proper operation of the boiler room of an up-to-date plant suggests the electric switch gallery of bygone years.

The first efforts toward providing proper boiler room instruments were aimed at supplying means of showing the fireman what state of affairs actually existed. No effort was made to do more than this as it was felt that the actual control of the fires must be by human hand actuated by human brain, and that instruments could be useful only as guides to indicate the results of adjustments made and the need for and direction of further adjustments.

At this stage of development the instrumental equipment generally consisted of some or all of the following :—

A flow meter to indicate the instantaneous steam output, and in some cases to record it also.

A draft gauge to indicate draft at some critical point within the furnace. Occasionally a recording device was added.

A draft gauge to indicate the draft at the boiler side of the damper. This also was occasionally made recording.

A pressure gauge reading in inches of water to show pressure under the fire when forced draft equipment was used.

A carbon dioxide indicator and recorder arranged to indicate and record the carbon dioxide content of flue gases leaving each boiler.

A temperature indicator of some sort to indicate and possibly record the flue gas temperature.

These instruments were intended primarily to guide the fireman in the minute to minute control of his fire, but they were also useful in indicating the condition of equipment. Thus the flue gas temperature should run high at a given rating if the boiler is

excessively dirty or if large leaks develop in the baffles. The drop through the boiler should decrease if large baffle leaks develop. Such things and many others can be determined inferentially from indications and records of this sort.

With proper instrumental guidance some boiler operators became exceedingly skilful in controlling fires and the boiler-room efficiency increased to such an extent that the carrying charges and maintenance and calibration charges on the necessary instruments became of small consideration. Other operators, generally in the smaller plants and in plants distant from large centres of population, proved incapable of the mental efforts required to analyse the meanings of the various indications and to adjust their fires accordingly.

It was also observed that even in the hands of the best operators and with a steady load and practically perfect feed water control, it was impossible to divide the load between boilers perfectly. Each boiler would show an exceedingly variable output, whereas the total output of all boilers would represent a practically steady demand. This would naturally follow from the efforts of individual firemen to hold the steam pressure on their boilers and at the same time maintain good fires.

Such considerations led to attempts to devise more pretentious fire control equipments. Some were aimed at control of individual boilers in such ways as to make necessary less mental capacity in operators, while others aimed at automatic control of the complete boiler room.

The simpler devices, intended to give satisfactory operating indications, have taken many forms and a few give promise of surviving. One of the most interesting and successful is based on the assumption that when a given fuel is burned in a certain setting, a given quantity of flue gas should result for each given steam output. More flue gas means excess air, and less flue gas means a deficient air supply. The boiler itself is used as an orifice meter, the drop in pressure through its gas passages being used as a measure of the quantity of gas flowing. The differential is indicated and recorded by a pen moving over a chart on which is also indicated and recorded the steam flow. The coördination is such that gas flow and steam flow indications practically coincide and follow each other when the furnace is properly controlled. In most cases a record of flue gas temperature is also included and draft gauges are also supplied. Such inferential

instrumental equipment works out exceedingly well when boiler operators do not have sufficient intelligence to use direct indications for control purposes.

The idea of controlling the entire boiler room automatically or semi-automatically is now coming rapidly into prominence. Certain rudimentary developments of this idea can be found far back in the history of boiler room practice. Thus complete damper control operated from station steam pressure has been used in many places for several decades. Similarly, automatic control of the speed of forced draft fans and of stokers on the basis of steam pressure has also been in use in some places for many years.

Recently, however, there has come to the fore the idea that all controls might be handled automatically to follow steam demand, leaving it possible for the firemen to superimpose a manual control of individual parts as may be necessary to achieve the best results with each individual boiler. The picture is somewhat like that of turbine governing. The speed actuated governor takes care of normal variations in adjustment necessitated by variations of load, but the operator manually effects distribution of load between units, takes care of plant frequency, emergency conditions, and so on.

These complete control equipments are as yet in their infancy and very few are in use, so that it is impossible to say just how successful they will ultimately prove to be. Most of them base control upon station steam pressure or steam flow or a combination of the two. The more complete schemes attempt to regulate everything, such as under-fire pressure, stoker speed, and draft in furnace. In some cases, the furnace draft is regulated individually with respect to each boiler so as to maintain proper furnace conditions corresponding to local variations.

Many engineers feel that these control equipments will prove highly satisfactory and desirable, provided they do not exclude the possibility of human control as well. Thus in the case of travelling grate or chain grate stokers local variations in the size of fuel may result in short fires in some furnaces and long fires in others. The operators should be able to adjust the dampers controlling the air supply to the different draft compartments so as to remedy or compensate for such defect.

Other engineers are unwilling to concede the possibility of such complete automatic control, at least for their conditions, but do

believe it possible to use a sort of human master control with a secondary or local human control superposed upon it. Such schemes are generally so arranged that all significant readings are brought to a central gauge board at which is seated the master controller of the boiler plant. From his station he controls fan speeds, stoker speeds and stack or boiler dampers, and the firemen then take care of those minor controls which are necessarily individual with each of the boilers.

Such automatic or human master controls are particularly promising in the cases of pulverised fuel, oil and gas firing, and the more progressive, or possibly the more daring, engineers are now picturing boiler rooms operated from galleries like switchboard galleries with a few operators on the boiler-room floor making minor adjustments and watching for defects in equipment.

RÉSUMÉ.

Cette note donne un aperçu sur la question des combustibles utilisés aux Etats-Unis pour les chaudières, sur leur mode de préparation, de transport et d'emmagasinage, ainsi que sur les types de chauffe employés. L'étendue de cette question est si ample, qu'une description minutieuse conduirait à un document trop volumineux et c'est pourquoi on s'est contenté d'une description générale.

La note est divisée en six parties principales, qui portent les titres suivants: 1-Charbon, 2-Préparation du charbon et emmagasinage, 3-Distillation du charbon à basse température, 4-Chauffage au mazout, 5-Gaz et 6-Contrôle de la combustion.

La première partie donne la situation et l'importance des dépôts d'Anthracite, de charbon Bitumineux et de Lignite, ainsi que les caractéristiques de chacune de ces qualités; ces renseignements sont en effet très importants pour les ingénieurs s'intéressant à l'utilisation des charbons dans les foyers de chaudieres à vapeur. On décrit les différents types de chauffe employés avec chaque variété de charbon ainsi que tous les détails de construction et d'équipement des foyers. On donne les valeurs maxima et moyennes pour la consommation de charbon par pied carré de grille, pour la chaleur dégagée par pied carré de volume du foyer, ainsi que les essais effectués pour la détermination du rendement du foyer et de la chaudière. L'emploi du charbon pulvérisé est également décrit dans ce chapitre.

La seconde partie traite la question de la réception du charbon, des moyens employés pour le décnarger et l'emmagasiner, pour approvisionner les silos de la salle des chaudières et alimenter chacune de ces chaudières. Des informations sont données concernant l'emmagasinage de charbons de qualités différentes et les divers procédés d'emmagasinage employés.

Le chapitre concernant la Distillation du Charbon à basse température ne donne pas de détails sur les méthodes employées, ni sur l'installation, car aucun de ces procédés n'a réussi commerciallement aux Etats-Unis. C'est

pourquoi le dit chapitre ne décrit que l'état actuel de la question, et laisse espérer que dans l'avenir l'adoption d'un tel procédé sera justifié.

Le chapitre concernant le chauffage au mazout donne la situation des différentes régions produisant le mazout, ainsi que les caractéristiques des différents mazout disponibles. Les méthodes de transport, de manutention et de mise en magasin sont décrites brièvement. On y donne la description des différents foyers de chaudiéres et les caractéristiques de chaque type. Des valeurs numériques sont données pour le volume des foyers de chaudières, ainsi que leur rendement pendant les essais et en marche normale.

La question du gaz examinée dans le chapitre V. est identique à celle décrite dans le chapitre précédent, concernant le mazout. On examine aussi bien le Gaz naturel que celui de haut fourneau pour la production de la force motrice.

Dans le dernier chapitre on s'efforce de décrire le contrôle de la combustion. Les ingénieurs des Etats-Unis ont travaillé activement cette question, et il est probable que c'est dans ce pays que le contrôle de la combustion est le plus répandu.

PREPARATION OF FUELS—FUELS GENERALLY AND COAL

DISCUSSION

Chairman: DR. D. S. JACOBUS (U.S.A.)

Thursday, July 3rd. *Morning Session*

THE CHAIRMAN, in opening the session, reminded them that the time was limited, and there were fourteen papers that were to be presented and discussed that morning. This meeting would certainly serve as a milestone in the history of engineering, in showing the progress which had been accomplished and in effecting an exchange of ideas. It was only through getting together and exchanging ideas that they could make real progress ; and they could never from such a Conference gain more than they were willing to give. It was, therefore, the duty of each of them to give where they thought they could help, and with the full knowledge that they would certainly receive help in return. He pointed out that these papers were, in general, the same ; they dealt with the gasification and carbonisation of coal ; the discussion might, therefore, be presented in a general way as bearing on all the papers.

The first papers were on *Complete Gasification of Coal,* and *Testing Department for Fuels, Technical College, Vienna,* by Dr. Hugo Strache. He was not present, however, and there seemed to be no one delegated to present these papers. The next paper was, *The Liquid By-products of Coal Carbonisation as Sources of Power,* by Mr. W. Gordon Adam. In Mr. Adam's absence, Mr. F. M. Potter presented the paper.

PROF. H. E. ARMSTRONG (*Great Britain*), then presented his paper *The Treatment of Coal, with special reference to Low Temperature Carbonisation.* He added that at the end of the paper there was a résumé in French for which he was in no way responsible, but it was a perfect summary.

DR. A. F. ENSTRÖM (*Sweden*), after presenting his paper *Preparation of Fuels in Sweden,* remarked that there was one question in connection with liquid fuels, which was quite new, to which he wanted to call attention. It was the idea of installing gas producers, charged with charcoal, on automobiles. That proposition was of course of very much interest to countries like Sweden, the other Scandinavian countries, Canada, and so on, where they had big forests and could easily produce charcoal and run cars cheaply in the big areas in the country where communications were not very much developed. He had heard that this charcoal gas-producing system was used, to a certain extent, in France and Austria, and he would be very glad to hear from the representatives of those countries how far this development had advanced.

MR. OSKAR TAUSSIG (*Austria*), in answer to the question as to what had been done in Austria, pointed out that they had similar conditions to those in Sweden. They had no coal, or very little coal, and they had no oil left ; but they had, for farming purposes, very small motor plants in Austria which had been using gasoline or benzine. After the war they had no oil at all ; they could not even buy it. Therefore something had had to be done, and in Austria there had been developed to a large extent the system of using small charcoal gasifiers. Those gasifiers were of various designs ; they were not at all complicated, because for such a purpose it was necessary to have

very simple apparatus so that it could be run by anybody. So far as the utilisation of charcoal for motor cars was concerned, it seemed to have been a great success. This system was mostly used for heavy motor cars, because it was not worth while in the case of light machinery. With regard to producing charcoal on a medium scale, it seemed to be not only a question of diminishing the scale, but of getting entirely new systems for medium plants. The question did not seem to be solved yet, and they would be very glad to hear something of the progress in that direction.

PROF. ARMSTRONG, called attention to what he described as the most interesting specimen of low temperature carbonisation he had ever seen. It was a length of an 8-inch core of Coalite, made from Kent coal. The great disadvantage attending the use of raw Kent coal was its extreme friability. When this product was examined, it would be found that it was not friable in the ordinary sense. It had been produced by carbonising in iron at a temperature of about 600°C. during four hours ; the yield, in this particular case, he thought, was about 80 per cent. of the material. It was not a high oil-yielding coal. He believed that the carbonisation had been effected, using the coal finely powdered, in the same time that it took to carbonise coal in small pieces, such as was obtained by washing, in a tube of 4 to 5 inches diameter. This illustrated the value of compacting the coal before distilling. With reference to the discussion on a charcoal gas-producing system, he would like to point out that he had long been a believer in the use of a material of such a kind for motor purposes in the future. It was possible by adjusting the conditions of carbonisation to get a fuel of any degree of combustibility. Before we committed ourselves completely to an oil policy, we should do well to consider the preparation and use of materials of this kind.

DR. FRANZ FISCHER (*Germany*), then introduced his paper, *The Conversion of Coal into Oils.*

DR. R. LESSING (*Great Britain*), said that there were other papers on the production of oil from coal, either at low or at high temperature. The value of the paper which Prof. Fischer had submitted appeared to be in the suggestions, partly his own and partly those of other workers, which he brought forward with regard to other methods of producing liquid organic substances from coal. As to hydrogenation, on which experiments had been made on a more or less large scale and which, according to him, seemed to have only a limited promise of success, it appeared to be clear, anyway, from his theoretical deductions, that they could never hope to convert the whole of the coal substance into liquid by hydrogenation. That was fairly obvious when they considered the carbon to hydrogen ratio in coal and in oils, quite apart from the question of the oxygen contents of the whole. The most interesting promise he had held out seemed to be the suggestion of a synthesis of liquid compounds from water gas. These were not really hydrocarbons ; in fact, a great many of them were oxygenated compounds from gas. That seemed to be, from the general economic point of view, the one avenue which led him to hope that a less limited amount of liquid fuel could be obtained from coal than he had, so far, been led to expect by mere distillation processes.

MR. B. F. HAANEL (*Canada*), said that he had been led to believe that there was a special plant established in Germany to manufacture, or to convert, coal into liquid fuel, using the Bergius process, and that it would meet with considerable success. He would like to hear from Dr. Fischer whether that plan was in operation, and whether it was meeting with success.

DR. FISCHER, denied that the process had anything to do with Bergius. Bergius effected the hydrogenation of coal, and they made a synthesis of oils from carbon-monoxide and hydrogen.

DR. C. H. LANDER (*Great Britain*), said that he was in agreement with many of Prof. Armstrong's remarks, especially the necessity, in the very difficult problem which had now been experimented on for more than twenty-five years, for complete co-operation between chemists and engineers. Unlike

many other branches of engineering, whilst these problems might be experimented upon and reach perfection in the laboratory or even on the intermediate scale, as soon as they got to the working scale where problems of heat conductivity, different thicknesses of material, and so on, came in, many theories went by the board, and results could only be arrived at by a practical trial. Prof. Armstrong had said that there had been no concerted attempt on the problem. He begged to differ from him in that respect. In his own paper entitled *Low Temperature Carbonisation*, he had tried to sketch what had occurred in Great Britain since the formation of the Lord Fisher Commission in 1912, when they had explored the question of oil fuel for the Navy. Of course it was not for him to claim that it had been in any way perfect. Much organised work had, however, been done, but unfortunately there were many roads open to them in effecting the translation from the laboratory scale to the large scale, and most roads which had been explored had proved to be blind alleys. In Great Britain, probably something like fifteen or twenty different suggestions had been tried—some under Government auspices, some financed by private capital; and the problem was not yet completely solved. He would say unhesitatingly that many processes which had been tried, had succeeded in producing good coke and good oil in sufficient quantity, but they had, up to the present, always failed commercially, either because the plant had a very short life, with the result that the capital costs became too heavy, or maintenance costs became too heavy, or the plant itself was much too complicated for it to be a financial success. However, there were several types of plant in the country now which were becoming very much more simplified. As he had said before, he hoped a solution was within sight.

He called their attention to a portion of his paper which laid some stress on the necessity for study of the oils, in order to overcome certain difficulties that existed at the present time if those oils were used for fuel purposes.

THE CHAIRMAN, observed that Prof. Armstrong had said that the days of raw coal were numbered, but he had also said that complete economic success had not yet been demonstrated. From that, and what had been said in the papers, it might be well to ask whether we were to continue to use raw coal to the present extent, or whether the distillation of coal would become more generally practised.

SIR RICHARD REDMAYNE (*Great Britain*), said that there was no doubt that we must use coal by way of distillation, and it seemed to him that the question of low temperature carbonisation really divided itself into two parts: (*a*) the consideration of the utilisation of fuel for domestic services; and (*b*) the utilisation of fuel for the generation of power. He thought that in dealing with the question of distillation, they must consider it from those two aspects. The difficulty had been, and still was, from the domestic point of view to produce a low temperature carbonised fuel which could be produced on a commercial basis, and in such a condition as to permit of transportation with a minimum of breakage.

There had been great difficulties in producing a fuel commercially which would bear the rough and tumble of transport. From the point of view of the generation of power, it seemed to him that the question was very much more simple. What they had to aim at there was to get as large an output as possible and continuity of throughput per retort. The production of a domestic fuel in this case was not so serious as in the first case, because they could consume the solid fuel as well as the waste gas directly—on the spot—for the generation of power. He considered that in endeavouring to answer the Chairman's question, which, he thought, went to the root of the whole matter, they must consider these two problems: the domestic side and the power generation side.

PROF. ARMSTRONG, asked Sir Richard Redmayne, with his special knowledge of mining, to deal with the question of the separation of dirt from coal, with regard to the economic advantages, and perhaps also the difficulties. This was a matter of extreme importance in connection with the whole problem.

DISCUSSION

SIR RICHARD REDMAYNE, agreed that the point raised by Prof. Armstrong was a very important one. It was a point which had come very prominently forward during the late war, as everybody interested in the making of gas had realised at the time. The percentage of dirt in coal had doubled during the war period. When the demand for coal exceeded the supply, the public would take almost any sort of coal; they had to be content with it and the collieries got rid of inferior coal or coal from stocks, and were not so careful in mining and preparing the coal for market; it was then undoubtedly that the percentage of dirt went up. He supposed that there was not that intense care exercised underground or on the screen, that there was when the collieries were scrambling for orders. At the present time they would find that the coal was becoming very much cleaner, because the demand was not quite as great as it had been. Undoubtedly it was very bad economics to sell coal plus dirt. To endeavour to carbonise coal containing a high percentage of dirt was absurd. He was inclined to suggest as a possible solution of the difficulty that which the United States had so largely adopted, namely, the purchase of coal on an analysis basis.

THE CHAIRMAN, here remarked that Mr. Leonard Harvey had come into the room. His paper had been put down both for this meeting and for the meeting in the other hall. He asked if Mr. Harvey would like to say anything.

MR. LEONARD C. HARVEY (*Great Britain*), said that if it were possible to combine the distillation of coal with subsequent use of the residue in pulverised form, then by the collection of the volatile constituents of coal, Great Britain, for instance, could undoubtedly be self-supporting in respect of heavy or light oils, motor spirit, and fertiliser materials. In the distillation of coal there was a greater or lesser quantity of high calorific value surplus gas. The great drawback to distillation had been the disposal of the gas produced. There were suggestions at the present time that this gas should be supplied to the municipalities; that low temperature distillation plant should be put up and the gas delivered to holders, so that this could be utilised at a low cost by the municipal gas supply companies. That was a very good idea, but there might still be a need for other methods of using power and distillation of gas. He had made the suggestion that apart from the sulphate of ammonia that could be directly recovered from the coal in process of distillation, the fixation of nitrogen from the air had now become nearer to a successful solution. There had been a plant operating in Great Britain. That plant was at Stockton, and was stated to be a commercial success; it was a very great advance in Great Britain in the direction of nitrogen fixation. As to the distillation of coal, there was a big market for the residue in solid form for domestic purposes. The chief difficulty that had been experienced in the past with regard to distillation had been the excessive cost of plant. If domestic smokeless fuel were required, this must be produced in lump form, and the only method of doing that in the past had been by the utilisation of vertical retorts, which were discontinuous in their operation, having to be charged and discharged. If they could get continuous distillation plant for producing lump smokeless fuel, or blast furnace coke, this would be of great importance. It was being done or had been tried in America, notably by Mr. Henry Ford, in the continuous retort. But there was also another retort which he had mentioned in his paper which would produce a sufficiently satisfactory residue fuel for subsequent pulverisation, but not for domestic purposes. That was the continuous fusion retort, which was a British production and had started well on its life, which he hoped would be a successful one.

MR. GEORGE A. ORROK (*U.S.A.*), said that in connection with the use of low temperature distillation, or the coke oven with the generation of power, they were not using this now, as it did not pay to do anything of the kind with load factors of the order of 30 to 35 per cent. The coke oven and by-product saving in connection with the power station was a perfectly simple operation, but it cost a lot of money. Gas could be stored a certain length of time; the coke always commanded a ready sale for blast furnaces, for

foundries, and also for domestic consumption. But the by-products were very tender articles. The moment they produced a little more sulphate of ammonia or tar, the market went to pieces and it no longer paid to produce it. If they could be assured that the farmer would buy sulphate of ammonia, for instance, and buy it in quantities, they would be perfectly happy. If they could be assured that the tar distiller would take their tar at a reasonable price, and more than it would be worth for fuel, they would be perfectly happy.

Mr. Harvey had spoken of the pulverisation of the product of low temperature distillation and burning it in power stations. If he did that, it meant that it must be applied directly as a fuel to the boilers in the plant, or else it must be stored. He thought that they had seven or eight experimental low temperature distillation plants in the United States. Some of them had been able to run, some of them had not; but the product would not stand storage. It would burn all right in powdered form. What it was going to cost to powder it no one knew, because the amounts so far had been rather small. Some of the experiments on the making of oils and motor fuels from the by-products, which had been made in the United States, showed that this was possible. The product was reasonably good and probably would be used, when the price of motor spirit rose to a sufficiently high point to make it commercially possible.

With reference to the preparation of coal, he said that the place to take the dirt out of the coal was at the bottom of the coal mine. They could never do that with the present labour conditions. The coal could be hoisted to the surface and put through a dry cleansing apparatus, but it cost a lot of money; it could be washed, but that cost a lot of money. The place to take the dirt out was down at the bottom of the mine and not after it had been loaded in the car.

MR. HAANEL, said that the disposition of fuel in Canada was in the extreme east and west, with a very large proportion of a very highly industrialised area in the centre of Canada devoid of coal of any description, a fact which had made that area almost entirely dependent on outside sources for fuel. They had no large oil fields and the oil fields they had in Ontario were rapidly approaching depletion.

The principal problem with which they were faced in Ontario and Quebec, the most populous and the most highly industrialised provinces of Canada, was that of supplying a domestic fuel. Previously this area had depended entirely on American anthracite, but that fuel was becoming of inferior quality. In order to improve this situation the Dominion Fuel Board, which had been created by the Federal Government, and of which the speaker was a member, had been conducting investigations to ascertain the feasibility of erecting larger by-product recovery coke oven plants at strategical points, with a view to utilising the Nova Scotia fuels in the east to produce a domestic coke, having anthracite characteristics, at a cost which would permit it to be used for domestic and industrial purposes. If such coke oven plants could be established on a commercial basis and supply a portion of the demands for the 5,000,000 tons of anthracite which were required by those two Provinces every year, and at the same time supply a gas which would take the place of the retort gas now manufactured in all the large centres, they would have done something towards assisting in the use of Canadian fuels.

The only fuel resources which they had in those two Provinces were their peat areas, which were very large and contained a very large quantity of fuel which could be converted into a domestic, and for some purposes, industrial fuel. Another Board which had been created by the Canadian Government had completed five years of investigation concerning methods for converting this vast quantity of fuel into a suitable product. They had employed the air-dried peat process without altering the process, but by devising machinery which was capable of carrying out automatically the various stages in the operation required in the manufacture, they had been able to produce a ton of fuel at 25 per cent. of moisture for 3½ dollars, including overhead expenses, interest on investment, etc. They were also importing more Welsh anthracite coal; this in some cases could only be burned

with difficulty, since it was shipped very largely in the form of slack.

He considered that the most important problem which faced not only Canada, but the entire British Empire and the whole world, was that of liquid fuel and since their country at that time could not boast of having any large commercial oil fields, they had been concentrating their attention on research work and investigations, with a view to ascertaining whether or not they could utilise their solid fuels as a source of oils by low temperature carbonisation or by other methods. For the purpose of rendering low grade lignites into a form which would enable them to be used successfully for domestic purposes and some industrial purposes, another Board had been created by the Federal Government and two Provincial Governments to discover a process for carbonising and briquetting. This work had been proceeding for five years and a large amount of money had been expended, but no commercial results could be said to have been attained. At the end of their investigation, they had adopted an internal combustion carboniser designed by Mr. Hood and Mr. O'Dell, of the United States Bureau of Mines, on his own recommendation. He was encouraging as much as he could the utilisation of low grade coals in the pulverised form for steam raising. This applied especially to their low grade lignites. These lignites, when freshly mined, contained as much as 30 per cent. of moisture, and in some cases had a high percentage of ash and a low effective heating capacity in that state. When they were exposed to the weather, they disintegrated very rapidly and in a short time some of them passed into a very finely divided powder. So that it would seem that the logical way of utilising them for steam raising was in the pulverised form, because pulverisation had been helped along very materially by nature. At the present time, in the west, they were operating a large central plant which was to use such a low grade lignite in a pulverised form with a moisture content which had never been tried before.

With reference to railway plant, where there were divisional points of 350 or 200 miles, since pulverised fuel could not be stored, it was necessary to supply only a sufficient quantity for 24 hours. That seemed to be the longest period that it was advisable to store pulverised fuel. That meant that it was necessary to have the fuel preparation plant at each divisional point, which would mean that the railways would have to draw raw coal to those divisional points and preparation plants. He asked if there was anyone there who could throw some light on what that would cost.

PROF. ARMSTRONG, said that a carbonised material such as was obtained by heating to about 600° could be safely stored, and therefore could be sent out from the source as the finest dust and conveyed very easily.

He directed the attention of the Conference to the importance of giving less attention to the oil side, and more attention to the solid fuel side. Oil must be in the main a passing fashion—a more passing fashion than coal. Coal might last a few hundred years, but oil would not last many years. He then briefly referred to the way in which the calorific value of coal was determined, by exploding it in a condition of extremely fine division in a bomb-calorimeter under considerable pressure—suggesting that such a process might conceivably be developed for power purposes.

MR. A. H. LYMN (*Great Britain*), in presenting his paper, *The Gas Producer as applied to Large Scale Power Generation*, drew attention to the almost criminal waste of most valuable materials involved in the usual methods of utilising fuels, whereby practically all the by-products contained in coals were thrown away.

Generally, the recovery of by-products was associated in the technical mind with the carbonisation of fuel, and consequently with the introduction of large quantities of coke, and therefore the coal was only partially converted into gas and utilised for the main object. The elimination of the coke reduced the thermal efficiency (*i.e.*, coal to gas) to approximately 25 per cent. The modern gas producer, however, utilised for the main purpose of gas production and power generation practically the whole of the carbon contained in the fuel, combining carbonisation and gasification in one process, and therefore it seemed fair to state that this was the only apparatus which really came into

the region of practical politics, so far as concerned the generation of power by means of manufactured gas (*i.e.*, in contradistinction to natural gas), because the modern gas producer, while recovering far more by-products than a carbonisation plant, would yield in the form of gas 80 per cent. of the thermal units contained in the original coal. Moreover, the capital outlay for the gas producer plant per unit of power produced, was a mere fraction of that required for the carbonisation plant, inasmuch as it had to treat only one-third of the fuel.

MR. R. JARAMILLO (*Chile*), said that for more than fifteen years, pulverised fuel had been used in Chile in connection with cement factories and cement copper furnaces. Owing to the success of pulverised fuel in this connection, the Chilean State Railways had been trying for more than a year to pulverise coal for use in locomotives. They had obtained the pulverised coal from the cement factories and sometimes they had the pulverised fuel stored for a few weeks. In the beginning, they had had some trouble with regard to the honeycombing of tubes of locomotives, but that had been avoided afterwards by a suitable arrangement of the brickwork in the fire box. They had, in Chile, two principal types of coal: one was bituminous of about 13,600 B.Th.U., about 7 per cent. of ash and 2 per cent. of moisture. The other was a lignite of about 9,500 B.Th.U., 4 per cent. of ash and 15 per cent. of moisture. Their ntention was to install a plant that would wash the screens of the lignite and would dry the lignite in the mine, in order to avoid carrying on the railways all this incombustible matter. They had been able to use that lignite with entire success in the more difficult parts of their line. The fire brickwork, that for some time had been the trouble in the use of lignite fuel in locomotives, lasted about 60 per cent. of the time that it lasted on locomotives using the ordinary hard coal fuel.

The CHAIRMAN then closed the session.

PREPARATION OF FUELS

CHAIRMAN: MR. OSKAR TAUSSIG (Austria)

Generaldirektor der Weiner Armaturen-und Maschinenfabriks-gesellschaft, vorm Teudloff und Dittrich

THE WINNING AND UTILISATION OF PEAT

Professor PIERCE F. PURCELL, M.A.I., M.Inst.C.E.
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INTRODUCTION.

The peat deposits, commonly referred to as moors or bogs, are post-glacial deposits of vegetable and plant debris laid down under suitable conditions of moisture. These deposits have been formed under two conditions—*the low bogs*, mainly in shallow post-glacial lakes or depressions from the debris of aquatic plants, whilst the *high bogs* have been formed above the general water levels and largely from the products of the partial decomposition of mosses, but such plants as the cotton grasses and heather also play a considerable part. The process of peatification or humification of the vegetable debris is a complex one; in the earlier stages, bacterial action brings about the decomposition of the celluloses and starches in the dead fibres, but at what stage bacterial action ceases and chemical action continues the process is a matter of doubt.[1] The process of humification is slow and, while evidence shows that, in particular cases, growth has been comparatively rapid, in most cases the formation must have been continuous during a great part of the post-glacial period. The essential condition in all cases seems to be the presence of an abundance of moisture and a moderate temperature. In the lower parts of the deposits the process of peatification is more complete and the quantity of residual fibre quite small, but higher up a greater quantity of fibre is found. In many cases we find mixed bogs in which the lower part of the deposit has been laid down as a low bog formed from aquatics, whereas the upper part is high bog formed from sphagnum mosses. In certain bogs practically no timber is met with, but in others it is met with in layers and in some shallow bogs a very large part consists of undecayed or partially decomposed timber and roots. In considering the methods to be adopted for the winning of peat, the possible occurrence of timber in any bog must be carefully investigated, as it will largely determine the methods to be adopted,

[1] "On Dopplerite: Studies on the composition of Coal." Tideswell and Wheeler. Transactions Chemical Society, 1922; Vol. 121, p. 2352.

and hence it is desirable to give some attention to the methods of formation of these deposits when devising appropriate plans for peat winning.

DISTRIBUTION.

Bogs varying in depth from one to fifty feet are found in most countries. In the Western Hemisphere we find them in the Falkland Islands, Patagonia, along the East Coast of the United States, in the districts surrounding the Great Lakes both in U.S.A. and Canada and further North in Alaska. In the Eastern Hemisphere, large deposits exist in Great Britain, Ireland, Italy, France, Belgium, Holland, Germany, Denmark, Sweden, Poland, Latvia and Russia. Table I. gives the approximate area of bog in a number of the principal peat-bearing countries :—

TABLE I.

AREA OF PEAT DEPOSITS.

Country	*Area in sq. kilometres*	*Authority.*
Great Britain ..	24,000	Thorpe.
Ireland	12,000	Bog Reports, 1809-1814.
United States ..	29,000	C. A. Davis.
Canada	96,000	E. Haanel.
Sweden	19,000	Swedish Peat Committee, 1921.
Norway	12,000	Hausding.
Germany	25,000	Hausding.
Russia	170,000[1]	Hausding.
Finland	100,000	Hausding.

A general idea of their fuel content may be obtained from the fact that the Irish peat deposits are estimated to contain 4,000 million metric tons of standard peat fuel[2] (*i.e.*, peat fuel containing 25 per cent. moisture), whereas those of the United States are estimated at almost 14,000 million tons[3] and from the data available those of Canada should contain about double that amount. In Ireland 14·9 per cent. and in the Southern part of Sweden 11·3 per cent. of the

[1] See " Les Ressources de Tourbe et l'etat de leur exploration dans S.S.S.R." by I. Wicwliajen (Transactions of W. P. C., Vol. I.), in which is given the area of the peat deposits of European Russia as 26,540,000 dessiatines or 290,000 sq. kilometres which is considerably in excess of the figure given by Hausding for the whole of Russia.—(AUTHOR).

[2] " The Winning, Preparation and use of Peat in Ireland " ; Reports and other Documents. Published by H.M. Stationery Office, 1921.

[3] " Peat Fuel Resources of the United States," by C. C. Osbon, published in " Combustion," Aug., 1922.

surface area of the country is covered by peat, and from the figures in Table I. it would appear that the world's peat deposits must exceed 600,000 square kilometres in area, capable of producing an amount of standard peat fuel which may equal 200,000 million tons, equivalent to, say, 100,000 million tons of coal.[1]

The annual production of peat fuel has fluctuated considerably during the war and post-war years, the following being the *maximum* figures recorded in each case for the principal peat-producing countries :—[2]

TABLE II.

Country.	*Output (metric tons).*
Russia	10,000,000[3]
Ireland	7,000,000
Germany	3,000,000
Denmark	2,250,000
Sweden	400,000
Italy	150,000
France	125,000
Norway	88,000

In countries possessing only moderate supplies of native coal or lignite and where imported coal is expensive, these deposits play quite an important part in the fuel supply of the country. For instance, in Ireland the author has estimated that peat provides over 43 per cent. of the total fuel requirements of the country for domestic and industrial power and heat.[4] Again, in the Province of Ontario there are no coal deposits and although Canada has considerable reserves of coal, these are so far distant from Ontario that to render the Province more independent of imported coal, it is quite possible that peat fuel will be utilised to a greater extent than at present. In Germany, owing to post-war conditions in the Ruhr, strong efforts have been made to develop peat and lignite on an increasing scale.

The possibility of utilising these deposits for fuel or power purposes presents itself for consideration from two distinct points of view;

[1] 600,000 sq. kilometres of bog, assumed 3 metres thick, equals $1{\cdot}8 \times 10^{12}$ cub. metres, and if the average moisture content is 92%, would produce 160 thousand million metric tons of standard peat fuel.

[2] These figures must be taken with reserve, as reliable figures are unobtainable; see Report Fuel Research Board 1922-23, First Section, "The Production of Air-dried Peat," H.M. Stationery Office.

[3] The production of peat fuel in European Russia in 1923 was only 2,400,000 tons, c.f. paper by I. Wichliajew.—(AUTHOR).

[4] "The Winning, Preparation and Use of Peat in Ireland"; Reports and other Documents. Published by H.M. Stationery Office, 1921.

first of all, can they be utilised at present in competition with coal and other fuels and, secondly, to what extent are they capable of extending our fuel resources when the present fuels—coal and oil —are exhausted ?

As the life of the British coal deposits at the present rate of exploitation is estimated at over 500 years, many will think that this contingency is so remote as not to merit consideration but, after all, 500 years is not an unlimited span in the history of European civilisation and long before that time, if the present procedure is adhered to of working on the thicker and more payable coal seams, the day will come when we must fall back on our reserves, which will then largely consist of thin and difficult seams and at greater depths. While even those who are sceptical as to the prospects of present day peat development will allow that, when the coal reserves are seriously depleted, the peat deposits will constitute a valuable addition to our fuel resources, any impartial investigator must admit that more has been accomplished on sound lines towards the practical and economic development of the peat industry by Wielandt, Strenge and Baumann-Schenck in Germany and by Moore and Haanel in Canada during the last fifteen years, than in all previous experience.

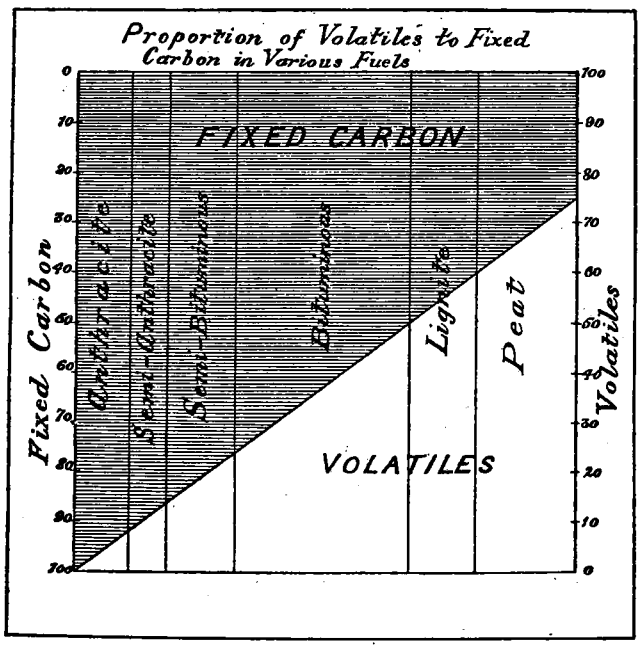
PHYSICAL PROPERTIES OF PEAT.

Before considering the more practical aspects of the winning and utilisation of peat, it may be as well to deal briefly with the general characteristics of peat. Naturally, owing to the wide distribution of peat and the extraordinary variety of plant life which has contributed to the production of these deposits, wide differences manifest themselves in analysis. As taken from the bog, raw peat may contain from 5 to about 12 per cent of dry material, higher figures being only found in bogs which have very special drainage conditions. The ash in the dried sample may be as low as 0·5 per cent. and in some cases as high as 25 per cent., but if a few extreme cases be excluded as well as samples taken from the bottom 20 cms. of the bog, when the sampling tool often includes matter taken from below the bog, 2 per cent. to 6 per cent. of ash may be assumed as fair limits. For sixty samples of Irish peat taken at all levels from the surface to depths of 30 feet all over the country, the average was 3·72 per cent. " Fixed carbon " varies from 25 per cent. to 35 per cent., the " volatiles " from 60 per cent. to 75 per cent., and the carbon-hydrogen ratio from 8 to 12. When by-product recovery is attempted, the percentage of nitrogen is of importance, and in Irish peat it varies from 0·83 per cent. to 2·74 per cent., the average

for seventy samples from diverse places and depths being 1·74 per cent. Generally speaking, in all countries, the surface peat and upper layers will give 1·0 per cent. to 1·5 per cent. of nitrogen, increasing up to 2·5 per cent. as the bottom is approached, and in a few cases results exceeding 3 per cent. have been reported. The sulphur content is low, 0·35 per cent. to 1·0 per cent. being usual limits, with an average of under 0·5 per cent.

The minimum calorific value of anhydrous peat is about 8,000 B.Th.U. (4,444 calories) per pound, which applies to the lowest grade of sphagnum peat and from this the heating value may range to 10,500 B.Th.U. (5,833 calories) per pound for dense black well-humified peat. For peat used for fuel purposes, 9,000 to 9,900

Fig 1

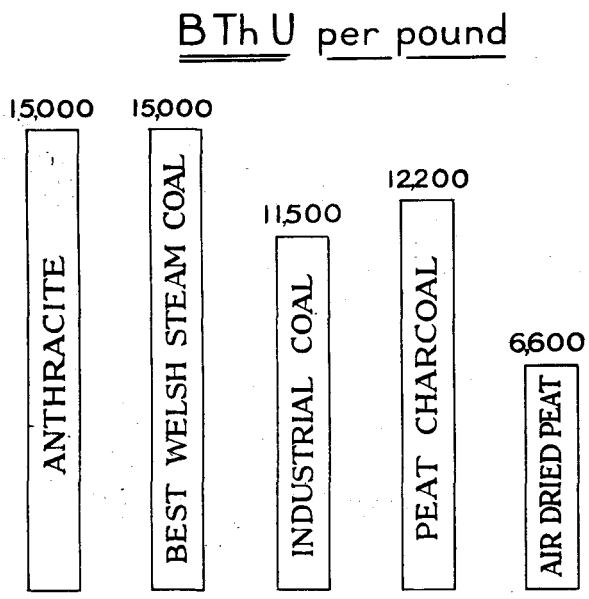


B.Th.U. (5,000 to 5,500 calories) would be usual limits, and when dried to 25 per cent. moisture content, the fuel should yield 6,500 to to 7,200 B.Th.U. (3,611 to 4,000 calories) per pound.

When considering the efficiency of utilisation of peat fuel, it is well to emphasise the necessity of exercising the greatest care in drawing

an average sample for calorific determination. The fuel, as it arrives at the power station, may vary considerably in ultimate analysis and to a large extent in moisture content, due to its being taken from different positions in the bog and being dried and stored under widely differing conditions. The moisture content often varies from the outer surface to the centre of an individual block of peat and if reliable results are to be obtained, the procuring of representative samples must be carefully supervised. Again, peat usually contains 5 per cent. to 6½ per cent. of hydrogen, or possibly 1 per cent. to 2 per cent. more than that in coal as used for power generation. If the peat fuel is used under boilers, the heat lost in

Fig 2



the steam produced by the combustion of the hydrogen will show about 1½ per cent. to 2 per cent. greater unavoidable loss than in the case of coal. For example, with a peat giving 5·5 per cent. of hydrogen and 10,000 B.Th.U. per pound, on anhydrous value, the unavoidable loss due to the combustion of the hydrogen will be 363 B.Th.U. per pound of peat as fired with 25 per cent. moisture content, and this loss is equivalent to 5·03 per cent. of its heating value. In a sample of industrial coal giving 4 per cent. hydrogen and 12,000 B.Th.U. per pound (anhydrous) the loss, if fired with 10 per cent. moisture, will be 314 B.Th.U. or 2·94 per cent. of its

heating value, the difference in these two cases being 2·09 per cent. This difference is worth noting in connection with the somewhat lower efficiencies reported for peat in steam boilers compared with coal.

Fig. 1 shows the relationship of peat to the older solid fuels with regard to the varying proportion of volatiles to fixed carbon, as revealed in proximate analysis. Fig. 2 shows graphically its calorific value relative to other solid fuels.

It is hardly necessary to remark here that the number of heat units per pound of a given peat is unaffected by the methods of winning adopted, *i.e.*, whether by hand or machine, although the economic value of the dense block which results from maceration of the raw peat previous to air drying will be greater. The energy contained in a given weight of peat is constant and fixed, and may be said to consist in the heat energy or B.Th.U. contained by the carbon and hydrogen. It is true that you can convert, make available or utilise the energy in the carbon and hydrogen in a number of ways; for instance, by burning it in a furnace, gasifying it in a producer, or by deriving from it charcoal and various oils by low temperature carbonisation, but the energy available is constant, except that one process of conversion may be more efficient than another or, on the other hand, one product of the peat may be more convenient for use or usable in some form of engine with greater or less efficiency than another.

On the other hand, peat may be made to yield certain chemical compounds which have a value apart from calorific or energy considerations—for instance, from the peat tar, some very powerful antiseptics may be derived and, if obtained in quantity, while at the same time the heat energy of the peat is utilised, these would have an appreciable effect on the economic value of the peat. A similar remark applies to the recovery of ammonia from peat.

DEHYDRATION OF PEAT.

In the case of an undrained peat bog with 95 per cent. of water, at least eight-ninths of the water is mechanically held, and even in a drained bog two-thirds of the water is so held and may be eliminated by pressure suitably applied. It would appear, however, that even with high pressures and the most efficient form of filter press, it is not possible to reduce the water content of the peat below 65 per cent. or 66 per cent. With black humified peat it is hardly possible to reach such low figures, but with some types of less humified fibrous peat, the problem is not so difficult. In some processes

where heat and pressure are combined, lower figures are obtained, but to what extent these results are directly due to the heat used or to the alteration in the character of the peat which allows the water to be more readily expressed, it is difficult to say. It seems to be generally admitted, that some 60 per cent. to 70 per cent. by weight of water is held by the colloidal matter in the peat, and cannot be removed in an ordinary filter press even by high pressures.

Numerous patents have been obtained for processes in which coke, dry peat or chemicals are added to facilitate the dehydration of the peat in presses, but none have proved satisfactory. A process on these lines, known as the Madruck Press, has recently been tried on a large scale in Germany, and a large unit press has been made and supplied to the Russian Government. The author is unable to say what results have been obtained in practice, but was present, in 1921, at a demonstration of a small model of the Press at Uerdingen, near Krefeld, and obtained bottled samples which, when analysed, show that the results looked for were not obtained. A raw fibrous peat containing 81·85 per cent. water was taken and mixed with one-tenth of its weight of finely ground dried peat containing 20·27 per cent. water. The mixture was then placed in a press with specially designed filtering surfaces, which were not liable to choke. A pressure of about 35 atmospheres was applied for six minutes, and a certain amount of water eliminated. Moisture determination showed that samples of this press cake contained 66.31 per cent. of water and, if the dry peat powder added to the raw peat is assumed to act mechanically as a diluent without either receiving or losing water, the actual moisture content in the remaining portion of the press cake would be over 71 per cent. It would appear from the above that no advantage resulted from the addition of the dry peat to the raw peat, but while its addition did not appear to secure any greater reduction in the moisture content of the raw peat than could be secured in ordinary pressing operations, a separate test showed that its presence had a certain effect. When similar raw peat was taken and placed in the same press without admixture of the dry peat powder and pressure was applied, the peat came freely through the filtering surfaces and no water was eliminated. It would, therefore, appear that the dry peat forms a kind of framework throughout the mass, which enables it to be pressed and the water eliminated without the peat extruding through the particular filtering surface used.

Theoretically, with 100 per cent. efficiency all round, it is possible to evaporate the water contained in peat and to recover the heat

used. Practically, such an efficiency cannot be even approached, no matter how elaborate the plant used may be, and the recovery of the low potential heat in the evaporated steam is such a difficult matter, that there appears to be little prospect of a solution being attained along these lines. If we assume 66 tons of peat fuel (25 per cent. moisture) to be produced each day during 300 working days to give an output of 20,000 tons per annum, this would involve pumping or otherwise transporting 940 tons (940 cub. m.) of 95 per cent. moist peat and evaporating therefrom 874 tons of water, to leave the 66 tons of peat fuel as the product. If it were possible to use the water contained in the peat, as a source from which the make-up water would be derived for some large power station and to look upon the peat fuel as the by-product, there might be some possible use for such a process, but of what size should the station be to use so much steam in connection with such a moderate output of peat fuel ?

Frequent attempts have been made during the last twenty-five years to dehydrate or partially dehydrate peat by processes based on electrical osmosis, but so far commercial success has not been obtained.

Too many enthusiasts have turned their attention to peat development ; and, having proved that certain fundamental laws exist which apply to peat in particular, just as rigorously as the law of the conservation of energy applies in general, have turned away disgusted, or been driven away by their disappointed—sometimes wiser, but always poorer—supporters. As a preliminary to successful peat development certain facts must be recognised :—

1. That, as the result of countless attempts, it has been shown that the original moisture content of peat cannot be reduced below a certain figure by methods involving pressure and artificial heat, except by the use of so much artificial heat and costly plant, as to render the process uneconomic.
2. The normal product from peat will be a low grade fuel containing anything from 20 per cent. to 40 per cent. of moisture, 3 per cent. to 5 per cent. ash, 60 per cent. to 70 per cent. volatiles (on dry analysis), and having a heating value of 6,000 to 7,500 B.Th.U. per pound (3,610 to 4,167 calories) and, hence, with a heating value of 45 per cent. to 65 per cent. that of coal.
3. For economic utilisation, the moisture content must be reduced certainly to below 50 per cent. and preferably to under 30 per cent., if it is to be used under steam boilers.

4. The apparatus in which the fuel is used must be designed and adapted for the particular properties of the fuel.

These conditions emphasise the necessity of employing only simple and inexpensive plants, on which maintenance and interest charges are low, when the object in view is the production of a low grade fuel such as peat. If expensive and complicated plants are used, then the output must be correspondingly large, if an economic result is to be secured. Every shilling per ton spent on the winning, preparation and transport of peat fuel is, roughly, equivalent to two shillings per ton in the cost of coal, and as peat fuel is more bulky and, generally speaking, would not be procurable from so many different areas as coal, it follows that unless local conditions are peculiarly suitable, or the organisation for its manufacture and utilisation complete, many difficulties have to be met, which are non-existent in the case of coal.

The heavy capital costs and maintenance charges per ton produced on plants, involving pressing, heating or electrical osmosis, when superimposed on the ordinary and unavoidable difficulties associated with peat winning, appear to the author to prove that the economic solution of this question, so often promised in connection with such systems, is unlikely to be forthcoming and that we must, in the light of our present experience, depend for a solution on the somewhat crude, but nevertheless effective, methods of air drying.

THE AIR DRYING OF PEAT.

It has been proved over long periods in the principal peat bearing countries that it is possible to air-dry peat fuel to 20 per cent. to 30 per cent. moisture content in all but the worst seasons and, as peat which has been dried to the anhydrous condition re-absorbs water hygroscopically to the extent of about 15 per cent. by weight, under good conditions air-drying will reach a point when the amount of residual water which may be *permanently* eliminated is small.

With a view to obtaining more definite information as to the factors involved in air-drying, and the rate at which drying proceeds under varying weather conditions, the Fuel Research Board carried out investigations on a bog at Turraun, Kings Co., belonging to the Leinster Carbonising Co. during the 1919 and 1920 peat winning seasons. The work carried out by Mr. E. J. Duffy, M.E., B.Sc., Research Assistant, will be found fully dealt with in the Report of the Fuel Research Board.[1]

[1] Report of the Fuel Research Board for the years 1922 and 1923: *First Section:* "The Production of Air-dried Peat": H M. Stationery Office.

As evaporation from the exposed surface of a block of peat proceeds, a continuous supply of moisture is transferred from the centre to the surface by the capillary pores in the peat. When heavy rain falls, much of it is thrown off without penetrating the peat block, especially if drying has progressed sufficiently for the block to have acquired a hard skin, and unless the fall is of long duration, not much is absorbed. Even in the case of heavy rainfall, just as the capillary transfer of moisture from the centre outwards is slow, so also is the absorption and transfer inward of the rain water slow. Its effects are largely confined to the region of the outer skin, and in a short period after the rain has ceased and drying action recommenced, practically all the added water is eliminated and the drying will only have been retarded by a small amount. This does not apply to extended wet periods, often followed by weeks of high relative humidity, but none the less, it is interesting to observe the considerable reduction in moisture content which takes place under very adverse climatic conditions. For instance, a sample of machine-formed peat exposed in the open on the Turraun Bog had a water to dry peat ratio of 6·3 on the 8th April, 1920, and on the 20th May, the water ratio was reduced to 2·6, so that considerably over one-half of its water content was evaporated during forty-three days, on thirty-seven of which rain fell, and on six of these days the rainfall reached almost half an inch. When macerated machine-formed peat was exposed under identical conditions with hand-cut peat, it was found that the former dried more regularly and at a quicker rate than the latter, and this advantage was especially apparent when the weather conditions were unfavourable.

Owing to the increased shrinkage on drying of macerated compared with " cut " peat, it is necessary, when the moisture content is reduced to about 40 per cent. or 50 per cent. in " footings," that the final drying should be carried out in large clamps or stacks, where the slower rate of drying prevents the outer skin from becoming relatively too dry and shrinking and cracking on the somewhat wetter core. This is especially the case in mid-summer when the rate of drying is rapid and a similar conclusion has been reached by Haanel in Canada.

The density of machine-formed peat is from 0·70 to 1·00 compared with 0·45 to 0·65 in the case of hand-cut peat and this, coupled with its more rapid drying under adverse weather conditions and its toughness, which allows it to stand transport with less loss, are factors which increase its economic value compared with handcut peat. The actual bulk per ton of machine peat is about 60 per cent.

of that occupied by a ton of hand-cut peat—a matter of great importance for both transport and utilisation. The work at Turraun indicated that the peat winning season under climatic conditions in Ireland could be considerably prolonged over that ruling in other countries.

PEAT WINNING METHODS.

The maximum output of a skilled peat cutter in a ten-hour shift is to cast out on the drying bank, as separate blocks, about 30 to 35 cubic metres of raw peat, which on drying should produce 4 to 4½ tons of standard peat fuel (25 per cent. moisture). The conditions under which the hand winning of peat is carried out, generally necessitate one or two additional men being employed to spread the peat cut by a skilled cutter, so that the output of spread peat will not exceed 1·25 to 1·5 tons per man shift. With a season of 100 to 130 working days, the output per worker will not exceed 125 to 200 tons per season, and for work on an extended scale, a very large number of workers must be employed on the cutting and spreading of the peat—work of an arduous character—apart from the even greater numbers that are required on the operations involved in drying and harvesting the peat. Taking a moderate output of 50,000 tons on one site, this would require 250 to 350 men cutting and spreading, and during the busy harvesting season about twice as many again, but the latter work may be largely entrusted to women and juveniles.

Peat cutting is a seasonal occupation, and, owing to the difficulty of finding alternative employment for the workers during the winter season, it is desirable to increase as far as possible the output per worker, and thus reduce the numbers employed. An additional reason is that housing the workers in remote bog districts means heavy capital expenditure in providing adequate accommodation. In the past, employers have often been careless as to how the employees lived while the peat work was closed down from September to March and many large peat works on the Continent have availed themselves largely of imported casual labour. There are many objections to this course and many advantages to be looked for in a permanent settlement of the workers near the bog, when considerable employment can be given to the families of the workers during the summer months, thereby increasing the earning power of the family. There is, therefore, every incentive to increase the output per worker during the short peat winning season available, and many efforts have been directed to this end apart from those

which seek to devise methods of peat winning which can be practised the whole year round.

The earlier attempts which were made to adapt mechanical appliances to this task, involved the cutting out of pieces of peat of the size and shape produced by hand winning methods. Such machines preserved the original structure of the peat and the product was of the same character as hand cut peat. The advantage of macerating the peat has long been recognised, that is to say, tearing and mixing the fibres so as to distribute them uniformly through the mass and to produce, on drying, a more compact and dense block. This results in the more uniform shrinkage on drying, which avoids the cracks and fissures so generally associated with hand-cut peat in which the original, more or less layered, structure is preserved. Elevators were also employed, on to which the peat dug by hand was thrown and the macerated peat was extruded from a mouthpiece or forming tube. In this way the peat could be cut and spread in sizes, which, when dried, produced compact blocks weighing one to two pounds each. As a rule, however, it is the economical distribution of the peat on the drying ground which presents the greatest difficulty.

Previous to 1910, the usual practice in Continental Europe was for the peat extruded from the mouthpiece of the macerator to be caught on boards bearing six to eight pieces. These boards or pallets were then taken to the drying ground on wagons with two or three tiers of shelves, the wagons being pushed by hand along a 60 cm. gauge track to a drying ground adjacent to the cutting face. With plants of this kind, four men excavate the peat and feed the elevator, three or four others attend to the engine and despatch the loaded boards, while eight more push the peat wagons and distribute the peat on the drying ground, the output of fifteen men not exceeding 20 to 30 tons per shift of eight hours. Professor Keppler gives the normal output of this system with stage wagons at 13 to 15 c.b.m. of raw peat per hour, but with extra men on the distribution, the output may be 21 c.b.m. per hour, that is, increased from 2·0 to 2·8 tons per hour. If the bog contains good peat, a block of good shape and density is produced, but the output secured shows little increase, if any, over purely hand-cutting methods. Some improvement on this method was effected in Sweden by the introduction of the Persson's conveyer, by which the loaded peat pallets are automatically placed on two parallel steel cables running out over the bog for a length of 100 to 200 metres. The boards are carried by the cables to the drying ground where they are lifted off by hand, and the peat tipped

on to the spreading ground near by, the empty board being returned to the peat machine. This semi-automatic system of distribution has proved reliable and economic, and has made a much wider spreading ground possible, while at the same time reducing the number engaged on distribution and spreading by one-half.

On bogs of moderate depth which have been well drained and are practically free from roots and buried timber, it has been found possible to utilise excavators in which a continuous chain of buckets or scrapers remove thin layers of peat and feed it continuously to the macerating and mixing element. In Canada, Moore has designed a modified Anrep machine, and in Sweden there are machines made by Andersson, A. H. W. and others, which excavate the peat in connection with automatic conveyers. In Germany there are many makes of peat plants which excavate, macerate and spread the peat automatically, among which might be mentioned the Wielandt, Strenge, Orenstein-Koppel, Baumann-Schenck and Dolberg machines. Generally, the macerated peat as it extrudes from a mouthpiece in a single or double string, is received on a chain of plates and automatically cut in lengths. The endless chain of plates loaded with peat runs out 30 to 70 metres at right angles to the cutting face and when the full length of the conveyer chain is loaded, the plates are tipped and the formed peat blocks deposited on the surface of the bog. When the moisture content of the peat is 88 per cent. to 90 per cent., the blocks retain their shape sufficiently well for all practical purposes, if tipped from not more than 20-30 cm. above the surface. In the Baumann-Schenck machine, each block of peat is separately formed in a drum attached to the macerator and placed on its own plate on the conveyer. The majority of the chain plate conveyers in Germany are 30 to 50 metres long, but at Wiesmoor and in Bavaria there are a number 65 to 75 metres in length and one of 100 metres. However, for many reasons, 70 metres seems to be the economical limiting length, so far as present practice goes. The author has endeavoured elsewhere[1] to show from an examination of various considerations bearing on the economic excavation, spreading, harvesting, and collection of peat, that if a bog area is to be usefully developed on a large scale (say, 50,000 tons per annum and upwards), the width of the spreading ground and, hence, the length of the conveyer or sod spreader should not be less than 100 metres. The mechanical difficulties associated with chain conveyers supported on caterpillars or rollers and moveable over the bog surface at a rate of ten

[1] Report of the Fuel Research Board for the years 1922-1923, First Section.

is sometimes used in gas producers, providing heat for the Martin furnaces. A regular distillation of peat in retorts in connection with the utilisation of by-products has not yet been practised, except for experimental purposes.

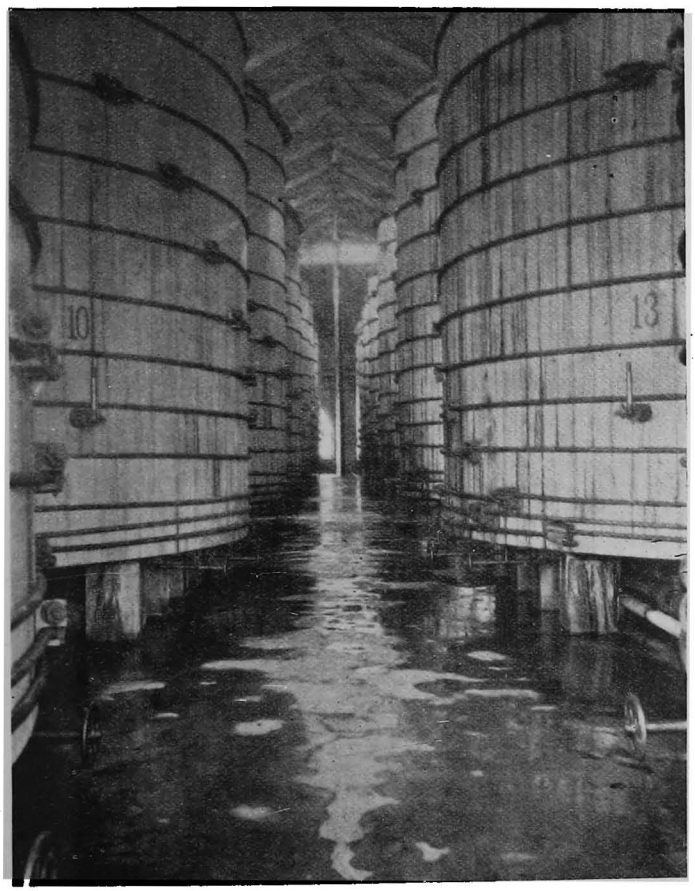


FIG. 9.

Much work has been devoted in Sweden to experiments on the production of a refined peat fuel, but without any economic success. Wet carbonising was tried amongst other methods by de Laval, and a rather big plant was built. The only practically successful proposition has been that of producing pulverised peat, which has been

night and day. With a 100 day season, working one 10-hour shift, they estimate the total cost of the peat loaded in railway truck at $4·48 per ton, but if two 10-hour shifts are worked, the cost becomes reduced to $3·50 per ton, the whole reduction being in the overhead charges. The Canadian Peat Committee completed its experimental work at the end of the 1922 season, and the work is to be carried on and extended by a private organisation which has been formed for the purpose.

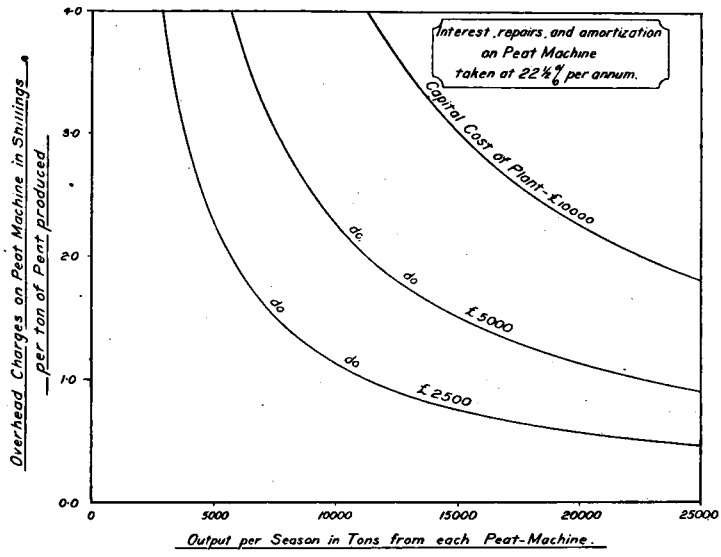


FIG. 4

The accompanying figure (Fig. 4) shows the effect of increased output on the overhead charges on the peat machine. For this purpose, interest is taken at 5 per cent., repairs at 5 per cent. and amortisation at 12½ per cent., making in all 22½ per cent. per annum on the cost of the plant, which may be taken as a reasonable figure to assume for overhead charges. This diagram relates solely to the peat machine, as 16 per cent. should be ample for the rails, wagons and other plant. When allowance is made for the other overhead charges in addition to labour, power, etc., the writer is of opinion that the plant charges on the peat machine for excavating, macerating and spreading the peat should not exceed 2/- per ton of standard fuel produced, if it is to compete with coal at normal prices. Accepting this limitation, then a plant costing £10,000 should have an output of 22,500 tons per season, and one costing £2,500 should

produce about 6,000 tons, or an output of at least 2¼ tons per season for every one pound (£1) cost of the peat machine.

The output of individual peat works rarely exceeds 30,000 tons, and in the largest at Wiesmoor, about 60,000 tons per season is the maximum. As this output is secured from six large peat machines, the problems which will arise when it is attempted to double the output, requiring the bogs to be laid out for double the number of plants, will present difficulties which have not yet been felt. The author[1] has shown that where large scale operations are intended in connection with a power station, an area of one acre of bog (assumed 20 feet deep after drainage) must be laid out for each 20 tons of annual output, if the operations are to be carried on for one hundred years without one plant interfering with another. Further, for economical working, the whole bog area must be laid out and drained from the beginning, not in the haphazard way which has been the practice, where one or two plants are at work, but keeping strictly in view the number and type of plants to be employed.

As a general rule, the output of peat machines has been limited by some particular part of the machine. In some it was the excavator, in others the macerator, power unit or the distribution, again in others the time lost in shifting the plant between different stages. Much of the work of developing peat machines has been concerned with the balancing of the output of the different parts of the peat machine. While this is so, great advances have been made in the past fifteen years in the winning of air-dried peat, and electrically operated plants may now be found working on many peat bogs and giving outputs of 5 to 10 tons of standard peat fuel per hour. The mechanical details of these automatic plants are being perfected as the result of each season's new experience, and it is not anticipating too much to say that within five years these plants will be recognised as practical working machines, giving regular and reliable service.

For a peat works with an output of, say, 60,000 to 100,000 tons per annum, the following costs should be possible :—

	Shillings per ton of standard peat fuel.
Overhead charges on peat machine ..	2.00
Labour costs, spreading and harvesting..	3·50
Rails, wagons, collection and power ..	1·75
Other overhead charges, administration, etc.	1·25
Total	8·50 shillings per ton

[1] Report of the Fuel Research Board, years 1922-23, First Section.

Within the last few years, much work has been carried out in Denmark, Germany, and also in Russia, on a hydraulic process of winning peat fuel, known as "Hydropeat" or "Hydro-torf." High-pressure jets of water are used to wash down the peat into large sumps in the bog, from which the peat pulp, containing 95·5 per cent. water, is pumped to the drying ground by specially constructed centrifugal pumps. In the experimental work at Schwaneburg, on the Ostermoor, in Oldenburg, a central sump is formed, into which the peat is pumped from two separate units, which pump the pulp as it is washed down. From the central sump, the peat is again pumped by a high-pressure pump through an 18-in. pipe line to the drying ground, where it is allowed to flow out and fill up a space 20 metres wide ×200 metres long, to a depth of 15 to 20 cm. The drying ground is specially prepared and drained and may be on the bog or preferably on the dry ground adjoining. When the wet pulp is spread, the added water is said to drain away in five to six hours, after which a special forming machine goes over the peat and divides it into separate blocks. The output from each centrifugal pump is said to be 10 tons per hour and the result of the 1923 season's work at Schwaneburg, to have been 20,000 tons of standard peat fuel. Ten men are employed on each shift for washing down, pumping and spreading and moulding of the peat. The power required to operate the plant is about 12 kW. hours per ton of standard peat produced. It is questionable if this system can produce air-dried peat in competition with the other automatic systems of mechanical winning, but it has the advantage of being applicable to wide spreading and drying grounds, and, further, that it can be used in bogs containing considerable quantities of timber and roots, where no other system is possible.

THE UTILISATION OF PEAT.

As the present Conference is concerned with sources of power and power production, it may be as well briefly to consider the utilisation of peat for the generation of power. There are three methods which may be adopted for its utilisation :—

1. Burning the fuel to complete oxidation under steam boilers : (a) in solid air-dried blocks as it comes from the bog ; (b) as a dried and pulverised fuel.
2. Complete gasification in producers with or without recovery of by-products.
3. Low temperature carbonisation of the peat with (a) the gas used in internal combustion engines or (b) the coke used for metallurgical purposes, or in producers or under steam boilers.

Necessarily, the general principles which determine the most economic and practical way of using coal must also apply to peat, and, generally speaking, where the production of large blocks of power is in question, coal is usually burnt in steam boilers, but where power is generated on a smaller scale, producers and gas engines are often employed.

With the rapid development of pulverised coal systems in America, the relative economy of such a system compared with mechanical stokers is arousing considerable interest. In the case of coal, the controversy ranges over a small percentage of advantage on the one side or the other, but there can be no such close issue in the case of pulverised peat versus peat in the solid block. In the case of coal, the moisture content rarely exceeds 10 per cent., in the case of peat, it is rarely less than 22 per cent. and often exceeds 35 per cent., which means much more work for the driers. Then the pulverisation of peat is more difficult than coal, as it may contain a large quantity of fibre which cannot be economically reduced to a fine powder and has to be sifted out and burnt as refuse peat. In Sweden, the State has for some years been responsible for the running of a pulverised peat works at Vislanda, the peat powder being used for locomotive firing on certain sections of the State Railways. The results of tests with pulverised peat on Swedish locomotives have been published[1] and have proved satisfactory, 1·45 pounds of the pulverised peat fired with 15 per cent. moisture being equivalent to 1·00 pounds of British coal. The author, however, is not aware that any definite figures have been given as to the relative costs of the fuels, but the charges on the heavy capital sunk in the plant, factory and equipment for dealing with the pulverised fuel would seem to render the cost prohibitive. Whatever case may be made for pulverised peat, compared with its use as a solid fuel for locomotive firing or for use in certain processes for which pulverised fuel is adopted, such for instance as rotary cement kilns, there can—in the author's view—certainly be no case so far as general power production is concerned. The increased efficiency procurable from the pulverised fuel over that from using the solid fuel in block form on a properly designed grate and furnace, could in no way counterbalance the increased cost. One or two out of the three pulverised peat factories erected in Sweden have now been closed.

At Wiesmoor in Ostfriesland, a power station of 200 H.P. erected

1 For a summary of the results see special Report No. 1 Fuel Research Board by L. C. Harvey, H.M.S.O. 1922.

in 1908 by the Siemens Schuckert Co. in connection with a large scheme of bog reclamation, has steadily increased its capacity until in 1921 it was 21,000 kW. The station has four coal-fired and eight peat-fired boilers, about 30,000 tons of coal and 60,000 tons of peat being used per annum. No results of recent tests on the plant are available, but the fact that the station has gone on steadily increasing in size is sufficient proof that the Siemens-Schuckert Co. find the utilisation of peat fuel an economic proposition. That the whole station is not supplied with peat fuel may be owing to the difficulties in the way of increasing the annual output of peat fuel to over 60,000 tons during a period when the peat winning plants were being developed and also to the advisability of keeping part of the plant on coal until sufficient experience was obtained as to the reliability of the mechanically won peat fuel and the danger of a failure of the supply of peat due to an exceptionally wet season. The only test figures published relate to 1910, when the consumption of peat was 3·01 kg. per kW. hour, the boiler efficiency being 73·5 per cent., but results as low as 2·2 kg. of peat per kW. hour have been obtained. With a properly designed furnace and air control, there is no reason why air-dried peat fuel with 25 per cent. to 30 per cent. moisture should not be burned with practically the same efficiency as coal, when allowance is made for greater unavoidable loss due to the combustion of the hydrogen already pointed out. Since the only difference in the efficiencies of utilisation of peat and coal are those which may occur in the steam boilers—all the other steps from steam to the switchboard being the same—we may conclude that apart from any slight extra cost for the boiler installation and bunkers over that for coal, the whole question resolves itself into our ability to deliver peat into the bunkers at a competitive price on the basis of the net calorific values of the two fuels, and to do this regularly one year with another. In fact, there is no inherent disadvantage in peat fuel for steam raising and hence for power generation, if the difficulties associated with its winning and transport can be overcome. If the power station is near the bog, then the latter does not arise and from what has already been said, the progress in the development of peat machines should before long remove the former from any doubts that at present exist. In some cases difficulty may be experienced in providing the large supplies of condensing water required with large steam units, and this may in itself decide whether the station is to be at the bog with no transport of the fuel and transmission to the area supplied, or

else transport of fuel and relatively shorter transmission.[1] At Wiesmoor the condensing water is obtained from a branch of the Ems-Jade Canal, and generally the water supply should not present too much difficulty in bog areas.

Two reasons have probably been responsible for the attention paid by many writers to the utilisation of peat by gasification in producers. In the first place, statements have been made that peat with 50 per cent. to even 70 per cent. of moisture could be gasified in producers and yield a gas of reasonable calorific value and, secondly, much has been said as to the results to be obtained from by-product recovery of tar and ammonia from peat. The prospect of using peat with such high percentages of moisture, and at the same time conducting operations all the year round, instead of for the comparatively short air-drying peat season, has also no doubt buoyed up the hopes of those who have given their attention and energies to filter pressing and other similar processes for the partial dehydration of peat. Of the large by-product producer plants set up for peat, only one is now working, that at Lake Massaciuccoli, Italy, and there the peat is dried to 25 to 50 per cent. moisture content.[2] At Schweger Moor, Osnabrück, a 3,000 H.P. producer gas power plant, erected by the German Mond Gas and By-products Co. in 1911, has been shut down and is now worked with coal. The outlook for large peat producer gas stations does not appear good, although there are many small non-recovery suction gas plants working on peat and giving good results. During the war, many plants in Denmark were converted to work on peat gas, and although some have now reverted to coal and oil, the results of an official test by the Technical Committee of the Ministry of Home Affairs on a 75 H.P. two-cylinder vertical Diesel Motor at Haslev, October, 1921, are encouraging. With this small plant, the result of a 72-hour continuous test gave a consumption of 1·93 kg. per kWh. at 89 per cent.

[1] The Neumünster district, N.E. of Hamburg, is supplied with current generated by 5,000 and 6,250 kVA. turbine sets. There are two Babcock & Wilcox boilers with sloping grates, using about 24,000 tons of air-dried peat, broken to two-inch size, and generating ten to twelve million units per annum.

[2] Both the Codigors and Orentano by-product producer gas stations have been shut down; the latter since 1919, mainly, it is said, owing to the unfavourable situation of the peat and the limited area of deposit. The Lake Massaciuccoli station, erected near Viereggio in 1920, has six large by-product producers. The gas, after cleaning, is burned under two Babcock & Wilcox boilers and six Tosi W. T. boilers of 750 sq. meters heating surface. There are three Tosi turbines with Brown & Boveri generators, each of 6,250 kVA., with another 1,325 kVA. turbo generator for supplying power for working the ten dredgers which dredge the peat from Lake Massaciuccoli.

load and 2.16 kg. per kWh. at 61 per cent. load and, further, the usual trouble with cleaning peat tar from the gas was overcome and no difficulty was experienced with the valves over a long period. At Portadown, Ireland, two Crossley producers, working on peat, have been successfully running the plant required in Mr. Hamilton Robb's linen-weaving factory for the last thirteen years, and the heating and steam required in the factory are derived from steam boilers fed with peat. The gas engines develop an average of 250 B.H.P. with a consumption of 2·56 pounds of peat per B.H.P. hour at 64 per cent. of their rated capacity.

Some years ago high efficiencies were claimed for gas-fired boilers and if these could be realised, the cost of one extra conversion of energy might be offset by the value of the by-products recovered. First of all the peat would be gasified in producers with by-products recovery and the gas used in gas-fired boilers for steam raising for a turbo-generator. Even with an efficiency gas-fired boiler it is hardly possible that the cost of the extra conversion can be borne. With 1·0 per cent. nitrogen in anhydrous peat and 70 per cent. recovery, the yield of sulphate of ammonia from each ton of air-dried peat (25 per cent. water) gasified, should be 55·4 pounds. In the case of Irish peat, an average nitrogen content of 1·7 per cent. may be safely assumed and with a recovery of 67 per cent. about 90 pounds of ammonium sulphate would be recovered from each ton of air-dried peat. If, after allowing for all capital, labour and other charges on the recovery plant, a profit of £5 per ton of sulphate were made, this would be equivalent to 4/- per ton of peat used. For moderate sized plants, where work is on a sufficient scale to make recovery worth while, such a contribution would be a great advantage.

Experimental work was undertaken during 1921 at H.M. Fuel Research Station, Greenwich, on 100 tons of machine-formed peat fuel, prepared at Turraun in the 1920 season, in connection with work on the air-drying of peat. The water content of the peat had fallen from 25 per cent. to 17 per cent. during storage at the Station and, after reduction to small pieces in the coal crusher, it was subjected to carbonisation in Glover West Vertical Retorts at temperatures between 750°C. and 1,000°C. To quench the coke, 6 per cent. of steam by weight of the peat carbonised was used, and in a carefully controlled test extending over fifty-two hours the following results were obtained :—[1]

[1] Fuel Research Board, Technical Paper No. 4, "The Carbonization of Peat in Vertical Gas Retorts" H.M.S.O. 1921.

Peat carbonised per retort per day	2·88 tons.
Carbonising temperature	820-875°C.
Yield of gas per ton of peat (cu. ft.)	13,760
Calorific value (net) in B.Th.U. per cubic ft. ..	310
Charcoal produced per cent. of weight of peat ..	27·0
Charcoal calorific value as discharged B.Th.U. per pound	12,210
Ash content of charcoal per cent.	9·98
Dry tar made, in pounds per ton of peat ..	210
Ammonium sulphate (pure), lbs. per ton ..	24·8

The volatile matter came off so freely from the peat that the throughput in therms per retort was practically the same as with coal. The peat as charged, had a calorific value of 7,710 B.Th.U. per pound and contained 172·5 therms per ton, of which 46·8 therms were contained in the gas and 73·8 therms in the charcoal. The gas and charcoal contained about 70 per cent. of the heat value of the peat. The tar contained a high percentage of paraffin wax and on steam distillation yielded 1·13 gallons of spirit (·866 Sp. gr.) per ton of peat. About one-third of the gas produced was used to heat the retorts. The charcoal contained 4 per cent. of volatile matter and formed a most suitable fuel for producer work. Some of the peat was also carbonised in steel retorts at 550°-600°C. The good yield of gas, its calorific value and the high quality of the charcoal produced in the Vertical Retorts are most encouraging and open prospects of future development along these lines.

While the writer has endeavoured to take a detached view of the future prospects of the peat industry, he has no doubts as to its ultimate successful development along the lines at present being tried for mechanical winning in connection with air-drying methods. When we observe the rapid development of the Brown Coal Industry in Germany from 40 million tons in 1900 to 86 million tons in 1913, and 110 million tons in 1920, and further note the steps being taken in Canada and Australia, at the present time, in connection with the development of the same industry, we may reasonably expect a similar expansion to manifest itself before many years in the case of our youngest fuel—peat.

RÉSUMÉ.

Les dépôts de tourbe, formés par la décomposition de débris végétaux sous l'influence d'agents bactériologiques et chimiques, existent dans beaucoup de pays. En superficie, ils dépassent probablement 500,000 kilomètres carrés et leur valeur calorifique équivaut approximativement à 75,000,000,000 de tonnes de charbon. La tourbe contient, en règle générale, environ 90 pour cent d'eau, dont les 2/3 à peu près sont retenus par la matière colloïdale et ne peuvent être éliminés par pression. Quand la quantité d'humidité est ramenée par le séchage à l'air à 25 pour cent, la valeur calorifique est d'environ 6,600 thermes par livre ; ainsi donc, deux tonnes de cette tourbe fournissent en moyenne un peu plus que l'équivalent calorifique d'une tonne de charbon.

Les méthodes d'extraction manuelles sont laborieuses et ne sont guère applicables à l'exploitation sur une grande échelle d'une région marécageuse, alors que par le procédé d'extraction mécanique on prépare un meilleur type de combustible et dont le séchage s'opère mieux dans des conditions climatériques défavorables. Des progrès considérables ont été réalisés au cours des derniers quinze ans dans le perfectionnement des machines automatiques à extraire la tourbe, tant au Canada qu'en Allemagne où des transporteurs à courroie et à chaîne sont utilisés pour l'épandage de la tourbe en vue de son séchage par l'air. Le procédé hydraulique d'exploitation de la tourbe par l'utilisation de jets à haute pression et de pompes centrifuges retient aussi particulièrement l'attention.

Il n'existe pas d'inconvénients inhérents à l'utilisation de la tourbe pour la production de la force, par comparaison avec le charbon, si l'on peut se procurer un approvisionnement régulier de tourbe au même prix, par unité thermique, que pour le charbon. Il semble probable que dans les cas où la production de la force sera expérimentée avec la tourbe sur une large échelle, on utilisera de préférence des chaudières à foyer à tourbe plutôt que des appareils à gaz producteurs de sous-produits, bien que l'utilisation de cette dernière méthode puisse être préférée dans les cas où les operations ne se font pas sur une large échelle. L'utilisation de la tourbe dans les cornues verticales pour la production du gaz et du coke métallurgique de haute qualité, mérite aussi de retenir davantage l'attention.

OIL REFINING

C. J. M. MILO

Oil-refining does not actually start in the refinery proper.

The crude oil, as it is produced at the well, is not always ready for being submitted to the different refinery-processes, whose object it is to manufacture certain well-defined trade commodities ready for marketing. Very often the crude oil must be freed from impurities, which, when left in, hamper a smooth refining-process, or even make this impossible. These impurities consist mainly of:

(1) Sand, grit and sediment;
(2) Water;
(3) Salt;
(4) Emulsions.

The oldest way of getting rid of these impurities is:

A *Settling of the crude oil, often aided by heating.*

This process often takes a very long time, thus necessitating huge storage capacity; it is rather expensive on account of evaporation losses and cost for steam heating, and often the separation of these impurities from the crude oil is very incomplete. This is especially the case where the crude oil contains emulsions—thorough mixtures of oil, water and sediment—which do not separate easily.

B. *Chemical process.*

Chemical substances are added to the crude oil, which help to break the emulsions. Tret-o-Lite, consisting mainly of an artificially prepared soap of oleic acids, is much used in the United States.

C *Mechanical processes.* (centrifuges).

Centrifuges will often help to overcome this trouble (Laval separators), but lately the method of:

D. *Dehydrating crude oil by means of electricity* has become more and more in vogue. In this connection the name of Cottrell must be mentioned.

The electric current used for these dehydrating purposes is of high voltage and its purpose is to break down the emulsion. When

adopting the general theory that an emulsion is an accumulation of small water globules, separated from each other by a thin film of oil, it can be well understood that an electric current, going through these oil-water globules in which the oil film acts as a dielectric, has a tendency to break the thin oil film, just as an electric spark breaks the air-dielectric between two electrically charged poles. When the oil film is broken, the water inside the two globules can unite, and by continuation of the process form a large water globule, which, being of greater specific gravity than the surrounding oil, sinks to the bottom of the apparatus in which dehydration takes place, and can be drawn off from there. To place sufficient resistance in the path of the current, the water globules must not unite in the shape of a chain, as this gives an easy way for the electric short-circuit current and consequently causes loss of energy. In order to prevent this, the crude oil is gently stirred. We may add that the elimination of the water also makes most of the salt disappear, which, of course, is in solution in the water and not in the oil.

DISTILLATION.

After the crude oil has thus been purified and is considered ready for further treatment in the refinery, the distillation process, or what is considered the actual refining, can be started.

The distillation process, pure and simple, is a physical process. The crude oil is gradually heated to a high temperature in such a way that between certain limits of temperature the vapours evaporating from the crude oil are collected separately and are cooled separately to different fractions.

This is the process that was first introduced in the crude oil refining process. It is the old still process, which is even now in use in the majority of the refineries. The usual shape of a still is a cylindrical container, placed horizontally. The general dimensions are: Length, 3 × diameter. These stills are made with capacities of up to 1,000 lbs. and more.

The still process can be divided into three different methods, *viz.* :—

I. The Periodical Method.
II. The Semi-continuous Method.
III. The Continuous Method.

I. *The Periodical Method.*

The entire process of distillation is carried out in one still only.

The crude oil is pumped into the still. When this is about two-thirds full, the fire under the still is lighted, and the oil is gradually heated. The distillation starts and the vapours, coming out of the still, are condensed. The lightest parts of the crude oil, having the lowest boiling points, will evaporate first. They arrive, condensed to a liquid, in the tailhouse, where their special properties (spec. gravity and colour) are examined.

The first liquid to appear in the tailhouse is benzine (gasoline). This liquid gradually becomes heavier and heavier, because gradually heavier constituents from the crude oil start evaporating. If they arrive in the tailhouse too heavy to be mixed with the benzine fractions, they are conducted to another receptacle. Their name is changed into kerosene and they are kept separate from the gasoline.

As the temperature in the still rises, other products are distilled over like stove oil and gas oil. Finally, when no more valuable products can be obtained by distillation, the process is stopped, fires under the still are drawn, and the contents of the still are allowed to cool, or are drawn straight off through coolers. What is left in the still (still bottoms) is used as liquid fuel, or can be submitted to another distillation, in order to obtain wax distillates, asphalt or coke. This depends on the nature of the crude oil.

II. *The Semi-continuous Method.*

This method differs only from the periodical method, inasmuch as during the process of distilling, fresh crude oil is constantly being pumped into the still at the same rate as the vapours are distilled. The distillation products are obtained in the same way as in I., but the semi-continuous method has the advantage that more distillates and more still bottoms are obtained, thus increasing the capacity of the still, though the time of working the still is longer.

III. *The Continuous Method.*

This method is generally used nowadays.

A continuous battery consists of several stills (from three or four up to twelve and more), built in tiers. The difference in height between stills is about 10 in. to 12 in. The stills are interconnected by pipe-lines, so that when the oil in one reaches the overflow, it runs automatically over to the next and so on. Each still is provided with by-pass valves in the interconnecting lines, so that it can be cut out of continuous service whenever necessary (for cleaning, repairing, etc.).

The temperature in the still is gradually raised, the first still, *i.e.*, the still receiving the fresh crude oil, having the lowest temperature and the last still the highest. It stands to reason that on account of the gradual rise in temperature each still produces different vapours, the lightest vapours of course coming from the still with the lowest temperature.

These vapours are condensed separately in coolers and form the different fractions of the distillation. According to their properties these fractions are again mixed into certain well defined marketable commodities.

What has been said about the three methods of distilling, is only theoretical and appears to be simple. In reality, however, it is far more intricate. The crude oil contains many constituents, all hydro-carbons of the aliphatic, aromatic, naphthenic groups, etc. Each constituent in its pure state has a very well defined boiling point. It is a well-known fact that the constituents of a mixture of different hydro-carbons have a great influence on the boiling points of the pure constituents. Consequently, at a certain temperature, not only one constituent distils over but a mixture of many which in themselves have quite different boiling points. The stringent specifications of the gasoline which is put on the market nowadays (initial boiling point, percentage distilling below 100°C. and up to different temperatures, final boiling point) and the different products made for special purposes (turpentine substitute, solvent naphtha, gasoline for mining lamps, etc., etc.) made it necessary to install special equipment, in order to obtain from the distilled vapours, very special products with very special properties, according to what the market demands.

For this purpose dephlegmators have been added to the refinery equipment, which, starting with a very simple construction, have developed into more complicated apparatus, of which the " Heckmann Colonnes " are widely used at present.

The principle of the " Heckmann Colonne " is, of course, well known. The main condition for proper working is that the cups in the baffle-plates are always full of liquid, and for this reason a certain amount of liquid must always be brought over the top of the apparatus and the baffle-plates must be placed horizontally.

The " Heckmann Colonnes " only form two products: gases leaving the top, and liquid (dephlegm.) leaving the bottom. The latter run back to the stills, where they are evaporated again.

The gases from the top are cooled down in one, two or three stages, making one, two or three different products.

Besides the *still process* of refining, another process has greatly developed during the last nine or ten years. This is the pipe-still process, or, named after its inventor, the Trumble process.

With the Trumble process, the crude oil is heated in a pipe coil of sufficient length and capacity to obtain the desired temperature. At the end of the coil the hot crude oil has turned into foam, consisting of vapours and the residue which has not yet entered the vapour-state. This foam enters the evaporator, a vertical cylindrical container, where the vapours can evaporate and are separated from the residue; the vapours, of course, leaving the evaporator at the top while the residue leaves at the bottom. Open steam is used at the bottom of the evaporator.

The vapours afterwards pass a system of six or eight dephlegmators, where they are separated into different products; the heaviest products are, of course, made in the first dephlegmator (highest temperature of the vapours), the lightest in the last dephlegmator (lowest temperature of the vapours). The dephlegmators have the same purpose as the "Heckmann Colonnes." The dephlegmation is made here by the condensed vapours and a certain amount of liquid pumped over the top of the dephlegmator falling down as a rain from baffle-plate to baffle-plate, through which the vapours from the separator have to pass.

The main difference between the still method and the pipe-still method of refining is that the former is based on *fractional distillation of the vapours*, whereas the latter is based on *fractional condensation of the vapours*.

Of these two systems, when equipped with the same apparatus, the fractional condensation gives the best products.

It often happens, of course, that some of the products obtained by either of the processes are not up to specification for marketable products. In this case a redistillation must take place. Usually this is done in special redistillation stills. The process is exactly the same as with the crude oil distillation. However, in view of the fact that the products to be redistilled are lighter (having a lower boiling point) than the products which were originally in the crude oil, the distillation can take place at a much lower temperature. In many cases no fires are used under the still and the products are distilled off by the use of steam (direct and indirect steam only).

In the pipe-still process, special apparatus is provided to redistil, if necessary, products coming from the dephlegmators. They are called "separators," and consist of horizontal cylindrical apparatus,

provided with coils, through which the hot residue from the evaporator can run and can act as a heat medium. The redistillation is supported by the use of open steam.

In a few instances, as mentioned previously, it has been said that open steam is used for the distillation. Open steam is used to facilitate the distillation, because the same constituents are driven off by lower temperature when using open steam. This is a consequence of the well known physical law of partial pressures.

HEAT ECONOMY.

Since the olden days, when only the periodical stills were in use, heat economy in refineries has advanced rapidly. It goes without saying that in periodical stills an enormous amount of heat was lost when contents of the still, containing hot residue, were simply drawn off and cooled by water or left to cool down in tanks.

In the modern refineries special attention is given to this point and the waste of heat is reduced to a minimum.

The hot residue of the last still of a continuous still-bench is always used now to pre-heat the crude oil before it enters the first still. The same happens in the pipe-still or Trumble plants, where the hot residue is partly used to pre-heat the crude oil and partly to redistil the unmarketable products in the separators.

Often the hot vapours, coming from the stills, are also used to pre-heat the crude oil, because the latent heat, freed by condensation of these vapours, is a factor not to be neglected in the heat economy of a refinery.

The principle of all such apparatus is the same, the hot residue or the hot gases being led in tubes through the crude oil, thus condensing and transferring their heat to the crude oil.

As mentioned before, the products obtained by distillation of crude oil are :

Gasoline (in different varieties according to market demands).
Kerosene do. do. do.
Stove oil
Gas oil
Residue.

The gasoline and kerosene, however, are not always ready to be sold after the distillation alone ; they often require a chemical treatment in order to improve their qualities and to make them more stable, especially as far as their colour is concerned.

This chemical treatment takes place in agitators, large cylinders with a cone-shaped bottom. Chemicals used for this treatment

are invariably sulphuric acid of 66° Bé. (sometimes stronger) and lye. This acid treatment improves the colour and the smell, takes away (to a certain extent) unsaturated hydro-carbons and also part of the aromatic hydro-carbons. The unsaturated hydro-carbons especially must be taken out, because they are liable to oxydation or polymerisation during storage of the gasoline (or kerosene), producing coloured products with a bad odour, which products will, of course, ruin the smell and the appearance of the gasoline.

The treatment takes place by means of air, which is blown into the agitator after the acid has been added to the gasoline. The air-blowing divides the sulphuric acid into minute particles in the gasoline, thus increasing its action on the undesirable products of the gasoline. After the treatment the bulk of the acid is drawn off at the cone-shaped bottom and the gasoline (still sour) is carefully sprayed with water, which is also drawn off. To neutralise the last parts of the acid still remaining in the gasoline, lye is added in solution of about 6° to 8° Bé. and also agitated with air.

After the lye has been drawn off, the gasoline is washed thoroughly with water, which is drawn off, and then the gasoline is allowed to settle in low-built tanks, after which it is ready to go to storage for marketing.

Kerosene or lamp oil is treated in the same way.

Instead of agitating with air, centrifugal pumps are used sometimes. Acid, or lye, is introduced into the oil just before entering the pump. The mixing of both liquids is so intense that they have to pass only once through the pump, after which the oil is refined just as well as with the air-agitating method.

Besides the acid and lye treatment, the " Doctor treatment " is also applied many times. The Doctor solution, used for this purpose, is a solution of Litharge (*PbO*) in strong soda solution. It has a very strong action on sulphur compounds, which are often the cause of a repugnant smell. They are removed to a large extent by the Doctor treatment.

Lately another process has rapidly become popular in the refining of oil products. This is the silica-gel process. Silica-gel is able to absorb on its surface and in its pores large quantities of sulphur and of aromatic compounds. It is not known exactly what the action of silica-gel is, but the fact remains that for sulphur and aromatic compounds it is an excellent absorbent and consequently a very good material for oil purification.

While speaking of aromatic hydro-carbons, mention must be

made of the Edeleanù process. Owing to the chemical constitution of aromatics ($CnH2n$-6) as compared with aliphatics ($CnH2n$-2), the percentage of carbon in aromatics is entirely different from the percentage in aliphatics. It is therefore, necessary, in order to obtain complete combustion in the lamp, to supply an amount of oxygen (or air), which for aromatics is different from the amount needed for combustion of aliphatics. For compounds containing the same amount of carbon atoms, the aromatics need less oxygen than the aliphatics; in other words, when there is sufficient air for complete combustion of the aliphatics, there is too large a supply for the aromatics, thus the flame gets colder and the candle-power decreases, or when there is sufficient air for complete combustion of aromatics, there is not sufficient to burn the aliphatics and the flame starts sooting.

Many kerosenes contain a large percentage of aromatics, and consequently they do not burn well in lamps.

In order to improve the quality of kerosene, the Edeleanù process was introduced. The principle is that aromatics dissolve easily in liquid sulphur dioxide while the aliphatics do not. By using sufficient SO_2 liquid, two layers are formed, the lower containing practically all the SO_2 and the larger part of the aromatics, the upper layer containing practically all the aliphatics and only a small percentageof the SO_2 liquid and the aromatics.

These layers are drawn off separately, the liquid SO_2 (boiling-point, 10°C.) is easily evaporated and the two constituents, aliphatics and aromatics, are obtained in a more or less pure state. The SO_2 gases are condensed again and returned to the process.

The residuum of the crude oil, which is finally drawn from the last still of a continuous bench or from the evaporator of a Trumble plant, is not always sold directly as fuel oil. This is only done when the residue does not contain (or contains only a very small quantity of) any other products, the manufacture of which can be undertaken lucratively.

Such products are:

Paraffin Wax;
Lubricating Oil;
Asphalt and/or Coke.

Paraffin Wax Manufacture.

The residue of crude oil containing paraffin wax is submitted to another distillation, in principle in exactly the same way as the original crude distillation. The only difference is that the temperatures in the stills are kept much higher, even up to 370°C.

Open steam is used again to facilitate the evaporation of the more viscous distillates and also to prevent cracking of these distillates to a too large extent. The stills are also placed one after the other and are generally equipped with two small dephlegmators and a box condenser, thus three products are obtained per still. The distillation is generally regulated by the congealing point of the heaviest distillate.

About the distillation process and the formation of crystalline paraffin wax, opinions vary widely, but in general it is accepted now that the wax in the residue is *not* present in a crystalline state, but in an amorphous condition, which is transferred into crystalline state by distillation and slight cracking. It is a fact that a too abundant use of open steam in the stills during the distillation decreases the cracking and the yield of crystalline wax.

Generally, all distillates are mixed to two grades, depending upon the congealing points of the mixture of the distillates. After weak treatment with lye (in order to get rid of asphaltic compounds which hinder the crystallization of the wax) the distillates are cooled down in the cooling chamber, where, of course, the wax, having a high melting point, crystallises first. The chilled distillate, containing the wax crystals mixed with oily distillates, is pumped through filter presses at a low temperature, where the wax is filtered and retained by the filter cloth or filter cakes, whereas the distillate, now containing no wax, or in any case less wax, runs through. If the percentage of wax in this "filter oil" is still large, then the operation is repeated at a higher temperature in order to obtain the balance of the paraffin wax.

From the filter cakes the paraffin wax is manufactured. They still contain a large percentage of filter oil which must be separated from the wax, because wax for the market may not be "oily." This can be taken out either by sweating or pressing or by a combination of the two processes. For sweating, the filter cakes are brought into sweating chambers. Owing to a rather high temperature prevailing in the sweating chambers, part of the wax melts; the filter oil which the cakes still contain gets less viscous and runs off with that part of the wax which has been melted. This improves the colour and the melting point of the remaining wax. The oil which has been sweated out of the wax still contains a considerable amount of wax, but of a lower melting point. This oil is brought back into circulation and goes through the same process of cooling and filtering, with the difference that the oil is cooled more, because it contains more fractions of a lower melting point. The sweating

room process is a periodical process. Lately a continuous sweating process has been introduced into the wax industry.

There are plants in which this process is repeated three times, in order to obtain all the wax possible ; the sweat-oil and filter-oil from the first and second cooling and sweating always returning to be circulated again. From this it is evident that the manufacture of wax is a very complicated process. In combination with the sweating process, ring presses are also often used. They are built for the purpose of pressing the oil out of the raw wax under high pressure.

The raw wax, as it is finally made, still contains a small percentage of oil and is of a yellowish colour. It is then further purified by chemical treatment in agitators. Chemicals used for refining are sulphuric acid, fuller's earth or other decolourising powders and lime. On account of the high melting point of the wax, this process of refining is usually carried out at a temperature of over 100°C. in order to be sure that during the refining process the wax does not solidify, thus clogging all valves and apparatus.

Fuller's earth or acid clay and lime are finally filtered off by means of filter presses and the wax is run into aluminium pans, where it is left to solidify into slabs of about 5 kgs. weight, 6 cm. thick, which are packed and shipped in gunny bags.

Instead of casting paraffin wax slabs, American practice is often to use wax chipping machines, comprising a hollow cast iron rotating drum, cooled by water in the inside. The drum turns through a shallow pan, containing the melted wax. This wax sticks to the cool drum in a thin layer and, after about ¾ turn of the drum, is scraped off by a special knife scraper and packed in barrels or bags.

The filter oil obtained from the deepest cooling still contains a small percentage of wax, which, however, cannot be removed in an easy way. The filter oil is the base product for the *Lubricating Oil Manufacture.*

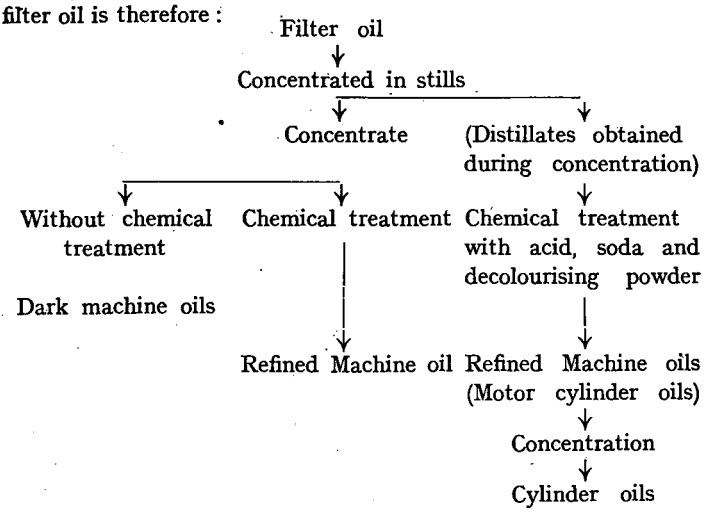
There are, however, other crude oils which do not contain paraffin wax and are yet very suitable for the manufacture of lubricants. The base product for the latter is the residue of the crude oil distillation after the lighter fractions (gasoline, kerosene, gas oil, etc.) have been distilled off.

It must be borne in mind that the filter oil is already a distillate and consequently it is a cleaner base product than the residue of the crude oil. Therefore, lubricating oil can be made by concentrating filter oil as well as from filter oil distillates, whereas

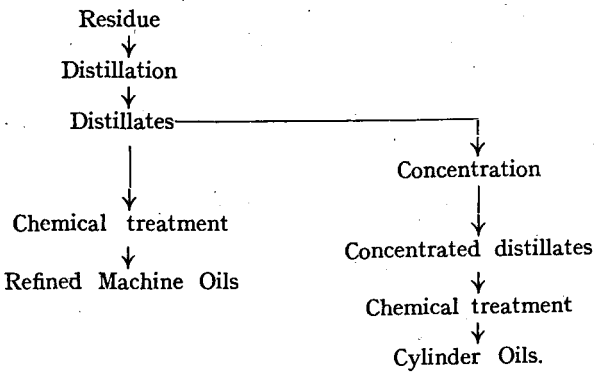
the residue of crude oil must be first distilled to obtain lubricating oil distillates. It is true that from a very few crude oil residues lubricating oil is made by concentration only, but this is not general practice and the lubricant obtained in this way is generally of inferior quality.

The distillation or concentration (or reduction) of the base product for lubricating oil takes place in ordinary stills, in principle the same as are in use for the crude oil distillation. A lot of open steam is used in the stills to prevent cracking.

The general practice for the manufacture of Lubricants from filter oil is therefore :



Lubricants from residues are obtained as follows :



In manufacturing lubricating oils, cracking must be avoided at all costs, because this has a very bad influence on the quality of the lubricants. Therefore many refineries have introduced the High Vacuum process in lubricating oil manufacture. The high vacuum (about 70 in. Mercury) is maintained by powerful vacuum pumps. The advantage of working under such a high vacuum is that the boiling temperature of the lubricating oil distillates is very much lowered and consequently the distillation takes place more easily and there is far less chance of obtaining cracked products.

Instead of chemical treatment (with acid and lye) many refineries use the Filter-process, by which the lubricating oil distillate is filtered through a thick layer (varying between 10 ft. to 20 ft.) of filtering material. This improves the colour very much, but the process is rather slow. Hot and cold filtering are practised, but cold filtering is desirable, because the colour of the final product is better.

During the chemical treatment with acid and lye it often happens (especially when treating heavy lubricating oils) that emulsions are formed, which are sometimes very difficult to separate. In order to avoid this, the dry-refining method has been introduced. After the acid treatment no lye is used, but a mixture of acid, clay and lime ; after agitation with air, clay and lime are filtered off. The process is much quicker than the " wet-refining," because formation of emulsions cannot take place.

For the manufacture of lubricating oil, mention must be made of the Sharpless process. The process takes place in specially built Sharpless super-centrifuges, operating at a speed of 15,000 to 18,000 R.P.M. It is specially used for the treatment of steam-refined cylinder stock. The process is carried out at a low temperature of about 5°C. and its main purpose is to free the cylinder stock from paraffin wax, which it always contains, to a certain extent, after the distillation.

The wax-free oil is later on concentrated (reduced in the ordinary way to cylinder oil), whereas the wax can be used as base product for petrolatum.

It seems to be necessary, however, for the raw material (steam refined cylinder stock) to be diluted with a rather heavy grade of gasoline in order to obtain the best results with the centrifuges.

The centrifugal process works continuously.

Asphalt and Coke.

Some crude oils (Panuco-California-Texas) have an asphalt base,

containing as they do a large percentage of asphalt and only a small percentage of paraffin. After the lighter products have been distilled off, the residue is often used for making lubricating oils and asphalt.

The lubricating oil is again obtained as a distillate. The asphalt is obtained as a residue in the still. The concentration of the residue is carried so far, that an asphalt suitable for the purpose for which it is intended, is obtained. Much steam is blown into the asphalt residue, in order to facilitate the distillation and to prevent cracking. Cracked products in asphalt decrease the value of the asphalt, making it unfit for several purposes.

Generally, the asphalt is distilled down to a certain penetration or to a certain melting point, dependent upon what the market needs. Asphalt can be just as well (or according to many authorities, better) made in Trumble-plants. It is a fact that the action of the steam, to prevent cracking, is far less in Trumble furnaces than in stills. On the other hand, the time that the asphalt is exposed to very high temperatures is far shorter in a Trumble furnace than in stills and consequently any cracking is not allowed to go so far in a Trumble with less steam than in a still with more steam. During the last years the process of manufacturing "' blown asphalts " has greatly developed. The process is carried out in such a way that the asphalt base product is heated in a specially constructed still to a certain temperature (about 450°F.), at which temperature air is blown through the heated product at about 20 lbs. pressure. It is not known what exactly happens in the still. Probably oxydation and polymerisation take place. The process develops so much reaction heat that the fires under the still can be drawn. The result is an oxydised or blown asphalt, which has a far higher melting point and a smaller ductibility than steam-refined asphalt made from the same base product. The yield of blown asphalt is much larger than of steam-refined asphalt (about twice as much), but it cannot be used for the same purposes as the latter. Whereas the latter is extensively used as road asphalt (asphalt-grout—Macadam and sheet asphalt), the blown asphalt is only used as a filler (between wooden paving blocks) and for the manufacture of roofing felt.

Coke is always obtained from any crude oil when distilled in the stills to " dry." The distillates from the " Coke-stills," which are invariably heavily cracked, always contain paraffins. The distillation to coke takes place in stills. It goes without saying that, when distilling to dry, the still bottoms are exposed to extreme

heat and therefore only have a very short life. The tension in the still bottom plates, when superheated, is very great. In order to reduce the expenses in connection with changing and renewing the bottom plates, the latter have lately been so constructed that they consist of a heavy still bottom plate in which strips of weaker construction are riveted. These small strips (about 1 in. wide) take up most of the expansion in the still bottom and, when in bad shape can be easily taken out and renewed without necessitating the renewal of the entire still bottoms. On account of the heavy upkeep, repairs and the long time that coke stills are out of operation, due to repairs and cleaning, the distillation to coke is a costly process and generally is only done when the distillates contain so much paraffin wax that the manufacture of wax from those distillates can make good the expenses involved in distilling to dry. The coke obtained in this way is of practical value for the manufacture of battery carbon.

Cracking.

Cracking is the decomposition of large molecules of hydro-carbons of high specific gravity and high boiling points into smaller molecules of lower speeific gravity and lower boiling points. This is generally done by heat.

Cracking can take place either in vapour-phase or in liquid-phase. Most of the present cracking processes crack in liquid-phase, because

(1). The thermal efficiency in the liquid phase is much larger.
(2). There is less chance of local overheating, liquid being a better heat conductor than vapour.
(3). There is less chance of coal deposits in the cracking apparatus.
(4). There is better regulation of the temperature in the cracking apparatus.
(5). Cracking takes place at lower temperatures.

Advantages of cracking in the vapour-phase are:

(1). Small amount of oil exposed to heat in case of breakage resulting in a fire.
(2). Easy adaptability for catalysis (platinum-sponge, nickel and other metals). There must be a great future in catalysis.
(3). Less pressure in the cracking system.

Of the many cracking processes invented in recent years, only a few have proved to be successful. These are:

Burton-process
Dubbs-process } and other variations.
Cross-process

all working in the liquid-phase, consequently under pressure.

Electricity has been applied as a source of heat, so far without practical success.

The constantly increasing demand for light hydro-carbons (gasoline) makes the cracking of heavy oils one of the most interesting subjects in the oil industry.

The knowledge that the supply of crude oil will some day be exhausted makes it exceedingly interesting to discover in what way our supply of hydro-carbons, so necessary for industrial and domestic purposes, can be obtained from other sources than crude oil.

Much can be said about this subject and interesting facts could be mentioned here (Bergius-process).

This, however, would lead us too far and would make our paper too long.

RÉSUMÉ.

L'huile brute contient différentes impuretés, telles que du sable, de l'eau, du sel et de l'émulsion, qui doivent être éloignés en premier lieu. On peut l'obtenir par le dépôt de l'huile brute et ensuite par des procédés chimiques (Tret-o-Lite), mécaniques (séparateurs) ou électriques (Cottrell).

L'huile purifiée de cette manière est ensuite soumise à la distillation. Suivant la méthode la plus ancienne, mais encore généralement en usage, cette distillation se fait dans des chaudières cylindriques, appelées "stills." Ce procédé peut être périodique, semi-continu ou continu. Les trois méthodes ont cependant le même but, notamment de distiller, par le chauffage de l'huile brute, des éléments, qui, après avoir été condensés, donnent des produits satisfaisant aux exigences du marché. Les produits obtenus de cette manière sont: la benzine, la kérosine, l'huile Solar et l'huile Diesel.

Dans les dix dernières années, on a développé, à côté de l'ancien procédé du "still," une nouvelle méthode appelée, d'après son inventeur, procédé Trumble, où l'huile brute est chauffée dans des fours tubulaires, à un tel point que finalement tous les produits que l'on désire soient obtenus ensemble sous forme gazeuse, de laquelle, par une condensation fractionnée, les divers produits sont séparés dans un état plus ou moins pur. La différence frappante entre l'ancienne méthode "still" et la méthode Trumble consiste donc en ce que, en appliquant la première méthode, on obtient les produits au moyen de distillation fractionnée, tandis qu'avec la méthode Trumble ces produits s'obtiennent par condensation fractionnée. Le plus souvent, avant d'être mis sur le marché, la benzine et la kérosine sont encore soumis à une épuration avec de l'acide sulfurique et de la soude.

Le résidu de la distillation est souvent vendu comme combustible liquide sans avoir subi aucun autre traitement, mais dans beaucoup de cas il contient encore des produits qu'il peut être profitable de recueillir. Ces produits sont: la paraffine, l'huile lubrifiante, l'asphalte et le coke.

Afin d'obtenir ces produits on continue à distiller le résidu de la première distillation, donc à une température plus élevée. La paraffine, qui se trouve dans le résidu sous forme non-cristalline, est convertie par cette distillation en un produit cristallin, qui est cependant encore en suspension dans les fractions d'huile distillant en même temps. Par un procédé compliqué de réfrigération (donc de cristallisation) et de suintement (" sweating "), c'est à dire de séparation des cristaux de paraffine de l'huile, on obtient finalement (selon la température à laquelle le distillat paraffineux original est réfrigéré) diverses espèces de paraffine brute, auxquelles il ne manque plus qu'une épuration avec de l'acide sulfurique, de la chaux et de la poudre décolorante pour pouvoir être mises sur le marché, comme paraffine blanche.

Le résidu, qui ne contient pas de paraffine, peut être traité directement pour obtenir de l'huile lubrifiante par distillation. Le distillat obtenu par la distillation de la paraffine peut être également traité pour l'huile lubrifiante, mais il est nécessaire alors que la paraffine, en soit préablement éloignée. Aussi on emploie toujours, comme matière première pour la fabrication d'huile lubrifiante, une huile paraffineuse, surnommée " filteroil," c.à.d. de l'huile qui est séparée du distallat paraffineux réfrigéré par la filtration.

Quelques huiles brutes contiennent un pourcentage élevé d'asphalte, que l'on obtient par la distillation du résidu provenant de la distillation primaire. Les distillats sont alors traités afin d'en séparer l'huile lubrifiante.

Le coke est produit par une distillation de chaque résidu, poursuivie jusqu'à un degré tel que le contenu du " still " se transforme en coke et se durcisse.

Afin de satisfaire à la demande de combustibles pour moteurs à explosion, on a essayé d'augmenter le rendement de produits légers, c.à.d. du benzol et de la kérosine, et on y a réussi en introduisant les procédés nommés " cracking," dont ceux de Burton, Dubbs et Cross sont les plus connus.

Le principe du " cracking " est fondé sur la décomposition d'hydrocarbures lourds, avec un point d'ébullition et un poids spécifique élevés, en hydrocarbures plus légers ayant un poids spécifique et un point d'ébullition plus bas. Cette décomposition, s'effectue au moyen d'une température très élevée, donc par une distillation destructive. Cependant, pour la préparation de beaucoup de produits, tels que l'huile lubrifiante et l'asphalte, une distillation destructive est peu désirable, attendu que les produits obtenus perdent quant à leur qualité. C'est pourquoi on emploie pendant la distillation, spécialement dans la préparation des deux derniers produits, de grandes quantités de vapeur. Cet emploi de la vapeur a pour but (par suite de la loi de la pression partielle) d'abaisser le point d'ébullition des produits à distiller et d'amoindrir par conséquent la chance de " cracking." C'est dans ce même but que, pour la préparation d'huile lubrifiante, on applique le procédé du vide, où la distillation a lieu sous une pression d'environ 6 cm. de mercure.

A NEW SYSTEM OF OIL PRODUCTION FROM SWEDISH OIL SHALE

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Sweden possesses very big deposits of oil shales. In the central and southern parts of the country, near railways and waterways, there are to be found about 5,000 millions of tons. The richest shale deposits, yielding from 4 to 7 per cent. of oil, are found at Kinnekulle and in Nerike. Part of these deposits, holding some 630 millions of tons of shale and representing about 32 millions of tons of shale-oil, may be cheaply mined in open cuts (Fig. 1). The thickness of seam of these deposits averages 30 feet. They contain thin bands and lenses of a bituminous limestone (orsten), easy to separate from the broken shale. According to Official Statistics, the country's annual consumption of mineral oil at present is about 150,000 to 200,000 tons, including 43,000 tons of motor spirit, and 44,000 tons of heavy motor and fuel oils. If the Swedish shale deposits were utilised for production of oil, the home market could thus be supplied for a considerable time by such native oil.

The author has for several years systematically studied[1] the Swedish oil shales, and chemical and physical research as well as experimental work have led him to the conclusion, that solvents applied as such, have no effect or very little effect upon the shale, while heat-decomposition of the shale will give as a result an oil similar to mineral oil. The greatest oil yield is obtained by quickly raising the temperature from about 270° C.,at which temperature decomposition begins, to about 450°C. An ordinary Swedish oil shale has an average heat value of 2,000 Cal. per kg. After such a heat-decomposition, it gives a coke-like residue, amounting to about 85 per cent. by weight of the shale and having a heat value of about 800 to 1,000 Cal. per kg. Combustion tests with this coke-residue, previously heated to about 500°C., have indicated a very characteristic temperature-curve and proved that a good

[1] Teknisk Tidskrift, 1920 and 1921 Svensk Kemisk tidskrift, 1921.

efficiency of combustion can be reached when the shale is broken to proper size.

On the basis of these results, the author has developed a method for destructive distillation of Swedish shales, with subsequent separate burning of the coke-residue in one continuous process,

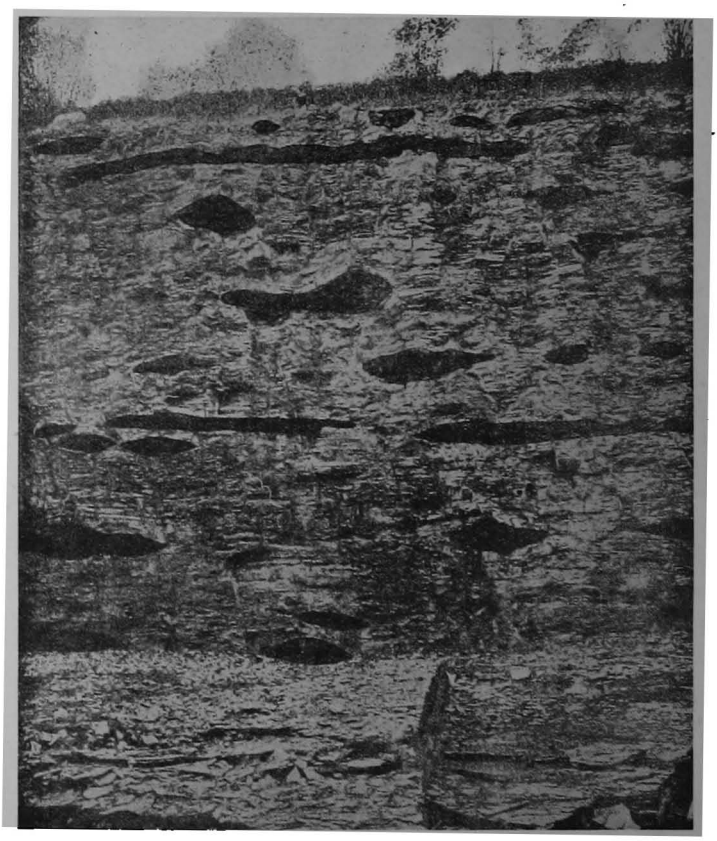


Fig. 1. A typical Swedish oil-shale quarry, from a photograph by the Swedish Geological Survey. The lenses and bands marked with a darker colour are bituminous limestone.

with carefully controlled temperature throughout the whole treatment, during which the heat obtained by burning the coke-residue is utilised so that no other fuel is needed. Such a treatment of the shale will result in a good low-temperature oil and a gas of

a high heat value. By-products, such as sulphur and ammonia, may also be easily recovered.

Practical experiments of this method were made possible by Government grants of about £2,400 in all. A small plant was erected in 1922 at the Klara gasworks in Stockholm, and in 1923 a full sized experimental plant was built at the Kinnekulleverken on Kinnekulle. These plants embody several of the author's inventions and were designed and operated by the author and his associate, Mr. K. E. Larsson, M.E.

Fig. 2. The full sized experimental plant (capacity 10 tons of shale a day) dealing with the shale deposits of the Kinnekulleverken. To the right the breaking-plant and crude-oil tanks; to the left the front or working-side of the retort battery and the engine-house.

Fig. 3. A rear view of same plant, showing the condensers and the gas-holder.

The plant of 1923 was built during July-August, and put into operation in the middle of September. After some experiments and necessary adjustments, it has been working continuously for about two months with very satisfactory results. Inspection of the inner parts showed that nothing was worn or otherwise damaged in any way, indicating that the plant very probably could have been

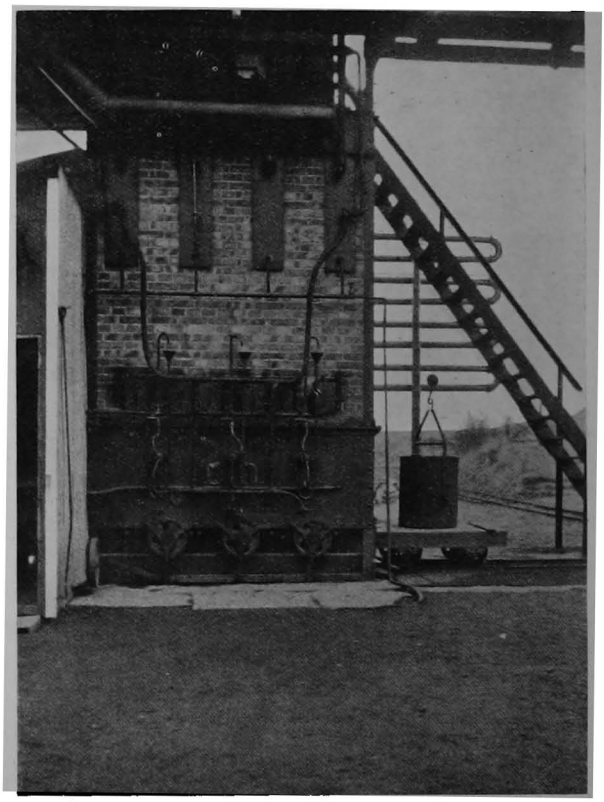


Fig. 4. A detailed front side view of the retort battery comprising three heating chambers with their retorts (with a capacity of 10 tons of shale a day).

run for years without any serious repairs. Now, a larger plant of industrial size will be built as soon as possible according to the same system.

Figs. 2, 3 and 4 show the plant at Kinnekulle. The furnace system consists of three equal chambers, provided with retorts and grouped together in a block or battery. The total outside

height of such a block is no more than 13 ft. Each chamber has an inner height of about 10 ft., a cross section of 1·8 × 3·9 ft., and is designed as a technical and economical unit. *Thus a retorting plant may be built up by such units to suit any quantity of shale.*

The shale, after being crushed to a certain small size, previously determined for each different kind of shale, is conveyed to the feed hoppers of the retort-battery and allowed to pass freely into and through the retorts and the furnace, where it is utilised and burned. The resulting ashes are automatically discharged through a rotating grate, which regulates the speed of the material descending through the furnace. The temperature in the retorts and heating chambers, as well as the drawing-off of the oil-vapours, is operated by self-controlling regulators of a very simple and solid

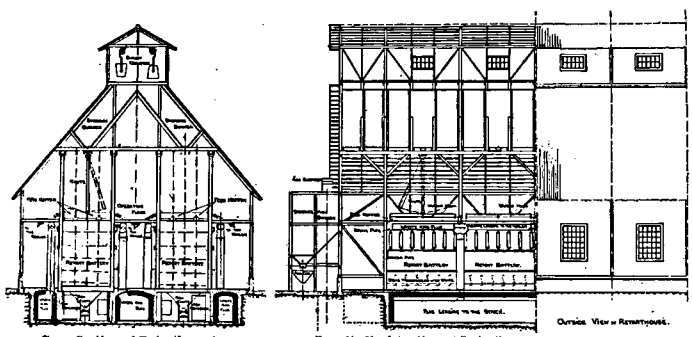


Fig. 5. A design of a larger plant of same system as the experimental plant.

construction. The retort battery works quite automatically and manual work is needed only for attending to the machinery and for conveying the raw material to and from the retort furnace.

The heat decomposition of the shale is carried out with superheated steam, about 20 per cent. by weight of the shale, and is accomplished in about 30 minutes. The steam is generated and superheated simultaneously by the heat of the coke-residue. In twenty-four hours a heating chamber with its retorts puts through 2·5 to 4 tons of Swedish oil-shale, according to size and nature of the shale.

An analysis of shale as received at the Kinnekulleverken during a 30 hours test gave the following result:

moisture	.. ..	1·29 per cent.
ashes ..	.. ..	74·20 „ „
sulphur	.. ..	5·81 „ „
crude oil	.. ..	4·75 „ „

The heat value of the same shale was 2,070 Cal. per kg.

One ton of shale yielded by distillation on the average 41·75 kg. of crude oil, that is, 88 per cent. of the oil-yield by analysis, and 60 cu. m. of gas with a heat value of 4,600 Cal. per cu. m.

The following table gives the average composition and properties of the crude oil obtained:

carbon	85·50 per cent.
hydrogen	10·76 „ „
sulphur	1·78 „ „
specific gravity 15°C.	0·978
viscosity at 20°C.	3·0
„ „ 50°C	1·4
flash point (Abel)°C.	35·7
igniting point (Marcusson)°C. ..	68·0
heat value Cal./kg...	9920

The crude oil remains quite fluid and without precipitation at —30°C.

Crude oil recovered from Swedish shale may be distilled into two fractions, namely *gasoline* and *heavy motor or fuel oil.* The gas is intended to be used for lime burning (raw material, the bituminous limestone accompanying the shale); for brick making (raw material, the ashes of the shale and some clay); for cement production (raw material, silicious limestone generally overlying the shale deposits).

The approximate cost of a complete plant for the production of crude oil and gas, including breaking machinery, is at present in Sweden about £9,000 for a capacity of 100 tons a day and about £76,000 for 1,000 tons a day.

Fig. 5 shows a drawing of a large plant designed for industrial use. In the design of this plant the best mechanical devices for rapid and efficient handling of the material were introduced, and safety measures were taken to avoid delays and shut-downs resulting from machinery break-downs. The retort battery and the retorts are simple, strong and cheap, and parts exposed to wear are easy to replace.

The estimated annual cost of running a plant in Sweden at present with a daily capacity of 100 tons of shale is as follows:

Raw Material	
Shale (30,000 tons+10 per cent.).. ..	£1,600
Cost of Manufacture	
Wages (6 men and 1 foreman)	£1,000
Power (103,750 kilowatt-hours)	£380

Repairs, etc...	£240
Amortization, interest, tax, etc.	£660
Administration	£720
Total ..	£4,600

When working shale from the Kinnekulleverken, the gas recovered is equivalent to 1,200 tons of coal with a present value of £2,200, and the crude oil recovered is 1,200 tons, with an oil yield at a low estimate of 4 per cent. Thus the approximate production cost of *one ton* of crude oil from this shale will be $\frac{4,600\text{-}2,200}{1,200} = £2.$

For a bigger plant and a greater output, the figures of course will be much more favourable.

RÉSUMÉ.

Une nouvelle méthode pour l'exploitation des schistes bitumineux de la Suède et en extraire l'huile et le gaz, à été inventée par Sven V. Bergh, ingénieur des mines à Stockholm.

Les gisements de schiste sont estimés à 5.000 millions de tonnes et occupent une situation centrale dans des endroits, ayant de bonnes communications. La consommation actuelle d'huile de la Suède est estimée de 150.000 à 200.000 tonnes. Si les gisements de schiste étaient utilisés pour produire de l'huile, les besoins du pays seraient satisfaits pour un temps considerable par ces huiles indigènes.

Pendant plusieurs années l'auteur a étudié scientifiquement ces schistes Suédois et est arrivé à la conclusion, que des dissolvants, employés comme tels, n'ont aucun ou très peu d'effet sur ces schistes, tandis que par une décomposition de ces schistes par la chaleur on obtient une huile analogue à l'huile minérale et le rendement en ile huest maximum si l'on augmente la temperature très rapidement d'environ 270°C. jusqu'à 450°C. Après la décomposition par la chaleur il reste un résidue d'un pouvoir calorifique absolu de 800 à 1.000 kilogramme-calorie. Des expérience effectuées sur ce résidu, préablement réchauffé jusqu'à 500°C. ont indiqué une courbe de température très caractéristique et prouve qu'un bon effet de combustion peut être obtenu, si le schisté est cassé en morceaux convenables.

Se basant sur ces résultats, l'auteur a développé une méthode pour distiller destructivement les schistes bitumineux de la Suède et pour brûler ensuite les résidus séparément, par un procédé continu, en contrôlant la température très exactement pendant tout le traitement. La chaleur, obtenue par le coke-résidu brûlé est le seul combustible.

Par ce traitement du schiste on obtiendra une bonne huile et un gaz d'une haute capacité calorifique, également des produits secondaires, tels que soufre et ammoniaque.

Cette méthode fait l'objet de recherches effectuées sur une échelle industrielle, subventionnées par l'État Suédois, et une usine d'essai a été érigée à Kinnekulle (Västergötland).

Le four d'expérience est composé de trois chambres de combustion, construites en une batterie et munies de cornues, chaque chambre formant une unité. *Ainsi l'établissement d'une usine peut être avec des réalisé unités semblables groupées en une batterie pour n'importe quel le production.*

Le schiste cassé en morceaux convenables est transporté dans des récipients, placés au-dessus des cornues, d'où il descend librement dans les cornues et le four, où il est distillé et brûlé. Les cendres, produites par la combustion, sont sorties du four automatiquement par une grille rotative, qui règle ainsi la descente des matériaux dans le four. La décomposition du schiste par la chaleur est obtenue avec de la vapeur surchauffée et tout le traitement a lieu en 30 minutes. La vapeur nécessaire est produite et surchauffée simultanément par la chaleur du coke-résidu. Pendant 24 heures *une chambre de combustion* avec ses cornues est capable de traiter 2,5 à 4 tonnes de schiste Suédois. Par tonne de ce schiste on obtient en moyenne, 41,75 kilogrammes d'huile brute formant 88 pour cent de l'unité analysée et 60 mètres cubes de gaz d'une capacité calorifique de 46,00 calories par mètre cube.

Le tableau suivant donne en moyenne la composition et les qualités de l'huile obtenue :

Carbone	85,50 pour cent
Hydrogène	10,76 „
Soufre	1,78 „
Poids spécifique à 15°C.	0,978
Viscosité à 20°C.	3,0
„ 50°C.	1,4
Point d'inflammabilité (Appareil d'Abel) ...	35,7
„ „ („ de Marcusson)	68,0
Valeur calorifique Cal/kilogr.	9920

Le prix approximatif d'une usine complète pour produire de l'huile brute et du gaz est actuellement en Suède d'environ £9.000, y compris les machines à casser le schiste pour une capacité de 100 tonnes par jour, et d'environ £76.000 pour une capacité de 1.000 tonnes par jour.

L'evaluation des frais d'exploitation d'une usine actuellement en fonctionnement en Suède et ayant une capacité journalière de 100 tonnes de schiste est la suivante :

Matières premières	
Schiste (30.000 tonnes 10 pour cent)	£1.600
Frais d'exploitation	
Salaires (6 ouvriers et chef d'équipe)	£1.000
Force motrice (103.750 kilowatt-heures)	£380
Réparations	£240
Amortissement. intérets, taxes, etc.	£660
Administration	£720
Total	£4.600

Le prix approximatif de la production d'une tonne d'huile brute de schiste de Kinnekulle sera de £2.

Dans une usine plus importante et pour une production plus grande, les chiffres seraient naturellement plus favorables.

POWER FROM THE WOOD-WASTE OF THE SWEDISH FORESTS

H. von ECKERMANN, Ph.D.M.E.
Managing Director, Ljusne Woxna Co.

The expansion of industry in Sweden during the Great War created a sudden and extensive demand for additional power. This could be obtained neither by harnessing the larger waterfalls, owing to the length of time required for building, nor from steam power stations involving the use of coal, owing to the export restrictions on this fuel at that time in England, Germany and America, so the power had to be recruited from home resources. Among the more successful solutions of this problem the gas-power station at Ljusne Sawmill and Iron Works may be cited as worthy of more than local interest.

Ljusne lies at the mouth of the Ljusne river, on the coast of the Baltic, 250 km. north of Stockholm, in the centre of a district rich in natural water-power and in large and extensive forests. After very thorough experiments on a minor scale, a station was erected in 1916, where the power is raised from the waste obtained in the industrial exploitation of the woods that grow along the course of the river. Since this, Ljusne power-station, planned for 4,400 h.p. in all, has been duplicated at several places, especially in Finland, and, as the more favourably situated waterfalls become fully developed, this new contribution of power may come to be of considerable importance, especially in wooded districts, a short description is given here of the power system as it has been adapted to Swedish conditions.

The process consists of gasifying in gas generators the waste obtained partly direct from the woods and partly from establishments for the utilisation of timber, that is to say sawmills and joinery works, and the subsequent conversion of the gas to power in suction-gas engines, tar being collected as a by-product. Since a portion of the wood-waste, in addition to that used in the generation of power, is always converted into charcoal, for use in Swedish iron production, in such districts where the iron and timber trades flourish together, the gases from the iron and charcoal furnaces can also be conveyed to the gas engines, and a common central

gas-power station thus obtained. The power system, as fully adapted to Swedish conditions, has, therefore, the diagrammatic construction illustrated in Fig. 1.

To judge the quantitative possibilities of development of this power system, the technical and economic results gathered during a trial of several years must be taken into consideration. Since the station at Ljusne has been subjected to severe tests and careful

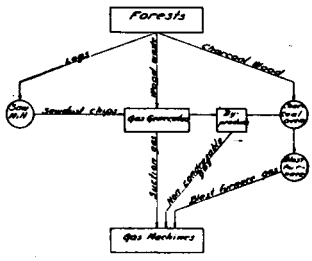


Fig. 1.
Diagram of the production of gas-power from wood waste.

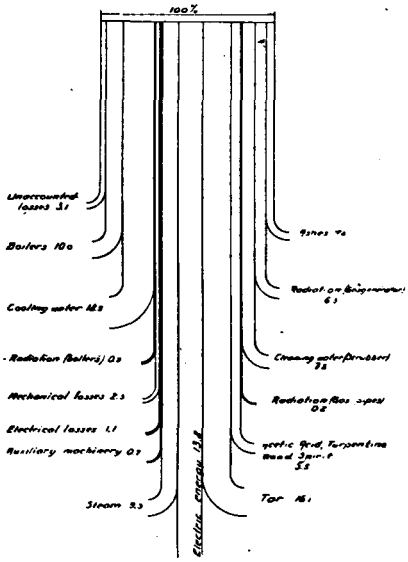


Fig. 2
Calorific balance sheet of the Ljusne gas-power machinery in 1917.

control for seven years, an account of results obtained there should be decisive. Sawdust and chopped-up laths from the sawmill, and brushwood, trees and stumps from the forests have been used as fuel.

This fuel is gasified in generators built of heavy sheet iron, provided with stationary grates and lined with fire-brieks ; owing to the small percentage of ash in the fuel, the accumulation of slag on the grates has been negligible, and no need has been felt for self-cleaning grates.

The gas is purified in a stationary scrubber and the tar then washed out by water in a rotary separator. Finally, the remaining acetic acid is removed by means of lime in special sheet iron tanks.

With 52 per cent. of water in the fuel, and the gas entering the engines at a temperature of 55°C. it was found, according to the measurements of 1917, that 2·90 kg. of fuel were consumed for each kWh produced by the motor. The heat content of the gas was 850 cal. per cubic metre and its specific weight at N.T.P. 1·178. Since then the fuel consumption has sunk to about 2·70 kg., the machinery having become worn in by use, and the friction losses reduced accordingly.

The gas motors, which consist of four cylinder groups of 550 h.p. each, consumed when new 2,420 cal. per h.p. hour, a rather high figure, which has now sunk to at most 2,200 cal., and even this quantity, in winter when the gas enters the engines at a lower temperature and the fuel is dry, is occasionally reduced.

The diagram of the heat balance, which was constructed by Mr. A. Håkansson, M.E., and Mr. H. Lundberg, M.E., during the trials in 1917, is reproduced in Fig. 2.

As mentioned above, the diagram is now more favourable, and the resulting effective electric energy can be estimated at 15 per cent. of the total calorific value of the fuel. Counting the by-products (tar and steam) the thermal efficiency is well above 32 per cent. With up to 71 per cent. of water in the fuel the gas generators have worked satisfactorily, while at the same time it proved impossible to keep the fire up under boilers with such wet fuel. Of course, full power could not then be obtained from the gas engines, but a load of 50 per cent, was maintained steadily.

The waste gases from the engines are used to heat the tubular boilers which are placed against the wall, and the steam obtained, about 1·1 kg. per kWh., is used for the purification of the by-product tar obtained from the rotary scrubber attached to the generators. The greater part of the water and all the soot are thrown out by centrifugal force before the final purifying of this tar is done with steam, removing the last 12-15 per cent. water.

Let us now attempt to calculate the maximum power that could be obtained in Sweden under present conditions, from the waste from woods and sawmills by the Ljusne system. This figure can be best ascertained by basing the calculation on the average yearly output of the woods with rational forestry. One can, by careful calculation, aided by the assessment carried out in 1913 by the

Swedish State, of a considerable portion of the Swedish forests (Vermland), compute the output as follows:

Timber for sawing	0·25	cubic metre per acre.
Pulp-wood	0·12	,, ,, ,, ,,
Charcoal-wood	0·06	,, ,, ,, ,,
Fire-wood	0·14	,, ,, ,, ,,
Total	0·57	cubic metre per acre.

When cutting up all timber in a modern sawmill, with an average net gain of 70 per cent. finished goods, 275 kg. waste per cubic metre sawn goods are obtained, in addition to which it may be calculated that there is left in the woods when felling the trees, waste to the extent of 10 per cent. of the timber and pulp-wood felled. Since the total area of the Swedish forests can be computed at 60,000,000 acres, the waste disposable amounts to:

From sawmills—2,900,000 tons, 50 per cent. water content.

From forests—2,600,000 cubic metre or 2,200,000 tons, 50 per cent. water content. Total—5,100,000 tons.

On a basis of the Ljusne consumption figures the maximum annual quantity of kilowatt hours for the whole country should be about 1,900 millions or, allowing an average of 4,500 working hours per kW. year, 420,000 kW.

This quantity far exceeds the largest amount of steam-power that could be obtained from the same fuel, even with machinery of the most modern and economical type, and in addition to this the tar as well as some acetic acid, turpentine and wood spirit, otherwise burned under the boilers, is retained.

According to Ljusne experience the average production of tar per kg. sawdust is 54 gr., and per kg. wood waste from the forests 35 gr., so that the total quantity of tar which could be obtained would be in even figures 230,000 tons, the above figures being calculated on fuel with a 50 per cent. water content.

However, only a lesser part of these quantities of power and tar, namely, 180,000 kW. and 80,000 tons, is obtainable from the sawmills, which are usually well situated for the production of power, the greater part being of course theoretically obtainable but practically out of the question owing to the geographical situation of the forests.

If, however, one assumes, with every reason of probability, that half of the wood-waste can be turned to account, the total actual production by this suction-gas system would be 300,000 kW. and 155,000 tons of tar a year.

If one now extends the compass of this production of power from wood-waste to beyond Sweden's shores, including only the largest timber-exporting countries, namely Finland, Norway, Canada and Russia with her border states, one can most easily draw a comparison between the actual power capacities of these countries by presuming these to be equal to their average production of manufactured wood. To their theoretical maximum values, a comparison of the extent of their forests will give the answer. On this pre-supposition one arrives at the following reserves of power :

Country	Acres of exploitable forests.	Prospective amount of kW. Actually	Theoretically
Norway	17,700,000	50,000	124,000
Finland	46,500,000	180,000	325,000
Russia	100,000,000 (estimated)	150,000	700,000
Canada	270,000,000 (50% of total)	360,000	1,890,000
Sweden	60,000,000	300,000	420,000
Total	494,200,000	1,040,000	3,459,000

Of the above quantity of about a million kilowatts, roughly half is obtainable from the waste of manufacture and half from the woods.

If one now considers under what conditions this power might come into use, it depends in the first place on the cost of construction.

Thanks to the income obtained from the tar, it is found, as I have previously shown in another paper, that the cost of running, including interest on capital and depreciation, exceeds only very slightly that of a Swedish water-power station. The building costs are always cheaper, owing to the low heads and large quantities of water of the Swedish falls, even if running costs are slightly higher, mainly due to a larger consumption of lubricating oil. In well situated districts, as for instance on the Baltic coast, this type of power production is actually a little cheaper. During the great war, prices of tar climbed to such a high level that the power station at Ljusne even had a net profit of a halfpenny per kWh., and produced the power free of cost as a by-product. Even to-day the power cost does not exceed a halfpenny per kWh.

As the larger and better situated waterfalls reach their full industrial development, there is in my opinion no doubt that the time draws nearer when gas-power from wood-waste will become of real importance.

This power can be considered both as a steady provision during the whole year, where there is a continual supply of waste obtainable from sawmills, and as a reserve behind water-power, waste being conveyed from the woods to the power station in the winter months, and then used in the periods of low water in the summer and in midwinter. As the waterfalls of the forest regions can in this way be harnessed for a larger amount of power—for instance, calculated on water of only six months duration—the wood-waste therefore certainly carries with it also a more extensive exploitation of the water-power.

Reference: Jernkontorets Annaler (Journal of the Swedish Ironmasters' Association) 1918, pp. 147-204.

RÉSUMÉ.

Le rapport examine les possibilités quantitatives d'une production de force motrice assez importante dans des pays boisés, basée sur la gazéification des déchets de bois et la transformation du gaz en force motrice dans des moteurs à gaz.

Les calculs sont dérivés de résultats obtenus dans une centrale située en Suède à Ljusne sur les bords de la Baltique, construite en 1916 et ayant une puissance de 4,400 chevaux, et qui a été en marche continue pendant sept années.

Comme résultat final on arrive, pour les plus grands pays exportateurs de bois, au total d'environ un million de chevaux de force.

Les stations centrales à gaz sont tout aussi bon marché comme construction, que les usines hydrauliques du type suédois à faibles chutes et grands débits.

Le goudron receuilli comme produit secondaire réduit les frais à un degré dépassant peu ceux des centrales hydrauliques.

Pendant des périodes de forte charge il est même probable que tous les frais seraient payés par le profit réalisé sur le goudron.

Environ la moitié de la force du gaz provient du déchet des scieries, la moitié du déchet des forêts.

Ce dernier est employé admirablement comme réserve, formant un appoint à la force hydraulique.

SAWMILL WASTE AS A FUEL.

OTTO NORDSTRÖM
Consulting Engineer, Sundsvall, Sweden

The world's production of sawn wood goods probably amounts to 25 or 30 million standards (50 or 60 million feet board measure) exclusive of Russia's production. Of this total the vast majority comes from the United States, which country alone produces 15 to 20 million standards. In Sweden more than two million standards are produced, about half of which are exported. The milling waste, solid measure, represents finally as much as the finished sawn goods. This waste consists of sawdust, slabs and edgings and mill ends. Besides this, the planing mills deliver more sawdust and shavings.

25 million standards sawn goods thus give $\frac{25\times165}{35}=118$ million cubic metres waste, solid measure. Figured as 30 per cent. moist fuel this waste should give about $2{\cdot}900\times118\times640=220{,}000{,}000$ million kilogram calories, or expressed in terms of coal of 7,000 kilogram calories $\frac{220{,}000{,}000}{7{,}000\times1{,}000}=30$ million metric tons, approximately.

Such a low percentage of moisture in this waste as 30 per cent. is, however, very seldom met with except from planing mills and in trimmings of seasoned lumber, because the trees, when growing, usually have a moisture of about 50 per cent., which is materially increased as the timber is floated down, especially in the sapwood, which later constitutes a large part of the waste. Under the conditions existing in Sweden, the moisture in the waste usually varies between 50 and 60 per cent., but in the autumn it often increases to as much as 65 per cent. On account of this high percentage of moisture it is natural that refuse, as it is delivered by the sawmill, is a very poor fuel.

About twenty-five years ago the sawmills had big ovens in which edgings and slabs were burned to no purpose, and at great expense. To-day one may see both in the United States and in Canada, large refuse burners in use for burning the mill waste, while large steam central stations near by are at the same time being fired with coal. However, one may say that in Sweden, now that suitable ovens have

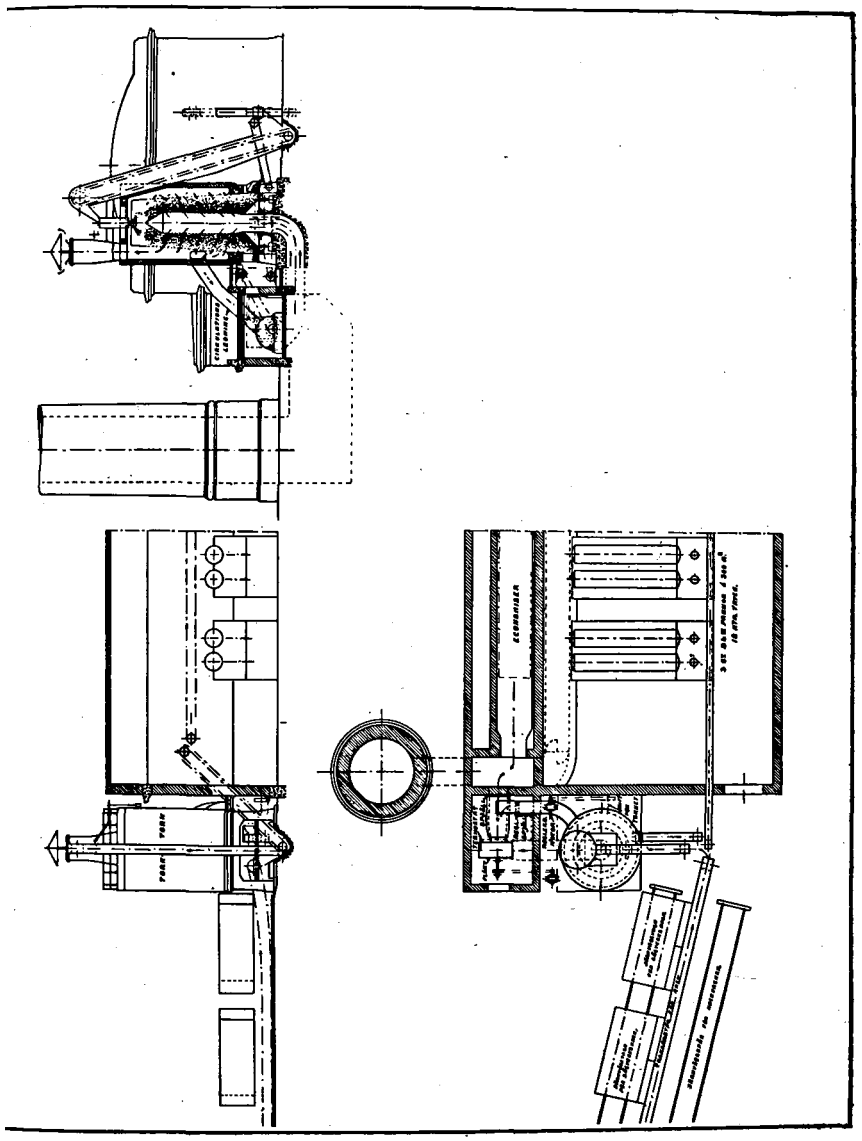
been constructed, practically all the sawmill waste is utilised. Before burning, the big pieces are chipped in special machines into sizes suitable for combustion. Nevertheless, the steam central stations, built for this waste fuel, are quite expensive on account of the large heating surface needed in proportion to the steam production. A large amount of fuel is consumed, partly due to the low effective heat value, partly due to the poor efficiency. Very large amounts of waste must be stored for winter, and as these are too large to be covered, the material depreciates utterly owing to the snow and freezing of the water contained in the wood. Under such circumstances it is often almost impossible to keep up the steam pressure with this fuel; disturbances take place and unforeseen losses occur.

Under such circumstances the idea of drying this fuel is very natural. Many experiments have been made, but no practical or economical method of solving the problem had been attained. After some years of work and investigation, this problem has now been solved, and already two drying towers are working satisfactorily and a third will be started within a short time.

Below is given a detailed description of the first complete plant in operation at the sulphite pulp mill of J. W. Enqvist AB, Tammerfors, Finland, since the end of May last year. The attached drawing shows the essential parts of the arrangement.

THE DRYING PLANT.

This is built near the boiler house of the mill, in which the dried waste fuel is to be used. This boiler house at present contains three B. & W. water-tube boilers each of 300 square metres of (300 boiler H.P.) heating surface and with economisers for heating the feed water. The flue gases, used for the drying, are sucked out of the flue, after passing through the economiser, by an electrically driven fan, erected in a separate building outside the boiler house. The waste fuel arrives at the mill in railway trucks and is discharged from these to a conveyor, which transports it to the tower's elevator. After being dried, the fuel is conveyed into the boiler room, where it is distributed to the furnaces of the boilers. The fuel may, in case of interruption in the operation of the drying plant, be conveyed direct to the boiler room. The speed of the discharge from the drying tower can be regulated to suit convenience, and in this way the quantity of fuel, delivered to boiler house, is controlled as required.



THE DRYING TOWER.

This tower, having a capacity of about 70 cubic metres of fuel, consists primilarly of an inner and an outer round tower of sheet iron, between which towers, the fuel, during the drying process, sinks down ; both the inner and outer towers are made sloping to prevent the chips bridging. In order to allow the drying gases to pass, both the inner and outer tower are perforated in such a way that the waste cannot attach to or pass through the perforation. Around the outer tower is a brick construction, with a roof of reinforced concrete, the latter having a steel plate chimney. The outer tower and the brick cover rest on a reinforced concrete construction. The inner tower, which is closed at the upper end, and is the continuation of the duct from the flue, is carried by a cast-steel collar, resting on the concrete foundation itself. At the upper end of the tower arrangement is made for the feeding in of the chips, and at the lower end for their discharge.

THE FEEDING.

This is done by a bucket elevator, which delivers the fuel into a special feeder. This feeder distributes the fuel into the ring-shaped drying space in such a way that the larger pieces are placed nearest to the inner tower, and the smaller ones, such as sawdust, etc., nearest the outer tower. This arrangement is made in order to decrease the resistance of the gases through the layer of fuel, which consequently gives the smallest resistance per surface unit near the inner tower, where the speed of the gases is highest, and the largest resistance near the outer tower, where the speed is lowest ; this saves power. Also the largest pieces come in contact with the hottest gases, which is, of course, preferable.

The drying space is always kept filled while the plant is in operation, thus preventing the gases from going direct from the inner tower out to the chimney. In order to provide for observation of the fuel level in the tower from outside, a float gauge is mounted on the roof.

DISCHARGING.

This is effected by a partially conical rotary bottom, filling the whole cross-section between the inner and outer tower, its flat part also extending to constitute the bottom of a ring-shaped space of a certain height, and lying outside the external tower. As both the conical part of the bottom and its plane part inside the outer tower have suitably arranged scrapers fastened to them, and as the bulk of the fuel rests on this bottom, the pressure on its conical part and the movement of the scrapers during rotation force out the fuel

through the ring-shaped opening, which is situated between the lower edge of the outer tower and the rotary bottom. The fuel in the ring-shaped space then follows the flat bottom, which is also equipped with scrapers, round to an opening in the side from which the fuel falls onto the conveyer and is transported to the boiler house.

THE GAS.

This is delivered through a fan, forcing it from below into the inner tower, and from this through perforations more or less radially through the layer of fuel, and subsequently through the perforated outer tower out to the gas collecting chamber, and from there through the chimney of the tower.

In order to keep the temperature of the ingoing gases constant, or regulated according to the variations of the moisture in the fuel, a thermostat is inserted in the fan's discharge channel and connected with an Arca type regulator. This regulates a damper, placed in a circulating duct between the gas collecting space in the tower and the fan inlet. When the temperature rises above the one for which the thermostat is adjusted, the Arca regulator opens this damper, the hot gases are diluted with part of those which have already been used for drying, until the temperature is stabilised. This gas is used for dilution, in order to avoid the necessity of heating fresh air for the purpose, and also, in order that the percentage of carbon dioxide in the drying gases may remain as high as possible.

THE DRYING.

This is done simultaneously through the whole pile, as the hot gases from the inner tower are continuously pressed through the layer of chips in a nearly radial direction, and on their way out to the circumference come in contact with almost every piece. The fuel adjacent to the inner tower soon becomes absolutely dry and the thickness of the dry layer increases as the fuel sinks downward, owing to the discharge and the feeding in of new fuel. The position of the various chips to each other being nearly always constant in the horizontal plane, there invariably exists a moist and cooler layer next to the outer tower, cooling down and saturating the gas, even over-saturating it, so that the outmost layer, especially higher up, is sprinkled with condensed water, which owing to the speed of the gases, follows them in the form of water.

TEST.

For the purpose of ascertaining the efficiency of the drying tower here described, tests were made on June 16th and 17th last year by representatives from the two Swedish Boiler Associations and The Association for Power and Fuel Economy in Finland.

As a result of a defect in the fan motor, the capacity of the drying plant could not, unfortunately, at the time of testing, be raised to the intended amount, since the drying plant was designed to dry, each day, 300 cu. m. (10,500 cu. ft.) of sawmill waste from a moisture of about 60 per cent. to one of about 30 per cent. and with a calculated dry substance of 150 kg. per cu. m. According to this calculation $\frac{300 \times 150}{24} = 1{,}875$ kilograms should be dried in one hour, but owing to the motor defect only 1,605 kilogram were dried from 58·1 to 43·6 per cent. Later on, when another motor was procured, the calculated drying capacity of the plant was nearly attained.

The fuel consisted of about 60 per cent. chips from slabs and edgings and about 40 per cent. sawdust. The chimney gases were taken out after passing through the economiser, at a temperature of 271°C. By circulating the gases, their temperature before being led into the fuel was reduced to 164°C. The waste gases from the tower had a temperature of 63°C. The air temperature was 9°C. By careful measurement of the gases, by analysing them and the fuel, and by weighing the fuel passing through the tower for drying purposes as well as other fuel burned simultaneously, the following resultant heat balances were obtained :—

Heat balance according to the official tests.
(See the graphical chart of heat distribution).

Supplied heat.

Total heat supplied to tower	1,084,900	(Calories
Heat returned through circulating duct ..	209,900	per hour).
Net total of heat supplied to tower ..	875,000	

Distribution of the supplied heat.

Heat in the gases escaping from tower to the atmosphere	164,000
Heat consumed inside the tower	711,000
Total	875,000

Distribution of heat consumed in the tower.

Radiation losses of the tower assumed to be about 5 per cent. of heat consumed in tower	35,000
Heat available for the drying of the fuel..	676,000
Total	711,000

Heat required for drying.

For evaporation of moisture from the fuel	619,900
Heat in discharged fuel 63°C.	123,400
Total	743,300

The difference between the heat required for drying	743,300
and the heat available for this drying, without calculating with condensation heat ..	676,000

makes 67,300 cals. per hr.

This, as previously assumed, must have been gained by condensation of steam in the tower, and is equal to 116 kilogram. condensate per hour, or 32 grammes per second.

It was also observed, at the test, that the condensate streamed from the tower in a quantity that probably reached 32 grammes, or 32 cubic centimetres per second.

EFFICIENCY OF DRYING TOWER.

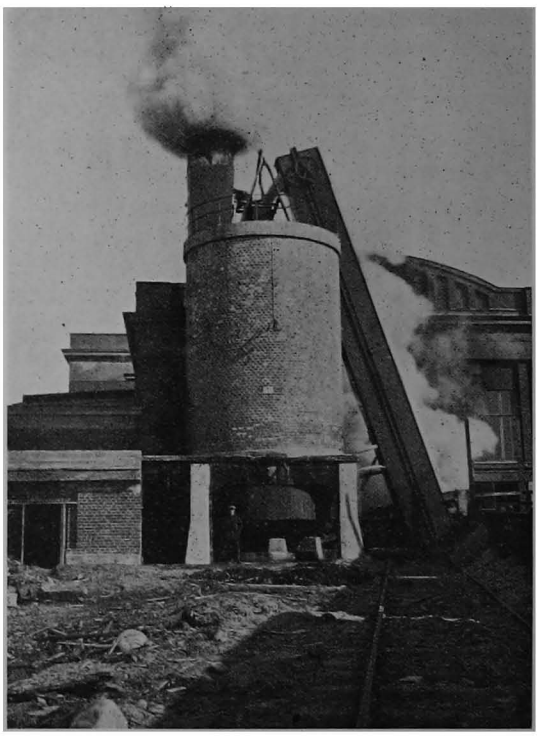
(Extract from the record of testing).

"If the efficiency of the drying tower is calculated as the ratio between the heat used for evaporation of moisture and the heat supplied to the tower above the temperature of the atmosphere, plus 9°C., exclusive of the heat in the condensate, the efficiency will then be $\frac{619,900}{875,000}$=70 per cent.

"However, it must be borne in mind, that, if the dried fuel, after being discharged from the tower, is immediately brought into the boiler furnaces, the heat contained in this fuel will be utilised. If none of this heat were lost, the efficiency would then rise to

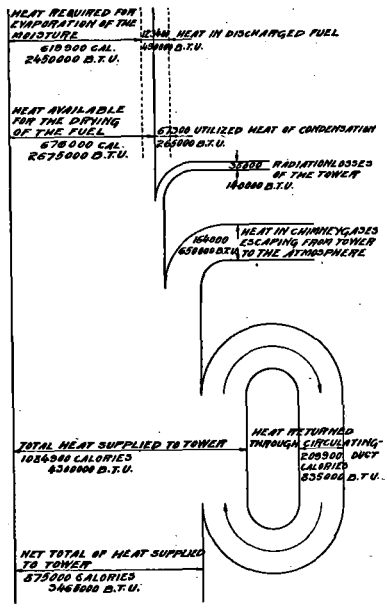
$$\frac{743,300}{875,000}=85 \text{ per cent.}$$

"The ability of the tower to conserve the supplied heat, in an effective way, is obvious. First, the fuel comes into close contact with the supplied gases, secondly the gases are cooled down to and below the point of saturation without those troubles which, through condensation of the moisture, invariably arise with an air pre-heater, and, finally, the radiation losses are negligible, the gases being supplied through the central inner tower and the surface temperature being low."



On the occasion recently, when a test was made on a similar drying plant at Västerviks Pappersbruk, in Sweden, the fuel coming into the tower contained about 65 per cent. moisture, about one-third of which was calculated to be ice; the temperature at time of testing being 10°C. below zero. The dried fuel contained about 30 per cent. moisture and had a temperature of 60°C., and the waste gases from the tower had a temperature of 59°C. In this case the chimney of the steam central station was closed by dampers, and all the waste

gases from the steam central went through the drying tower at that temperature; at the same time a great deal of condensed water ran off from the tower. No examination of the efficiency of this plant was made, but in view of the prevailing atmospheric conditions everything pointed to its efficiency being even greater than that of the above-mentioned plant in Finland. Apart from the great advantages of steadier operation in the boiler house and the need for smaller heating surface, etc., by drying and warming up the fuel, the gain, which is partly due to the increased effective heat value, and partly to increased efficiency of about 25 to 30 per cent., equivalent to an increased fuel value of between 33 and 40 per cent., is assured.



TEST ON A NORDSTRÖM DRYING TOWER AT ANTIEBOLAGET J.W. ENQVIST'S SULPHITEPULP MILL. DIAGRAM OF HEAT BALANCE. TAMMERFORS FINLAND

Since the results obtained on this plant in Finland have become generally known, great interest has been shown both in Sweden and Finland in this drying system, and it is probable that several similar plants will be constructed in the near future.

Besides the drying of fuel, I have also made successful experiments in the drying of chips for sulphate-pulp mills, using the waste

gases from the recovery plant. Not only is a material saving in fuel effected by this method of drying, due to reduced steam consumption in cooking the pulp and in evaporating the black liquor, but also a saving in chemicals, as the chemicals escaping in the ordinary way with the waste gases, are filtered off by the layer of chips, follow the chips into the cooking liquor, and are thus recovered. This method possesses another advantage in that the objectionable smell from these mills disappears completely, as the wood chips have the power of absorbing mechanically the odoriferous constituents, which are later oxidized and destroyed.

RÉSUMÉ.

La production mondiale des bois sciés est de 25 à 30.000.000 de standards par an, sans compter la Russie. Lors du sciage, on obtient des déchets—sous forme notamment de sciure de bois et de " bouts " coupés au moment du mesurage—dont le total est d'un cubage sensiblement égal à celui des produits finis. Ainsi, 25.000.000 de standards fournissent, sous forme de déchets, environ 118.000.000 de mètres cubes de matière solide. En admettant que ces déchets aient une humidité de 30 pour cent, on constate que cette quantité équivaut à une quantité de houille (de 7.000 calories par kilogramme) qui n'est pas inférieure à 30.000.000 de tonnes.

Or, étant donné que le combustible fourni par les déchets dont il s'agit ici présente généralement un pourcentage d'humidité variant de 50 á 60 pour cent., on s'est heurté, dans la pratique, à de grosses difficultés en voulant l'utiliser.

C'est afin de pouvoir faire un usage vraiment économique de ces déchets, par exemple dans un établissement de chaudières, que j'ai recherché, au cours de ces dernières années, une solution du problème qui consiste à sécher préalablement ce combustible. Le fait que j'ai réussi est amplement prouvé par le fait que deux usines " ad hoc " fonctionnent régulièrement depuis quelque temps, la première depuis fin mai dernier et qu'une troisième va être mise en marche ces jours-ci. La chaleur nécessaire est fournie par les gaz d'échappement, introduits directement dans l'amas de déchets qu'il s'agit de sécher. Le schéma ci-annexé montre les dispositifs installés dans la première de ces usines. Le combustible est introduit, au moyen d'un élévateur, dans la partie supérieure de l'appareil (ou, si vous voulez, de la tour) de séchage. On veille à ce que l'espace réservé aux déchets qu'il s'agit de sécher soit constamment alimenté en abondance. L'évacuation du produit fini s'obtient au moyen d'un disque rotatif, en partie conique, qui forme le fond de l'appareil. Quant aux gas, ils sont evacués de la cheminée, surmontant l'économiseur, au moyen d'un ventilateur qui les chasse dans un tuyau placé à l'intérieur de la tour de séchage de là en traversant l'amas de débris qu'il s'agit de sécher, ils sont forcés à travers les perforations de la paroi extérieure et jusque dans la chambre où ils sont recueillis avant de s'échapper par la cheminée de la tour de séchage. Ces gaz, en s'échappant ainsi, enlèvent une partie très notable de l'humidité contenue dans les débris. En installant une canalisation de récupération

réglée au moyen d'un thermostat—et communiquant avec la chambre où ils sont recueillis, on peut donner aux gaz de séchage une température constante et réglable à volonté. En conséquence, on peut utiliser les gaz dont on dispose quel qu'en soit le degré de chaleur. L'effet extraordinaire—85 pour cent—qu'on obtient au moyen de cet appareil est illustré par la graphique ci-annexé.

Etant donné que les gaz sont refroidis au dessous du point de saturation, une partie de la chaleur fournie par l'humidité contenue dans ces gaz et libérée par la condensation peut être utilisée pour le séchage. Quant à l'eau formée au moment de la condensation, elle est en partie évacuée par les gaz auxquels elle se mêle sous forme de gouttelettes. Une autre partie de cette eau, précipitée quand les gaz frappent les parois de la tour, s'écoule par les canalisations ménagées au fond de la tour.

PREPARATION OF FUELS

DISCUSSION

Chairman: MR. OSKAR TAUSSIG (AUSTRIA)

Friday, July 4th. *Morning Session*

THE CHAIRMAN, said that at a previous meeting they had been speaking of coal and fuel preparation, on the assumption that they had the coal in the power station. But, as Sir Richard Redmayne had been explaining, the preparation of fuel began at the bottom of the mine, and it was a long way from the bottom of the mine to the power station. In Austria, they had given very much care to this subject of saving fuel, and had found it was necessary to keep a sharp look-out on the coal and other fuels all the way from the mine to the power station; because in winning, in handling, and in storing coal, there were many heavy losses. Therefore, he expressed the hope that at the next World Power Conference the means to decrease such losses would be discussed.

With reference to the discussions of the day before, there were still two questions which had not been answered. (1) What was the cost of pulverising fuel? (2) Could pulverised fuel be stored? Mr. Douglass would answer these questions before proceeding with the papers for consideration at that session.

MR. A. E. DOUGLASS (*U.S.A.*), said that the cost of preparing coal varied considerably on account of the following:—

1. Hardness, as well as ash content of coal.
2. Percentage of moisture in coal as received.
3. Cost of labour and cost of power.

While the use of pulverised fuel for generating steam was comparatively new, pulverised coal had been used extensively in the United States for the past twenty odd years. At the present time, the United States alone was using approximately 25 million tons of pulverised coal per year.

As the preparation of the coal in up-to-date plants was the same regardless of its ultimate use, whether in cement kilns, metallurgical furnaces or boilers, his Company which had furnished equipment for pulverising approximately 75 per cent. of the coal used in the United States, had had an excellent chance of obtaining correct costs.

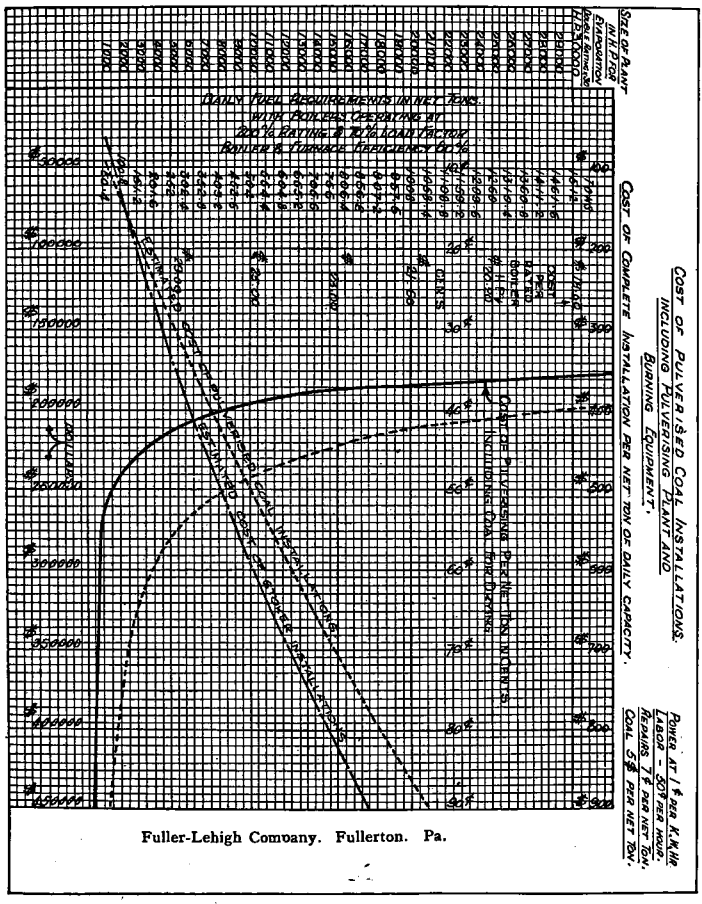
They had recently averaged the costs of a number of their recent plants, the average being as follows:—

	Soft or bituminous coals.	Anthracite or high ash coals.
Capacity 100 tons per day	45¢	63¢
,, 150 ,, ,, ...	41¢	55¢
,, 200 ,, ,, ...	40¢	53¢
,, 400 ,, ,, ...	36¢	48¢
,, 500 ,, ,, ...	34¢	45¢
,, 1,000 ,, ,, ...	31·5¢	43¢
kWh. per ton including all handling from cars to furnaces	15 to 17 kWh.	19 to 27 kWh.

These costs did not include fixed charges such as interest and depreciation on the equipment, but did include labour, repairs, operating materials, power and supervision.

The principal difference between the anthracite and bituminous costs was due to increased repairs to the pulverising equipment, and the higher power required for pulverising and drying; labour and general operating costs were the same in each case.

He referred them to a chart showing preparation costs, installation costs, as well as a comparison between the first cost of pulverised coal equipped plants and stoker equipped plants (see below).



The figures were based on present day cost of materials and average labour rates in the United States, and all costs were taken from the average of a number of plants, in which were included both hard and soft coals. The difference between the first costs of stoker and pulverised coal plants was based on a 70 per cent. load factor. Any variation from this would change the relation; the lower the load factor, the more favourable to pulverised coal, as only sufficient preparation plant would be required for the average

load, while with stokers, sufficient stoking equipment must be installed to carry the highest load called upon.

The diagram showing first cost of installation had been based on equipment necessary for unloading and handling the fuel and the ashes in both the stoker and pulverised coal plants. Boiler settings, boilers, steam and water equipment had not been included in either case.

The storing of pulverised coal was being done without any difficulty in hundreds of plants in the United States, and no trouble would be experienced from storing coal in pulverised form, if the following provisions were made :—

If properly dried and dried at a proper temperature.

If stored in properly designed bins, where the entire mass of coal would pass through the bin uniformly. Slopes of hoppers should not be under 70°. Most of the difficulty in this respect had been from using flat hoppered bins, where much of the coal had laid dormant for weeks or months, finally firing from spontaneous combustion. It was not uncommon for steel plants, cement plants and boiler plants to disregard the amount of coal in the bin, even when furnaces were shut down for repairs taking several weeks to make.

MR. F. G. TRYON (*U.S.A.*), enquired whether Mr. Douglass felt that powdered coal might be used for heating residences if it were properly prepared, and if a storage tank could be designed to contain the stored coal ? Would there be any material danger of fire or explosion ?

MR. DOUGLASS, replied that that had been done in several places in the United States. He referred to a plant in Seattle, where there were a number of hotels, public buildings and schools to which the coal was distributed in motor trucks, similar to those which were used to distribute oil. It was quite practical and feasible, and there was no danger ; but they had found that unless a coal company used waste fuels and was well located, the cost of delivery of the pulverised coal and the preparation was prohibitive.

Another plant in Chicago had carried the fuel round in steel barrels, fitted with special tops. A barrel, when empty, was removed from the feeder and another loaded barrel placed on top of the feeder ; so that nothing more was required than a portable barrel and a feeder.

A DELEGATE, asked whether, so far as American practice was concerned, Mr. Douglass could give them any information as to whether pulverised fuel really paid in the smaller industrial boiler plants. If a boiler plant were properly looked after and frequently overhauled, an efficiency of 50 per cent. could easily be obtained, and with coal costing 18s. a ton, it was possible to get steam generated at a price of 21d. per 1,000 lbs., which included every charge there was, including fixed charges. Of that figure, a cost of about 8d. per ton represented the cost of maintenance of mechanical stokers. If, as the previous speaker had said, the cost of preparation of the pulverised fuel for small consumers amounted to about 45 cents per American ton, that would be very nearly 31d. per English ton. Where was the economical advantage to be gained by the application of pulverised fuel as a substitute for steam generation under present conditions with the figures he had just stated ? He believed that advocates of pulverised fuel were forced back upon the contention, that the use of pulverised fuel enabled cheaper fuels to be used ; but the difficullty arose there that, if there were a big demand for poor quality fuels arising out of the application of the new principle, then the price of those fuels would go up, and then, of course, the economical advantage of pulverising would disappear altogether.

MR. DOUGLASS, replied that on many plants running from 20 to 30 tons of coal per day, they advocated the use of unit pulverisers, in which case the efficiency would be better than by hand firing or stokers, and labour would be greatly reduced as compared to hand firing, and the repairs on a system of that kind would not be any greater than the repairs on stokers. Even on plants using less than 20 tons per day, pulverised coal could often show advantages. When they spoke of 45 cents for the cost of preparation, a great many engineers jumped to the conclusion that this amounted to 45 cents more than would be

required when using stokers, while, in fact, in many cases, the cost with stokers of handling a ton of coal, including the power for driving the stoker, power for crushing the coal, power for forced draught fans and repairs to the stoker, including the handling of the coal and removal of ash, exceeded the 45 cents. This was particularly true with repairs, for in the United States, repairs to the stokers would run to very nearly double the cost of repairs to the pulverising equipment; so that the cost of preparation did not increase their coal cost above firing with stokers to any great extent, if at all.

PROF. F. K. TH. VAN ITERSON (*Holland*), said that on the Continent, especially in Belgium and Holland, and in the North of France, the use of pulverised coal was very quickly spreading, and especially the use of the pulveriser for small plants. The general opinion was that the price of the small kind of fuel, coal dust, was cheap now and would always be cheaper than the coarser grades. He considered that an enormous quantity of fuel could be saved in England by the application of the coal pulveriser. In England, a great amount of small coal was left in the pit. It was not merely a question of fuel in the boilers; the most important aspect of the use of pulverised fuel was not in the boiler house but in the collieries. Another way of getting fine coal from waste was by the froth flotation process. In one of their mines in Holland they had obtained 200 tons of fine coal in that way, and it had been a source of great profit.

He disagreed with the statement that the cost of small coal would be very much increased it if were used in this way. There was too much fine coal left in the pits, which could be used, and would be used as soon as pulverisers were generally applied. To avoid misunderstanding, he added that he did not advocate the use of the small unit type of pulveriser, which in some cases rendered good service. For larger plants he preferred the central pulveriser and dryer.

MR. B. F. HAANEL (*Canada*), said that in the case of a power plant which was equipped with mechanical stokers using lump coal, the stand-by losses when the plant was not operating were considerable, whereas in the case of a powdered fuel plant those losses would be reduced to a minimum. Again, they had better control over combustion in a powdered fuel plant. Where they were burning powdered fuel, the combustion was complete or very nearly complete. Another point was that fuels which were very difficult to burn on mechanical stokers or hand fired grates, could be burned with great ease in powdered form with the system as now developed. Where power was used intermittently, and therefore with a power factor which would not be especially high, the powdered fuel system would be more economical, inasmuch as when the plant was not running, or when the load was dropping off, one, two or three boilers could be shut off and started up again in the shortest space of time with the smallest expenditure of fuel. The lignites of North Dakota were very similar, if not identical with those of Saskatchewan. It was very difficult to burn these coals in their raw state when employing ordinary methods, and, if they were to be used on a large scale or on a small scale for power purposes, he thought that they might be burned to the best advantage when pulverised.

He also suggested that powdered fuel could be applied successfully to the railroad system in Canada, but especially on that part of the railroad system which traversed Provinces in which there were only low grade or lignitic coals. Since the lignites, when mined and exposed to the air, disintegrated into a finely powdered condition, it seemed natural to think that the best condition in which to use them was in the powdered form, since it required little more power to reduce them to that form. He had been informed that lignites could be burned in the powdered form with a very high degree of moisture content, as compared with the permissible moisture content of bituminous coal. He was especially interested to know whether Mr. Douglass or somebody else could give some information, concerning the cost of pulverising coal and delivering it to delivery points for locomotives.

MR. DOUGLASS, said that the cost of preparing coal for locomotives was the same as for boilers or any other use, with the exception of the cost of transportation from the pulverising plant to the point of use. The cost of hauling the coal, which would be done in special cars, was the only additional cost that would be required as compared with central station use. He had been asked about coals having a high moisture content, particularly lignites, and stated that it was right to assume that lignites or coals could be satisfactorily prepared and burned with a high percentage of moisture.

PROF. P. F. PURCELL (*Great Britain*), after presenting his paper *The Winning and Utilisation of Peat*, remarked that in Ireland there was a very considerable opportunity for the increased use of peat fuel for domestic purposes. Distribution and transport charges were very serious. If it were possible to perfect a producer which would run on peat coke, then he thought they could look forward to extending the use of peat fuel in Ireland to a very considerable extent.

MR. K. B. ELLER (*Great Britain*), remarking on Prof. Purcell's estimate of the peat resources of the world, thought that the figure should be doubled. Hausding was a great authority on peat but, with regard to Russia, according to the last survey of the Russian peat experts, the figure for European Russia within the present borders was 290,000 square kilometres; and further, the Russian peat experts asserted that the quantity of peat available in Siberia was far larger than that in Russia.

With regard to the manufacture and use of peat fuel, Prof. Purcell had given air-drying as being practically the only method possible. In point of fact it was very expensive. Every ton of peat which had to be dried in that way had to be spread out on an area of about 120 square metres, which meant that for the production of 30,000 or 40,000 tons per annum, a tremendous area for drying was required. The whole of that area must be carefully drained, the peat must be turned and footed, piled, stacked, etc., which entailed a very large amount of labour.

The attempts to press peat had not been successful, no doubt for the reason that they had practically all been made in a wrong way, very largely by people who were ignorant of the properties of peat.

This matter was perhaps not very interesting to engineers, because it was partly a botanical question. From well humified peat formed from certain plants, practically no water at all could be pressed, whereas from peat formed from other plants the water could easily be pressed out to the extent of about 70 per cent. When pressing had been tried, as a rule it had been done by large filter presses, no doubt with the object of obtaining large production. He had seen filter presses used, three to four metres long, but he was certain that by pressing a peat layer of one decimetre it would be possible to press out far more water (proportionately) at less pressure in ten seconds than it would be in ten minutes from a layer of one metre.

For gas producers, peat containing 40 per cent. of water could be used. If the moisture were reduced by pressing to 70 per cent., a further reduction by evaporation to 40 per cent. would require about one-third of the gas produced.

At some peat bogs containing an average of 3 per cent. of nitrogen, it was possible to get from 20/- to 25/- worth of sulphate of ammonia from one ton of peat. And whereas one-third of the gas produced would be used for reducing the moisture, by-products could be recovered from all the peat.

MR. HAANEL, said that attempts had been made in Canada to manufacture peat by mechanical pressing, artificial drying, and even carbonising of the peat. The most interesting of the processes which had been devised to convert peat into a substance which looked like coal, with a higher heating power, was the process devised by Ekenberg, which had lately been very much improved by other engineers, especially in regard to the elimination of the stage of carbonisation, *i.e.*, wet carbonisation, by so changing the character of raw peat that it could be pressed down to 70 per cent. moisture content. But he was of the opinion that that process was not at the present time commercially successful, and that they had to revert to the old method of air

drying peat. The amount of money which they could expend on the manufacture of peat depended purely upon the cost of coal. If engineers who were interested in this question would get together and discuss the various processes, it would be of great help to the world.

PROF. VAN ITERSON, said that in Holland they considered peat not as an inferior fuel, but as a superior fuel for boiler houses. The percentage of ash was only 1 to 1½ per cent. The development of peat was of great importance owing to its connection with the problem of water transportation. In order to produce peat, it was necessary to drain the bogs, and it had been shown that it was necessary to make canals so large and so good that in the future they must inevitably constitute a means of conveyance. It was generally found in Holland that the winning of peat was never profitable, unless it was the means of converting land unfit for cultivation into arable land of first quality.

PROF. PURCELL, said that he was well aware of the importance of getting down the water content from 90 per cent. to 80 per cent., or 75 per cent., but even if it were possible readily to press water out of the peat down to 70 per cent., he still doubted very much whether the production of peat from that stage could be made economical. Certainly he thought experience had proved that it was not possible to use peat containing 70 per cent. of moisture in a producer.

MR. A. H. LYMN (*Great Britain*), here remarked that 50 per cent. was a fair limit.

PROF. PURCELL, said that his reply must be that it was not economical if it were necessary to go from the 70 per cent. moisture attained by pressure to 50 per cent. by artificial drying before using it in a producer. With regard to the point raised by Prof. van Iterson with reference to Holland, the Irish Peat Inquiry Committee which had reported upon the winning of Irish peat had stressed very strongly the importance, from an economic point of view, of reclaiming the bogs and using them for agriculture in connection with their development for fuel purposes. He himself strongly favoured that view.

MR. LYMN, said that one point to which he had omitted to draw attention on the previous day was that in the hydraulic gas producer process, as applied to Power Production whether through steam boilers or through internal combustion turbines, the internal combustion engine being on another plane, it would be found in his paper that the cost per kilowatt was practically the same for both cases, while the fuel consumption for the steam power was 20 per cent., or more, higher than that through the gas turbine. The reason for this was that the by-products practically paid for the coal.

THE CHAIRMAN then closed the session.

STEAM GENERATION—
UTILISATION OF FUELS

CHAIRMAN: MR. W. H. PATCHELL (Great Britain)
President, The Institution of Mechanical Engineers

THE RECIPROCAL UTILISATION OF WASTE ENERGY

OBERBAURAT ING. BERNHARD MORITZ GERBEL
Vice-President of the Chamber of Civil Engineers in Vienna

As long as the present laws of nature obtain in the world we live in, we cannot transform a certain quantity of heat into the equivalent quantity of work without reducing another quantity of heat from a higher temperature to a lower one. This fundamental law is irrevocable, and in consequence, the transformation of heat into work is always combined with the depreciation of another much greater quantity of heat, called waste heat. Thus the consumption of steam, even in an ideal engine without any losses whatever, amounts to more than the quantity of steam equivalent to the actual output of the engine, and the greater part of the heat of the steam supplied reappears as waste heat.

To avoid the complete loss of these immense quantities of energy the engineer is compelled to make use of this waste heat to the greatest advantage, and technical science has been compelled to combine the utilisation of hot and high pressure steam for producing work with the utilisation of steam of low pressure and temperature in various manufacturing branches, by utilising the waste heat of steam engines for boiling, heating and drying purposes.

The consumption of steam, the quantities of heat transformed into work and those reduced to a lower temperature as well as the amounts of the utilised energy and waste energy with regard to various kinds of steam engines, are shown in Table 1. The figures given are approximate averages; their exactness is completely sufficient to explain the different kinds of utilisation of waste heat by numerical examples.

In column 8 and 9 it is stated in what form waste heat leaves the engine in the different cases. In condensing steam engines the condensed water at 39° and 70° carries the waste heat, in the counter pressure engines 650 and 670 calories leave the engine in the form of steam of 120° and 150°C. We see from this table that the larger the consumption of steam, and the smaller

TABLE 1.

UTILISED ENERGY AND WASTE ENERGY IN THE WORKING OF STEAM ENGINES

Pressure of admission 12 atm. abs., Temperature 280° C., heat content 720 calories per kg.

Type of engine	Conditions of working (Vacuum or counter-pressure)	Consumption of steam per H.P.-hour quoted in kg.	Utilised energy			Waste energy		
			per 1 kg. steam quoted in		per cent. of heat content of steam	per 1 kg. steam quoted in calories	Medium carrying the waste heat	Temperature of Medium carrying the waste heat, in °C
			H.P. hours	Calories				
1	2	3	4	5	6	7	8	9
Condensing steam engine	High vacuum (0·05 atm)	4·0	0·25	158	22	562	water	39
Ditto	Low vacuum (0·3 atm)	5·3	0·182	120	17	600	,,	70
Non condensing engine	Counter pressure of 1 atm. abs.	7·0	0·143	90	12	630	wet steam	100
Counter pressure engine	Ditto of 2 atm. abs.	8·3	0·125	70	10	650	dry steam	120
Ditto.	Ditto of 4 atm. abs.	12·0	0·084	50	7	670	superheated steam	150

the useful effect, the larger the quantity of waste heat and the higher its value, because of its higher temperature.[1]

The conditions of steam turbines are similar; there are only small differences that make the waste steam of turbines in special cases even more valuable (waste steam free of oil, etc).

The most favourable conditions for the utilisation of waste steam are, of course, found only in the special cases where the different sections of a plant require just as much waste steam as is supplied in this plant by the steam engine. If the quantity of waste steam required is greater than the quantity supplied, we must add live steam; if the quantity required for boiling and heating purposes is smaller, we must choose steam engines working with extraction of steam from the receiver or bleeder turbines. The different contrivances invented for regulating purposes and considering the different working conditions, are generally known, and also the results obtained by utilising waste steam. For instance the sugar industry has, within 30 years of its development, reduced its requirement of fuel from more than 20 kg. coal per 100 kg./best to less than 7 kg. for the same quantity. However, all these results are but a small part of the results still obtainable in this respect, for the majority of industrial plants do not yet utilise their waste energy, but burn fuel exclusively for the generation of power, losing thereby 80—85 per cent. of the heat contained in the coal.

The reason why the utilisation of waste heat in steam plants has, up till now, not assumed larger dimensions, is that the leaders of large industries, the managers and the other competent persons, are interested only in the progress of heat-technics as far as their own plant is concerned. In cases where, in their own plant, steam is required not only for the generation of power, but also for boiling, heating or drying purposes, a combination as before mentioned must be considered and introduced, as the saving of coal effected by these combinations is a sufficient motive. But plants requiring power alone, generally only produce this power out of coal, and the great losses of heat are accepted as unavoidable, *i.e.*, immense quantities of hot water are allowed to run unused into the drains. The utilisation of this waste heat *beyond* their own plant is generally

[1] The engines quoted in the table have an admission pressure of 12 atm. The modern efforts to raise the admission pressure up to 30, even up to 60 atm. are bound to diminish the quantity of waste heat, but will, on the other hand, furnish exhaust steam of 6 atm. pressure and more; the waste heat in such cases will, therefore, be of higher temperature, *i.e.*, considerably higher value.

not thought of, whereas the possibility of developing the utilisation of waste heat is founded especially on its employment *outside* their own plant, a combination which would be extremely economical for the various plants and of greatest importance for political economy.

The future development of the utilisation of waste heat does, therefore, not only depend on the combination of the generation of power with the employment of waste heat for boiling and other purposes within the reach of one and the same plant, but on the co-operation of different plants for the purpose of the utmost joint utilisation of their fuel.

The above deals with waste energy in the form of waste heat; there can be found also waste energy in the form of waste power in steam plants, as will be shown in the following paragraph.

Steam of higher pressure can be generated with nearly the same quantity of fuel as steam of lower pressure, as there are 647 calories in 1 kg. steam of 2 kg. atmospheric pressure, while for example steam of 14 atmospheres and 300°C. contains not more than 729 calories. The amount of calories contained in the second case is, therefore, only 13 per cent. larger, and the quantity of fuel required in both cases is approximately in the same proportion. In large plants requiring great quantities of low pressure steam for manufacturing purposes we can, therefore, instead of low pressure steam, generate without great cost high pressure steam and utilise the higher pressure of this steam in counter-pressure engines for the generation of power, where the steam leaving these engines will still have the pressure required for the said purposes. In this case we obtain a certain quantity of very cheap power which we are entitled to call "waste power."

We may therefore say that in plants chiefly requiring power, and generating it in steam engines, there is always cheap heat in the form of waste steam; its amount is, according to the type and steam consumption of the engine 6-16 kg.[1] per H.P.-hour, in certain cases still more; on the other hand, in plants requiring chiefly great quantities of steam of low pressure we can obtain, at practically no cost, $\frac{1}{16}$—$\frac{1}{6}$ H.P.-hour of waste power per 1 kg. steam.

Plants requiring about 6—16 times as much steam as H.P.-hours for manufacturing purposes can, therefore, themselves consume the whole or most of their waste energy. In this respect such plants

[1] The steam consumptions (col. 3, table 1) of 7-12 kg. steam corresponds with amounts of exhaust steam from 60 to 11·5 kg.; in special cases, for instance in counter-pressure-turbines, the quantity of exhaust steam rises to 16 kg. per H.P. hour.

offer the highest efficiency. But these cases are rare; in most industrial branches we find a different proportion between the steam and the H.P.-hours required and therefore most of the plants could feed other plants with either waste heat or waste power in great quantities. The price of these waste energies could, of course, be very low and the sale of this energy could be all the more profitable, the more the proportion mentioned differs from the figures given above, *i.e.*, 6—16. If the proportion is below the figures mentioned, the plants can supply heat (waste steam), in the other case power can be supplied.

Therefore, this proportion which states the amount of steam required per H.P.-hour in a certain plant, states at the same time whether this industry may itself consume its waste energy in both forms or dispose of waste heat or waste power in greater or smaller quantities.

Table 2 is an attempt to classify different industries according to the points of view given above. The different branches are divided into three main groups, the first of which contains industries consuming power without, or almost without, requiring heat for manufacturing purposes. The power required per unit of production—shown in column 3—is quoted in column 4, the steam required for manufacturing purposes is stated in col. 5, both referring to the unit of the finished product.

The industries of the first group require almost no steam for manufacturing purposes, their characteristic figure is 0 or nearly 0, that means that, if they are driven by steam power, they dispose of waste energy in form of waste steam. The quantity of this heat is given in column 7 and amounts to 2,400 to 11,000 calories per H.P.-hour, according to the temperature, and the pressure of the exhaust steam.[1]

In the second and third group there are branches requiring power *and* steam for manufacturing purposes, the same columns as for the first group. The figures quoted are to be understood as highest and lowest limits, for the characteristic figures; moreover, an average is quoted, according to which the classification has been made. The characteristic figures of the second group lie between 6 and 16; there remain, therefore, neither waste heat nor waste power.

The third group shows characteristic figures above 16, that means that these industries require a comparatively large quantity of

[1] See footnote page 1095.

TABLE 2. ENERGY REQUIRED AND WASTE ENERGY OF DIFFERENT BRANCHES OF INDUSTRY

No.	Branch of Industry. (Type of Plant.)	Unit of production referred to.	Energy required.		Characteristic figure. (proportion of col. 5 to col. 4.)	Waste energy.
			Power required quoted in H.P. hours.	Steam required for manufact. purposes.		
1	2	3	4	5	6	7
	Group 1 : Industries disposing of waste heat.					
	Electro-chemical industries.					
1	Aluminium	1 kg.	35	—	0	Where these industries are driven by steam power, the results are according to the type of engine employed per H.P. hour : 2,400 cal. in form of 4 kg. vacuum steam or 50 kg. condensed water of 70° C. ; 3,800 cal. in form of 6 kg. steam of 1 atm. ; 5,000 cal. in form of 7·5 kg. steam of 2 atm. ; 7,800 cal. in form of 11·5 kg. steam of ·4 atm., etc.
2	Air-nitre (saltpetre)	1 kg.	11	nearly 0	nearly 0	
3	Hydrogen	1 cu. m.	1	,, 0	,, 0	
4	Lime-nitrogen	1 kg.	5	,, 0	,, 0	
5	Calcium carbide	1 kg.	5	,, 0	,, 0	
	other industries :					
6	Oxygen (air-distill.)	1 cu. m.	4	,, 0	,, 0	
7	Wood pulp (mechanical)	1 kg.	2	,, 0	,, 0	
8	Spinning mills	1 kg.	2	,, 0	,, 0	
9	Electricity	1 kWh.	1·5	,, 0	,, 0	
10	Rolled iron	1 kg.	0·16	,, 0	,, 0	
11	Cement	1 kg.	0·13	,, 0	,, 0	
12	Wheat mills	1 kg.	0·1	,, 0	,, 0	
13	Ice	1 kg.	0·05	,, 0	,, 0	
	Group 2 : Industries not disposing of very large quantities of waste energy.					
14	Beer	1 litre	0·1—0·2	0·5—0·9	3— 6— 9	The waste energy (exhaust steam) resulting from the generation of power is entirely or almost entirely consumed for own manufacturing purposes.
15	Potato starch	1 kg.	0·1—0·2	0·1—1	3— 6—10	
16	Paper	1 kg.	0·4—0·6	2·5—3	4— 6— 7	
17	Weaving mills	1 kg.	1 —1·5	8 —12	5— 8—12	
18	Cellulose	1 kg.	0·4—0·5	5·5—6·5	11—13—16	
19	Leather	1 kg.	1 —1·3	15 —22	12—16—22	
	Group 3 : Industries disposing of waste power.					
20	Artificial silk	1 kg.	6—8	110—150	14—20—25	Per 1 kg. steam required for manufacturing, 1/16—1/6 H.P. hour can be obtained ; there remains, therefore, a considerable quantity of free power to be disposed of.
21	Press yeast	1 kg.	0·6—1	16—22	16—25—40	
22	Matches	10,000 boxes	30—35	700—1,100	20—27—37	
23	Sugar	1 kg.	0·15—0·25	5—6	20—30—40	
24	Laundries	1 kg.	0·3—0·4	9—11	22—30—37	
25	Glue	1 kg.	0·7—0·9	25—35	28—40—50	
26	Potato syrup	1 kg.	0·05—0·07	2—2·8	30—45—56	
27	Dyer's works	1 kg.	0·05—0·1	3—5	30—65—100	
28	Distilleries	1 litre	0·1—0·2	6—15	30—70—150	
29	Soap	1 kg.	0·1—0·2	6—18	30—80—180	
30	Bathing plants	1 compl. bath	0·3—0·5	40—70	80—100—230	
31	Central heating station	1 cu.m. air/h	0	0·02—0·04	nearly infinity	

steam for manufacturing purposes per H.P. hour required. The average characteristic figures are between 20 and almost infinity. This group is the most interesting because of the possibility of deriving large quantities of cheap power from these industries, the utilisation of which has up till now been completely neglected. In these plants the quantity of steam required for manufacturing purposes is very large in comparison with the power required. Even if the power required is in such cases generated in counter-pressure engines and the whole waste steam is fully utilised, there is still a large quantity of steam necessary in these industries, which must be drawn directly from the steam boilers. The industries working in this manner are quite up to date in respect of their heat technical apparatus; they fully utilise their waste heat, and the useful effect, attained by employing the added live steam, can be made nearly 100 per cent. Nevertheless the added live steam is not utilised so well as would be the case it if were first to pass also through an engine in order to generate power and to be utilised afterwards, with a lower pressure, as waste steam. In this case the result would be a certain amount of very cheap disposable power.

The costs of installation to make this possible are reduced to the small increase on the costs of a larger engine, as the size of the boilers is not altered by this.

By means of such utilisation of the steam pressure it is, in this group, possible also to generate very cheap electric current in steam plants, and these sources of energy are far more productive than people generally think. Here there are still endless problems, of undreamed of importance, to be solved.

As regards the groups of industry in Table 2, we at once see the advantages offered by joining some branches of the first group to some of the third, in order to utilise mutually their waste energies. The first group only requires power which the third group leaves unused, and this waste power of the third group can be supplied far cheaper than the power generated in the plants of the first group. The possibilities of such local combinations are numerous, and they would be still more advantageous in cases where the industries have also other common interests besides the intention of joint utilisation of energy.

For instance the distilleries and the manufactories of press yeast, industries of the third group, are closely related to mills, an industry of the first group, and often these two kinds of industries are situated near one another. But in spite of such favourable juxta-position we generally find in both of these plants, a steam generator

as well as a power station; the distillery is provided with great boilers, whereas the mill is generating the power required out of coal, without utilising its waste heat. A common steam generator and power station would save both plants nearly 70—80 per cent. of the coal required for the mill.

Another combination is, for similar reasons, the joint working of spinning mills with weaving mills, dyer's works, print works, etc. Spinning mills require hardly any steam, but chiefly power (group 1.), while dyer's works require large quantities of steam (group 3.) Weaving mills (group 2.) do in many cases consume the whole of their own energy, but if they also dress their products they require a great deal of steam and therefore dispose of waste power. These industries are also often found situated close together, therefore the mutual utilisation of heat and power would save them a great deal of fuel.

If there are no other common interests, such as those mentioned above, between plants of the first and the third group, a combination will nevertheless be of great advantage if the costs of the coal required form an important item in the expenses of these plants. Such plants are, for instance, on the one hand, steam power electric stations, on the other hand, heating and bath plants. The waste heat of an electric station can easily be utilised for the heating of a large district of a town to which it is also supplying electric current. In some cases arrangements have already been made to conduct the warm water, heated by the vacuum waste steam of the electric station, through the heating pipes of the houses in the neighbourhood, and to sell the heat under similar conditions as the electric current. The inhabitants of such houses get their bills for heating like those for electric current. Of course the heating with this waste heat generated at such small cost, can be supplied far cheaper than by special heating plants.

To realise such ideas, the engineer must comply with two conditions limiting the local extension of such establishments. First, the possibility of accumulating heat without great losses must exist, for the requirements of heat for heating purposes are the largest in the morning, the requirements of current in the evening. Therefore the waste heat obtained in the evening has to be stored for the next morning. That can be done for instance in large warm water reservoirs, the contents of which are heated in the evening by waste steam. If the insulation of such reservoirs is well executed, the loss of heat is very small and the whole heat is available in the morning. The quantities of warm water required and the size of

the reservoirs assume in these cases large dimensions and form therefore a limit for the extension of such establishments.

The second condition is the existence of the possibility of conducting heat to distant places without considerable loss. The development of insulation has brought about already great progress in this respect and is sure to go on improving in consequence of the development of long distance heating plants. In this respect, the speed of the medium conducting the heat in the pipes is especially important. Special pumps, forcing the warm water at a considerable speed through the pipes make it possible to conduct the heat, still with profit, over distances of 3 km. and more.

This shows us a new line of development for electric stations. The dimensions of these stations have been, up till now, incessantly growing in consequence of the economic advantages of *centralisation*. According to the above, on the other hand, the economic importance of utilising the waste heat of these stations for long distance heating purposes requires a *division* of them into smaller plants, the size of which is limited by the districts to be provided with waste heat.

In the event of there being no buildings to heat in the neighbourhood of electric stations, the waste heat can still be utilised by improving cultivated soil by means of heat. Experiments already carried out have proved that the warming of cultivated soils had the most favourable results, and it would, for instance, easily be possible to erect in the neighbourhood of the central electric stations of great towns large hothouses heated with waste heat. In these hothouses the whole quantity of early vegetables required in this town could easily be grown, by means of which such a town would be, in this respect, completely independent of foreign import.

Considering the statistics of industrial production of different countries with regard to the proposals made above, we find, in most cases, quantities of waste power not to be neglected and often surpassing the quantities of the water power existing there.

Nevertheless there are also great difficulties in the combination of plants requiring power, with others disposing of waste power. The quantity of power required, in most cases, varies considerably at every moment, as does the disposable waste power, but in such cases not in the same direction. Therefore it will be advantageous to utilise the waste power of the plants in question for supplying current to a common electric network, which then feeds all plants requiring power, with electric current. The existing electric stations could considerably reduce their costs of generation by inducing all

industries disposing of waste power and situated within the reach of their network, to help to feed this network with current. If this is done, the differences between the power supplied and consumed by the various plants are of less importance, as they are compensated by the great number of customers. Especially if the industrial waste power is again supplied back to other industrial plants, even in the pause at noon, and during the night, there will be no disturbing difference, provided that the number of customers is sufficiently great. The electro-technical problem of making possible the feeding of various current suppliers in a common network without danger for the central station, can be solved in most special cases, so that, in this respect, no objection could be made. For instance the Vienna electric central station already collects waste energy of different industrial plants in its network and schemes of extending this procedure are in hand.

For the present this central station, however, collects waste power only from central power stations, and does not yet use the waste power of steam or heat consuming industries and plants, according to the above methods; this can, therefore, only be considered as a first step to be followed, let us hope, before long by further steps in this direction. At all events the utilisation of waste power of heat consuming plants does not present difficulties greater than the collection of electric energy in long distance networks which has already been accomplished.

But even if the way to this economical improvement by means of the above combinations may appear steep and irksome, the difficulties must not prevent the engineer from making the greatest efforts to surmount the obstacles and achieve a work of great importance.

Great successes in engineering have always been attained in cases where great difficulties were encountered.

RÉSUMÉ.

(Force perdue et chaleur perdue [par ex. vapeur d'échappement] dans des branches différentes de l'industrie.—Classification des industries selon l'espèce et la quantité des énergies perdues.—Coopération d'établissements industriels pour l'exploitation de leurs énergies perdues en vue de réduire par ce procédé la consommation de combustible.)

Sur tous les lieux où l'on produit du travail provenant d'une source de chaleur, il en résulte aussi de la chaleur perdue, car la conversion en force d'une certaine quantité de chaleur donne lieu, en même temps que s'abaisse la température, à une autre quantité de chaleur.

L'économie calorifique résultant de l'emploi de différentes machines à vapeur est représenté au tableau 1.

La chaleur perdue (col. 3) est déjà employée assez fréquemment à différents procédés de fabrication, par ex. à l'ébullition, au chauffage, au séchage, etc.

L'utilisation de la vapeur d'échappement devient le plus profitable si l'usine en question a besoin exactement d'autant de vapeur que n'en fournit sa machine. Au cas où la quantité de vapeur nécessaire à l'ébullition, etc., est plus grande que la quantité de vapeur d'échappement, il faut ajouter de la vapeur d'admission ; à l'inverse on fait usage de machines extrayant de la vapeur de la chandière ou l'on se sert de turbines à basse pression.

Mais on trouve aussi beaucoup d'usines à vapeur où il n'y a point d'occasion pour utiliser la vapeur d'échappement.

Dans la plupart de ces cas jusqu'ici on n'a pas même considéré la possibilité de l'utilisation de cette énergie en excédant *hors* de l'usine propre. Cependant le développement de l'utilisation de l'énergie superflue ne tient pas seulement à la combinaison de la production de force avec l'exploitation de la vapeur d'échappement dans les sections particulières *de la même usine*, mais plutôt à *la coopération de plusieurs établissements industriels* en vue de l'exploitation de leurs énergies superflues, l'utilisation commune plus rationnelle des combustibles.

Les énergies superflues ne se trouvent pas seulement sous forme de *chaleur perdue* (vapeur d'échappement), mais on trouve *aussi dans les usines à vapeur* de l'énergie superflue sous forme de *force perdue*, comme l'expliquera la considération suivante :

La production de vapeur à haute pression n'exige qu'un peu plus de charbon que la production de la même quantité de vapeur à basse pression. Par conséquent si l'on a besoin d'une grande quantité de vapeur à basse pression pour les procédés de fabrication, on peut, à peu de frais, produire cette vapeur nécessaire à haute pression et, jusqu' à la pression exigée, s'en servir pour la production de force au moyen de machines à contre-pression. Il en résulte, dans ce cas, de grandes quantités de force à peu près sans frais, nommées, à juste titre, " force perdue."

Il s'ensuit : la production de force au moyen de machines à vapeur fournit *de la chaleur perdue*—(d'après la note 1. du tableau 1.) à peu près 6 à 16 kg. de vapeur d'échappement par cheval heure ; d'un autre côté l'utilisation de vapeur à basse pression pourrait être combiné, à peu de frais, avec la production de $\frac{1}{16}$ à $\frac{1}{6}$ *cheval heure* a kg. de vapeur nécessaire.

Les usines ayant besoin de moins de 6 kg. de vapeur d'échappement pour la fabrication (toujours par cheval heure vapeur) disposent de chaleur superflue ; si la quantité nécessaire de vapeur d'échappement est à peu près 6 à 16 kg. par cheval heure vapeur, l'usine peut consommer totalement sa chaleur superflue ; enfin si la quantité ci-dessus dépasse 16 kg., on peut y produire de la force perdue à bon marché.

Au tableau 2.) l'auteur donne une classification de différentes industries établir suivant ces points de vue. Les industries du premier groupe n'ont guère besoin de force, leur force motrice par excellence est la force hydraulique ; actionnées par une machine à vapeur, elles disposent de grandes quantités de chaleur perdue. Celles du groupe 3 n'ont guère besoin que de vapeur, elles sont, donc qualifiées pour produire de grandes quantités de force à bon marché, par ex. du courant électrique.

Les sources de force sont beaucoup plus productives qu'on ne le croirait.

Ici des problèmes d'une portée dont on ne s'est pas encore douté restent à résoudre par la technique calorifique en commun avec l'électro-technique, car, si nous regardons, en considération des propositions ci-dessus les statistiques de production des différents pays nous y trouvons, dans la plupart des cas, des quantités d'énergie superflue qui surpassent de beaucoup les forces hydrauliques des pays en question.

Le groupement du tableau 2.) que nous discuterons donne, avant tout, l'idée d'une coopération d'industries des groupes 1 et 3 en vue de l'exploitation de leurs énergies perdues, surtout si ces industries sont, en outre, liées par d'autres relations.

Par exemple les distilleries et les manufactures de levure sèche, ayant toutes besoin de beaucoup de vapeur et fréquemment situées près de moulins à vapeur, pourraient obtenir de la vapeur d'échappement de ces moulins ou de leur côté, pourraient leur fournir de la force perdue résultant de la production de vapeur nécessaire chez elles pour la fabrication. De même les teintureries et les imprimeries de tissus d'une part, les filatures d'autre part ont toutes les qualités requises pour coopérer.

Sans relations de ce genre la coopération d'industries des groupes 1 et 3 sera pourtant profitable si le prix des combustibles a une importance pour la gestion de ces industries. C'est le cas, avant tout, pour les stations centrales électriques d'une part et les établissements de bains et de chauffage à distance d'autre part. Au moyen de la chaleur perdue de grandes stations centrales électriques à vapeur on pourrait chauffer des districts entiers de grandes villes, y compris leurs établissements de bains. Au cas où ces stations sont situées loin des habitations, on pourrait chauffer, au moyen de cette chaleur, de la terre cultivée (serres-chandes pour la culture des primeurs, etc.) L'état actuel de la technique des calorifuges rend déjà possible, non seulement l'accumulation de chaleur (dans des grandes réservoirs à eau chaude) mais aussi son transport profitable jusqu'aux distances de 3 km. et davantage.

Cette utilisation de la chaleur perdue des stations centrales électriques indique une voie nouvelle pour le développement de ces stations. Tandis qu'on s'efforcait jusqu'ici de les réunir, c.à.d. de les agrandir, pour economiser de cette manière, à présent, en vue de l'utilisation la plus économique de la chaleur perdue, on s'efforcera de les répartir, pour placer toujours une station pas trop grande dans le centre du territoire à pour voir de chaleur.

Les combinaisons proposées ci-dessus présentent, il est vrai, aussi des difficultés, par ex. l'énergie exigée de l'une des industries coopérantes n'aura pas toujours son maximum au moment où l'énergie superflue de l'autre est au niveau le plus élevé. Mais ces inégalités se compenseront, si l'on réunit tous les établissements en question ; dans ce cas ceux qui disposent de force superflue peuvent fournir du courant électrique au réseau d'une grande station centrale électrique, lequel réseau transporte ensuite ce courant à ceux, qui ont besoin d'énergie. Et cette compensation sera encore plus efficace, si les fournisseurs et les consommateurs sont des industries à temps de travail à peu près égal.

Il est certainement possible de vaincre toutes les difficultés qui se présenterons encore et avancer de cette manière une œuvre de la plus grande l'importance pour l'économie politique.

HEAT ECONOMY IN AUSTRIA

ING. Dr. J. TOMAÏDES

In Austria, the Society for Heat Economy (Gesellschaft für Warmewirtschaft G.W.) leads the way in the endeavour to utilise fuels and sources of energy to their greatest economy.

After a start in 1920, the Society entered into its real activity in January, 1923. It is maintained by the " Hauptverbad der Industrie Oesterreichs " and is at present formed by a Council whose executive office consists of the following working Committees:

1.—Solid fuels; 2.—Liquid fuels; 3.—Gaseous fuels; 4.—Power; 5.—Domestic use; 6.—Central heating; 7.—Industrial heating arrangements; 8.—Heating arrangements for transport; 9.—Heat conduction; 10.—Heat insulation; 11.—Steam engines; 12.—Internal combustion engines; 13.—Iron industry; 14.—Textile industry; 15.—Chemical industry; 16.—Glass and ceramic industry; 17.—Chalk and cement industry; 18.—Waste energy; 19.—Waste materials; 20.—Mercantile and economic questions; 21.—Publicity; 22.—Instruction and consultation; 23.—Standardization and measurements; 24.—Statistics and records.

These working committees have for their chief aim the exchange of experiences of experts on a comprehensive basis. The results of the conferences are to be published in the periodical of the " G.W.," which is also of great value for the publicity afforded to memoranda and reports. Propaganda, in fact, is one of the most important tasks of the " G.W."

The " G.W." is further responsible for professional consultation on industrial undertakings. For dealing in detail with research work and the preparation of projects, etc., special experts are nominated.

The Society carries out systematic improvement in the sphere of industrial heating, largely by establishing continuation courses for stokers. These improvements are, in some cases, already in operation, in other cases, under consideration.

Some of the questions discussed are given below.

The committee occupied with fuels gives a survey of the whole province of research. In this connection there have been established records of Austrian coal-fields of practical importance, the

preparation of standards for the examination and standardisation for liquid fuels and the collation of the definition of gases of importance to heat economy.

A start has also been made on the economical utilisation of gases in industry and on a rational method of storing solid fuels.

The committee for power occupies itself with questions of the general management of power in Austria. The question of replacing coal by water power is at present the subject of considerable discussion.

The committee for domestic heating has published two reports on " Economical Heating in the Household," and the " Utilisation of Gas in the Household." These papers are circulated to a large number of consumers by associations of producers of heating appliances and gas companies.

The committee for industrial firing has considered in a comprehensive manner the use of pulverised fuel. The first application of this in Austria will be put into operation in the buffer furnace of a rolling mill.

The committee for heat conduction is going to set up detailed recommendations for economy in the erection, testing and working of steam pipe-lines. In connection with this, preparations are being made for practical experiments regarding the losses of energy caused in the different elements of the pipe-line under different conditions of loading, losses upon which there are but few available data.

The committee for heat insulation has taken steps to embody in a report the results obtained by the German Institute of Heat Insulation (Forschungsheim für Warmeschutz) together with some points of economy of general interest in Austria.

The establishment of an Austrian institute for examination of means of heat insulation at the Technological Industrial Museum (Technologisches Gewerbemuseum) in Vienna has already been decided upon.

The sub-committees for internal combustion engines are making every endeavour to draw the attention of the consumers to questions of economy by drawing up records and reports on the working of such engines.

The committees of the different professional industries deal exclusively with questions of their particular industries. In this connection the following points are worthy of mention:

Heat economy in iron foundries with special regard to drying stoves, the duties of the heat engineer in iron works, the use of

hot water, gradual heating and storing of heat in textile industries, drying and evaporation in the different branches of the chemical industry, the production of gas and the working of the stoves in glass, ceramic, chalk and cement industries.

Some of these committees considered necessary the installation of practical heat laboratories for purposes of research and experiment.

The committee for waste energy, after having examined the question of storage and regeneration of exhaust steam, is occupied in clearing up the question of the utilisation of waste which has, for a long time, constituted a question of special interest to the industry. This question is gaining importance in the advancing development of water power in Austria, whereby considerable waste quantities of water are available for the industry.

The committee for waste materials has gone thoroughly into the question and has made certain recommendations to the federal railways.

It would take too long to describe in detail the activities of committees 20-24, which to a certain extent are occupied with the results of the investigations of the other committees.

Special attention must be called to the extensive work carried out upon heat measurement, which forms the basis of several reports for use in practice.

RÉSUMÉ.

La Société " Gesellschaft für Wärmewirtschaft " représente les efforts des constructeurs autrichiens pour l'exploitation économique des combustibles et de l'énergie en général. Le rapport montre l'organisation de la Société (G.W.). ainsi que la composition de ses comités de travail. Échange des expériences dans les Conférences. Éclaircissement et propagande. Consultation de l'industrie. Organisation de cours d'instruction pour les chauffeurs. Programme d'études et résultats des sections de travail.

LES EXCEDENTS D'ENERGIE DISPONIBLES DANS LES GRANDES USINES SIDERURGIQUES FRANCAISES.

ANDRÉ CORNU-THÉNARD,
Professeur de Métallurgie Générale à l'Ecole Nationale Supérieure des Mines de Paris.

Le développement inattendu qu'ont pris, au cours des 50 dernières années, toutes les branches de l'industrie, a accru, dans de telles proportions, les besoins mondiaux d'énergie, sous toutes ses formes, qu'on est arrivé à douter que les ressources reconnues du globe en combustibles suffisent à faire face à la demande, constamment croissante, jusqu'au jour où l'esprit inventif de l'homme aura réussi à mettre au point des modes encore ignorés de production de puissance et de force.

Cet ordre de préoccupations a été, ces temps derniers, dans les pays les plus riches comme dans les pays les plus pauvres en charbon, le point de départ de travaux très nombreux et très importants. Economie et utilisation maxima des combustibles : récupération, jusque sous ses formes les plus dégradées, de la plus grande partie de l'énergie qu'ils récèlent : mise en oeuvre de toutes les sources de puissance, dénommées houille blanche, houille bleue, houille verte et autres : tel a été, en totalité ou en partie, le programme commun d'activité de tous les industriels et de nombre d'organismes officiels ou privés créés spécialement à cet effet.

L'Industrie Métallurgique étant, en France, une des plus fortes consommatrices de charbon, il était naturel qu'elle mît à l'étude, une des premières, la question de l'économie des combustibles. C'était, d'ailleurs, pour elle, une nécessité vitale puisque, pour être en mesure d'affronter l'âpre concurrence du marché mondial auquel la conviait sa capacité normale de production, elle devait chercher à comprimer au maximum ses prix de revient.

Mais on peut aller plus loin : on sait, en effet, que l'élaboration de la fonte entraîne nécessairement la consommation de tonnages importants de coke et qu'elle donne simultanément naissance à des volumes considérables de gaz combustibles, susceptibles d'être utilisés soit comme agents de chauffage dans les fours, soit comme

carburants dans les moteurs. Depuis le brillant Rapport de M. Benjamin Talbot au Coal Conservation Committee (1918), on a fréquemment fait ressortir qu'une grande usine sidérurgique moderne n'a pas à mettre en oeuvre d'autre combustible que la houille nécessaire à la fabrication du coke réservé à l'alimentation de ses hauts-fourneaux : la discussion théorique du problème, jointe à l'observation des résultats pratiques obtenus dans certains établissements bien conduits, a même amené les techniciens à penser que la Grosse Métallurgie doit normalement, dans des conditions de marche satisfaisantes et sous réserve de certains aménagements, pouvoir mettre à la disposition de la collectivité des quantités importantes d'énergie, si elle n'utilise pas elle-même, immédiatement, cet excédent à des fabrications plus ou moins distinctes de son objet principal.

La France étant un des principaux pays producteurs de fonte, il est intéressant de chercher à donner une idée des disponibilités qu'elle peut attendre, dans l'avenir et tout au moins théoriquement, de sa Métallurgie. Il est évidemment très difficile, dans cet ordre de questions, de se livrer à des calculs précis, car le problème fait intervenir une foule de facteurs dont il est impossible de tenir compte et dont nous n'aurons même le loisir de ne citer qu'un petit nombre, dans la suite. Il parait toutefois opportun, à l'occasion du Congrès de Londres, de se demander, à titre de première approximation, quelle est la limite supérieure des quantités d'énergie que la collectivité française peut raisonnablement espérer recevoir de ses usines sidérurgiques, dans les prochaines décades. C'est l'examen de cette question que nous nous proposons d'aborder succintement dans les lignes qui vont suivre.

Nous chercherons d'abord à préciser les catégories d'établissements métallurgiques qui peuvent participer à ces livraisons. Nous essayerons ensuite d'en présenter les différentes sources, en chiffrant, sous forme d'énergie électrique, la valeur du débit qu'on peut attribuer à chacune d'entre elles et en ne retenant que celles dont l'exploitation ou l'aménagement ne se heurtent pas à des difficultés financières ou techniques importantes. La récapitulation des observations ainsi faites nous conduira aux conclusions de cette étude où nous voudrions faire apparaître l'ordre de grandeur des disponibilités théoriques des usines sidérurgiques françaises en énergie électrique, sans méconnaître, à priori, que cette limite ne sera jamais atteinte et sans avoir la prétention de prévoir dans quelle mesure on pourra jamais s'en rapprocher.

I.—Et, tout d'abord, quels sont les Etablissements Sidérurgiques

Français susceptibles de participer aux livraisons d'énergie en excédent ?

La formule simple, d'après laquelle " la tonne d'acier doit être normalement fabriquée sans mettre en oeuvre plus de 1,7 ou 1,8 tonne de houille, toute consommation supplémentaire de charbon étant considérée comme un gaspillage inutile," ne s'applique évidemment pas aux produits désignés, dans le langage courant sous le nom d' " aciers." Pour éviter toute erreur d'interprétation, il faut préciser, dès maintenant, que la formule dont il s'agit ne se rapporte qu'aux Etablissements formant un ensemble complexe, groupant toute la série des organes de transformation des matières premières qui concourrent à l'élaboration du produit fini et comprenant, par exemple, fours à coke, hauts-fourneaux, convertisseurs, fours Martin, laminoirs, etc.

Les usines comme celles du Centre de la France, dont l'activité est limitée, tout au moins en grande partie, à la fabrication des aciers dits " spéciaux "—comme à Sheffield—n'ont pas la possibilité de produire la tonne de métal à moins de 2,5 ou 3,0 tonnes de houille : pour certaines classes d'alliages, même, comme les métaux à blindages, les aciers fins pour outillage, les aciers rapides, etc. dont l'élaboration est particulièrement délicate, le tonnage de charbon indispensable atteint et dépasse 3 ou 4 tonnes. Il n'y a donc pas à faire intervenir l'éventualité d'excédents dans ce genre d'établissements, où la quantité de charbon mis en oeuvre est considérable par rapport à la production de métal et où toute récupération se traduit, non par une disponibilité d'énergie, mais par une réduction de la consommation de combustible.

Ces usines spécialisées, on ne peut, par ailleurs, sous prétexte d'économies, en envisager la disparition, puisque, d'après l'expérience de la dernière guerre, elles sont, sur le territoire, les seuls centres d'élaboration de l'acier sur lesquels on puisse compter. Des considérations supérieures, en l'occurrence des nécessités de la défense nationale, légitiment donc le maintien en feu de ces usines, malgré que, du fait de leur localisation géographique, elles travaillent dans des conditions défectueuses au point de vue de l'utilisation des combustibles. Mais, d'après ce qui précède, cette catégorie d'établissements sidérurgiques ne rentre évidemment pas dans l'ensemble de ceux qui peuvent participer aux livraisons d'énergie en excédent.

De façon générale, nous sommes donc amenés à écarter de nos calculs les usines productrices exclusivement d'aciers, dont la majorité est localisée dans la France centrale, et à ne faire intervenir

que les usines du Nord, de l'Est et du Littoral; c'est pour tenir compte de cette observation que nous rapporterons nos investigations non pas à la tonne d'acier mais à la tonne de fonte.

II.—Le cadre de ce Rapport ne comporte évidemment pas l'étude individuelle de toutes les usines sidérurgiques des 3 régions distinguées ci-dessus, en vue de déterminer les disponibilités éventuelles de chacune d'elles en énergie. Etant donné que nous avons comme objectif de déterminer une limite supérieure approchée de la disponibilité totale, nous chercherons, pour simplifier, à classer l'ensemble des établissements en un petit nombre de catégories générales, et ce sont ces catégories générales pour lesquelles nous nous bornerons à préciser les éléments du problème.

Il semble, à ce point de vue, qu'on puisse répartir les usines du Nord, de l'Est et du Littoral en 3 classes principales : d'une part,—c'est la première classe—celles qui sont en mesure de réaliser toute la suite des transformations successives des matières premières, à partir de la houille et du minerai, jusqu'á l'acier, et qui comportent, outre des fours à coke, des fours Martin ; d'autre part,—c'est la deuxième classe—celles qui réalisent une suite analogue de transformations, mais à partir du coke et du minerai, et qui ne comportent ni fours à coke, ni fours Martin : les établissements possédant des fours Martin, mais pas de fours à coke, pourront rentrer, d'après ce qui sera dit plus loin, dans cette 2ème classe. Enfin la 3ème classe groupe les hauts-fourneaux isolés, qui ne poussent pas la dénaturation de leurs produits jusqu'à l'acier et se bornent à élaborer la fonte et à la vendre, soit en gueuses, soit en moulages. Cette classification ne renferme évidemment pas tous les cas particuliers de la pratique : mais elle parait suffisante, dans les limites de la très large approximation à laquelle nous pouvons prétendre. Examinons donc successivement les 3 catégories d'usines ainsi déterminées.

Pour la première, nous supposons que le type en est réalisé par le groupement de fours à coke à récupération de sous-produits, hauts-fourneaux, convertisseurs, fours Martin, laminoirs et des usines annexes pour le traitement des huiles de goudron, la mouture des scories Thomas et la fabrication des ciments ou des briques avec les laitiers de hauts-fourneaux : nous admettons que l'usine a une capacité annuelle de production de 500.000 tonnes de fonte et qu'elle livre au commerce 300.000 tonnes d'acier Thomas, 150.000 tonnes d'acier Martin (dont l'élaboration utilise les chutes, riblons et scraps de l'ensemble) et une cinquantaine de mille tonnes de fonte brute. Nous admettons, en outre, que l'usine est munie d'un bon

outillage moderne courant, sans toutefois, ce qui est le cas le plus général, que l'application des conceptions les plus récentes relatives à l'utilisation optima des combustibles y ait été encore réalisée.

Que peut-on, théoriquement, attendre d'un pareil organisme comme disponibilités d'énergie ?

Renvoyant aux calculs effectués fréquemment par les techniciens, nous constatons que, pour élaborer 500.000 tonnes de fonte, l'ensemble sidérurgique dont il s'agit met en oeuvre.

$1{,}25 \times 500.000 = 625.000$ tonnes de coke, ce qui correspond au passage, dans les fours, de

$625.000 : 0{,}7 = 900.000$ tonnes environ de houille par an.

Les gaz de hauts-fourneaux suffisent à assurer le chauffage des Cowpers et celui des fours à coke, ainsi que l'alimentation des moteurs à gaz fournissent le courant électrique nécessaire à la marche de l'établissement.

Quant aux gaz de fours à coke, on trouve l'emploi des $\frac{4}{5}$ de la production au chauffage des fours à température élevée, fours Martin, fours de laminoirs, fours à recuire et autres. Reste donc $\frac{1}{5}$ de cette production à titre de disponibilité éventuelle. Elle correspond, en l'exprimant en unités électriques par tonne de fonte, à raison de 1 kilowatt-heure par 1,1 m^3 de gaz à 4.000 calories, et en supposant qu'on mette en oeuvre 1,8 tonne de houille par tonne de fonte pour recueillir 275 m^3 de gaz par tonne de charbon carbonisé, à

$$\frac{1}{5} \times \frac{275 \times 1{,}8}{1{,}1} = 90 \text{ kilowatts-heure par tonne de fonte.}$$

Pour tenir compte de certaines utilisations particulières éventuelles, comme, par exemple, l'alimentation en courant de petits fours électriques, il faut réduire quelque peu l'évaluation ci-dessus et nous croyons pouvoir raisonnablement fixer à 50 kilowatts-heure par tonne de fonte la disponibilité de l'organisme complexe considéré.

Envisageons, maintenant, le cas de l'usine de 2ème classe, ne possédant ni fours à coke, ni fours Martin, mais élaborant annuellement la même quantité de fonte, soit 500.000 tonnes, dont elle livre le dixième au Commerce à cet état, et dont elle transforme les 9 dixièmes en laminés Thomas : on constate que, dans les conditions d'utilisation ordinaires, les gaz de hauts-fourneaux suffisent, mais sans excédent, à assurer la force motrice nécessaire à son fonctionnement et le chauffage des appareils : toutefois, comme elle ne dispose pas de sous-produits de la carbonisation, en particulier de carburants liquides, il faut prévoir un certain tonnage supplémentaire de houille pour l'alimentation des locomotives. De ce fait, la quantité

de combustible, exprimée en charbon, à mettre en oeuvre par tonne de fonte élaborée est de 2 tonnes environ, au lieu de 1,8 tonne. En outre, l'établissement ne dispose pas de l'excédent de 50 kilowatts-heure par tonne de fonte que nous avons reconnu plus haut.

Les usines possédant des fours Martin, mais pas de fours à coke, se comportent comme celles de la 2ème classe : mais, en outre, il faut faire entrer en ligne de compte le charbon nécessaire à l'alimentation des gazogènes fournissant le gaz aux fours Martin. Pour les productions envisagées ci-dessus, on constate que la quantité de combustible, exprimée en charbon, à mettre en oeuvre par tonne de fonte élaborée, atteint 2,1 tonnes environ.

Passons à la troisième classe. L'utilisation des gaz était, autrefois et de façon générale, assez peu poussée dans les établissements français ne comportant que des hauts-fourneaux ; mais de grands progrès ont été réalisés dans ces derniers temps ou sont en cours d'exécution. Les usines de cette catégorie disposent, normalement, d'un certain excès de gaz qu'on peut évaluer, approximativement, à 25 ou 35 pour cent de la production totale : nous adopterons, dans la suite, un chiffre de 20 pour cent, un peu inférieur aux précédents (soit 180 kWh. par tonne de fonte), pour tenir compte des consommations supplémentaires des fonderies adjointes à certaines installations de ce groupe.

III.—Ces premières données étant rappelées, revenons à l'établissement métallurgique type et proposons-nous de chiffrer la valeur des récupérations qui peuvent être réalisées sous réserve de certaines améliorations dans la conduite des opérations courantes et de certains perfectionnements de l'outillage. Nous ne ferons allusion ici, naturellement, qu'aux solutions qui ont reçu, d'ores et déjà, des applications industrielles, et, délibérément, nous ne prendrons pas en considération les hypothèses, même le plus séduisantes, que la pratique n'a pas sanctionnées.

Les trois ordres de dispositions, auxquels il semble qu'on puisse légitimement faire appel pour rendre de nouvelles disponibilités d'énergie aux usines, paraissent être les suivantes :

a) récupération des chaleurs d'échappement des moteurs à gaz.

b) réduction de la consommation moyenne de gaz dans les Cowpers

c) récupération des chaleurs perdues des fours Martin et des fours de réchauffage.

La récupération de la chaleur contenue dans le coke au moment du défournement est bien une opération sur laquelle est attirée, depuis longtemps, l'attention des techniciens, en raison des quantités considérables de calories qu'elle rendrait à l'économie générale de

l'usine et de l'amélioration notable que son application assurerait à la qualité du coke produit. Elle a bien été effectivement mise en oeuvre, ces temps derniers, dans une usine à gaz suisse : mais il semble que l'encombrement et le coût des dispositifs, tels qu'ils sont actuellement réalisés, sont encore prohibitifs. D'après cela, et bien que le procédé d'extinction à sec paraisse devoir être vraisemblablement mis au point, de façon pratique, d'ici peu, nous ne croyons pas être en droit d'en faire état dans ce rapport.

Nous ne ferons pas davantage état de la possibilité de recueillir les calories contenues dans les laitiers. C'est un problème qui fait, depuis longtemps, l'objet de nombreux travaux ; mais, à notre connaissance, aucun procédé pratique n'a encore été proposé et rien ne permet de pressentir que la mise au point en soit réalisée dans un délai relativement court. Bornons-nous donc à faire porter notre examen sur les 3 sources éventuelles d'énergie signalées plus haut : on verra, d'ailleurs, qu'elles sont susceptibles, à elles seules, d'un rendement important.

La récupération des chaleurs d'échappement des moteurs à gaz est, dès maintenant, normalement effectuée dans un certain nombre de Centrales d'usines sidérurgiques : d'autre part, plusieurs installations sont actuellement en montage, tant en France qu'à l'étranger. L'expérience n'est donc plus à faire : elle a prouvé que l'on recueille aisément, aux bornes du turbo-alternateur, alimenté par les chaudières de récupération, 15 à 16 pour cent de la puissance des générateurs : en outre, le turbo-alternateur, monté en tampon sur la Centrale, absorbe les à-coups qui se manifestent dans la demande et son intervention automatique, à point nommé, permet de faire tourner normalement les moteurs sous une charge plus élevée et plus régulière, condition essentielle au bon rendement de ces machines. L'avantage de cette disposition est donc considérable. Occupons-nous seulement de la question de récupération et cherchons à chiffrer le bénéfice de l'opération. Les besoins de l'usine type en énergie électrique étant de 350 à 380 kilowatts-heure par tonne de fonte produite, l'opération dont il s'agit donne, d'après ce qui précède, de 52,5 à 57 kilowatts-heure : adoptons, en nombre rond, le chiffre de 50 kilowatts-heure par tonne de fonte. Au point de vue de la réalisation pratique, il faut ajouter que l'encombrement de la station de récupération est extrêmement réduit : un appentis de 7 à 8 mètres de largeur le long de la Centrale, suffit à recevoir les chaudières. Par ailleurs, le coût de l'installation complète est peu élevé ; de sorte que, sous réserve d'un débouché convenable pour le courant produit, l'amortissement de l'ensemble doit être rapide.

D'après cela, il parait vraisemblable d'admettre que la grande majorité des Centrales sidérurgiques se compléteront par une annexe de ce genre, dès que les conditions économiques et financières le permettront.

En ce qui concerne le chauffage des Cowpers, on compte très généralement qu'il faut y réserver 35 à 40 pour cent de la quantité totale des gaz produits par les hauts-fourneaux : c'est le chiffre de 35 pour cent que nous avons retenu, dans ce qui précède, pour l'établissement des besoins de l'usine, en supposant un rendement moyen des appareils. Mais si, d'une part, la combustion est réglée avec soin ; si, d'autre part, on introduit certains perfectionnements dans l'aménagement des empilages, si on accroit les dimensions des appareils et si on confère aux gaz une vitesse suffisante pour faciliter les échanges de chaleur entre fluides et briquetage—le procédé Pfoser-Strack-Stumm n'est que l'application de ces observations générales—on constate que la consommation des gaz diminue dans une proportion notable. Des expériences précises ont fait reconnaître que la proportion de gaz réservée aux Cowpers peut être ramenée de 35 pour cent, chiffre considéré comme satisfaisant par la majorité des usines, à 30 pour cent de la production totale des fourneaux, et même moins. En exprimant cette économie en énergie électrique, on arrive à une disponibilité éventuelle de 40 à 45 kilowatts-heure par tonne de fonte ; prenons le nombre le plus bas, soit 40 kilowatts-heure. Ici, encore, comme dans le cas précédent, l'aménagement des installations existantes est facile et la considération de l'encombrement supplémentaire n'intervient pour ainsi dire pas. Sous réserve de la question de trésorerie et des difficultés sérieuses qu'on éprouve, fatalement, à effectuer, en pleine marche, toute transformation quelque peu importante de l'outillage, il semble donc que les établissements sidérurgiques doivent être rationnellement portés à s'assurer, assez rapidement, le bénéfice du mode particulier d'exploitation dont il s'agit.

La récupération des calories emportées par les fumées des fours métallurgiques a fait l'objet d'études nombreuses, au cours de ces dernières années, tant en France qu'à l'étranger, spécialement en Amérique : les disponibilités auxquelles elle donnerait naissance, dans l'usine considérée comme type, peuvent être évaluées à

10 à 12 kilowatts-heure par tonne de fonte pour les fours Martin et 5 à 6——————d°——————les fours des laminoirs.

C'est relativement peu par rapport aux chiffres antérieurement rencontrés : en outre, la réalisation des installations nécessaires à cette catégorie de récupération peut rencontrer, dans la pratique, de

sérieuses difficultés techniques. Il faut, en effet, disposer, matériellement, de la place suffisante pour placer les chaudières sur l'évacuation des fumées : il faut, en outre, que les générateurs de vapeurs soient assez voisins des appareils d'utilisation pour qu'il ne soit pas nécessaire d'avoir recours à de longues canalisations. Il n'est pas douteux qu'une installation mal appropriée, n'aurait qu'un rendement insuffisant et, de ce fait, ne payerait pas les dépenses engagées. En d'autres termes, seules les usines en construction ou en réfection totale seront en mesure dans la majorité des cas, de généraliser l'application du mode de récupération auquel il est fait allusion ci-dessus, et, en conséquence, il ne semble pas opportun d'en faire état dans le décompte final que nous nous proposons de donner comme conclusion à ce rapport.

IV.—Cherchons, maintenant, à rapprocher les divers résultats qui précèdent, en les rapportant à la capacité annuelle moyenne de production de fonte, dans les Etablissements Sidérurgiques Français du Nord, de l'Est et du Littoral. Cette capacité moyenne de production, qui est, pour les régions considérées, d'une dizaine de millions de tonnes, peut se répartir de la façon suivante :

		tonnes
1ère catégorie :	Hauts-fourneaux avec Aciéries Thomas et Martin, avec fours à coke	2.500.000
2ème catégorie:	Hauts-fourneaux avec Aciéries Thomas avec ou sans Aciéries Martin, sans fours à coke	4.800.000
3ème catégorie :	Hauts-fourneaux isolés	2.700.000
	Total ..	10.000.000

Nous allons examiner d'abord les disponibilités d'énergie qui ne dépendent pas de l'application des moyens de récupération décrits ci-dessus : puis celles qui sont fonction de la mise en oeuvre de ces procédés spéciaux.

En ce qui concerne le Ier cas, si l'on suppose que l'utilisation des gaz est faite au mieux, en particulier par la généralisation de l'emploi des moteurs à combustion interne, les usines de 1ère catégorie pourraient, d'apres ce qui précède, se mettre en mesure de recueillir un excédent d'énergie égal à 50 kWh. par tonne de fonte : celles de 3ème catégorie, un excédent de 180 kWh. soit :

1ère catégorie : 2,5 millions × 50 kWh. = 125 millions de kilowatts-heure ;

3ème catégorie : 2,7 millions × 180 kWh. = 486 millions——d°——

Au total, et en chiffres ronds, 600 millions de killowatts-heure.

La plupart des Etablissements, rentrant dans ces deux classes, sont localisés dans le Nord et dans l'Est de la France : ils sont ainsi à proximité des grandes lignes du Réseau National, qui est décrit dans un Rapport présenté au Congrès ; pour un certain nombre d'entre eux, le raccordement est déjà étudié et il est vraisemblable qu'une certaine portion des 600 millions de kWh. dont il vient d'être question, sera rendue, dans un délai pas trop éloigné, à la consommation générale.

Passons à la récapitulation des disponibilités d'énergie qui sont fonction de l'application des procédés modernes de récupération.

La mise au point de la combustion et de l'exploitation des Cowpers libérerait, avons-nous dit, 40 kWh. par tonne de fonte ; soit, sur l'ensemble,

40×10 millions $= 400$ millions de kilowatts-heure.

D'autre part, en supposant, ce qui est fort loin d'être réalisé et ce qui ne peut être envisagé que dans un avenir éloigné, que toutes les usines sidérurgiques affectent, à la production de l'énergie électrique par moteurs à combustion interne, tous les gaz qu'elles n'utilisent pas au chauffage, la récupération des chaleurs d'échappement produirait.

50×10 millions $= 500$ millions de kilowatts-heure.

En faisant intervenir les diverses sources de disponibilités éventuelles que nous avons retenues et sans tenir compte des délais différents probables d'entrée en exploitation de chacune d'elles, nous arrivons ainsi au chiffre global de 1,500 millions de kilowatts-heure. Si l'on rapproche cette évaluation du tonnage de houille (18 millions de tonnes) nécessaire à l'élaboration des 10 millions de tonnes de fonte considérés, on constate que les récupérations possibles correspondent à 8 pour cent environ du charbon mis en oeuvre.

Tel parait être, dans l'état actuel des choses, le " maximum maximorum " des quantités d'énergie que les Etablissements sidérurgiques français sont susceptibles, *théoriquement*, de rendre à la consommation générale. Mais—nous l'avons déjà dit et nous ne saurions trop le répéter—ce maximum ne sera sûrement jamais atteint. Nous nous sommes, en effet, systématiquement et constamment placés, dans les hypothèses les plus favorables. Nous avons supposé, par exemple, que l'énergie était produite uniquement par moteurs à gaz, à haut rendement, alors que nombre d'établissements sont pourvus de machines à vapeur, capables encore de fournir un long service : or, l'opportunité de la transformation de ces installations existantes, dans l'avenir, est subordonnée économiquement à la réalisation d'une série de conditions

variées, dont on ne peut préjuger l'occurence, telles que l'ascension, d'ailleurs peu souhaitable, des prix du charbon, la réduction des frais d'installation et d'entretien des grands moteurs à gaz, la prospérité de l'industrie métallurgique, etc. Nous avons imaginé, en outre, que la marche des ateliers était parfaitement regulière et continue, sans à-coups, que l'outillage était utilisé suivant les meilleures règles de la technique, que le travail était convenablement réparti entre les divers engins de fabrication suivant un programme rationnel, etc., toutes conditions qui ne sont que rarement vérifiées dans la pratique courante, et seulement dans les périodes normales au point de vue économique.

Par ailleurs, un grand nombre d'usines sidérurgiques—et cette orientation ne peut que s'accentuer dans le cours du temps—tendent à employer elles-mêmes leurs excédents d'énergie à des opérations qui ne sont pas en relation directe avec l'objet principal de leur activité, pour mettre en valeur la plus grande partie possible de leurs sous-produits et de leurs déchets de fabrications. D'autres préfèrent céder aux agglomérations urbaines voisines, comme gaz d'éclairage, une fraction plus ou moins importante du gaz de distillation de leurs cokeries. Ces emplois réduisent d'autant les possibilités de production et de livraison de courant électrique.

Enfin et surtout, l'exécution de la plupart des modifications ou aménagements dont il est question ci-dessus, conduit à des décaissements plus ou moins importants dont les Sociétés ne peuvent assumer la charge que si elles ont l'assurance de tirer un profit suffisant des dépenses consenties ; encore faut-il, en outre, qu'elles jouissent d'une situation financière aisée, ou qu'elles soient en mesure de faire appel à des capitaux nouveaux dans des conditions convenables.

V.—En résumé, l'examen rapide, auquel nous nous sommes livrés dans cette Note, nous a amenés à constater que, dans l'état actuel de la technique et dans les hypothèses les plus favorables, la limite supérieure des disponibilités éventuelles d'énergie des Etablissements Sidérurgiques ne peut être évaluée à plus de 7 à 8 pour cent du tonnage de houille mise en oeuvre pour la fabrication du coke, en ne considérant que le combustible consommé dans les hauts-fourneaux du Nord, de l'Est et du Littoral de la France. Nous avons signalé, en outre, que cette limite supérieure ne serait certainement jamais atteinte et qu'il ne fallait pas s'attendre à voir récupérer, dans l'avenir, plus d'une portion relativement faible, impossible à fixer d'avance, du maximum proposé.

Cette conclusion manque doublement de précision; il nous a cependant paru utile de la présenter telle quelle, parce qu'il est intéressant de se rendre compte de l'ordre de grandeur de ces excédents éventuels de puissance, auxquels la littérature fait fréquemment allusion et dont elle n'a pas, jusqu'ici, à notre connaissance, donné une idée d'ensemble pour notre pays.

Si ces excédents éventuels ne peuvent être calculés que très approximativement, l'incertitude est encore beaucoup plus grande en ce qui concerne les délais dans lesquels les disponibilités en courant électrique des Usines pourront être cédées à l'économie nationale. La mise en valeur des diverses sources d'énergie envisagées soulève, en effet, une foule de problèmes techniques dont on ne doit méconnaitre ni le nombre, ni l'importance, et dont l'énoncé ne rentre pas dans le cadre du présent Rapport. A côté des difficultés de toute nature qui surgissent constamment, dans la pratique courante des ateliers métallurgiques, et qui doivent être solutionnées à mesure qu'elles se présentent, la mise au point des procédés et des appareils nouveaux exige un effort supplémentaire considérable de la part des Ingénieurs, pour éviter, point essentiel, que la marche normale des fabrications ne souffre des innovations. Aussi les modifications aux formules éprouvées d'exploitation ne sont elles introduites dans les usines qu'après une expérience minutieuse et décisive ; en outre, il y a lieu de faire intervenir les contingences locales, qui changent profondément l'aspect d'une même question, d'un établissement à l'autre, et qui rendent telle solution, satisfaisante pour une Usine déterminée, franchement mauvaise pour telle autre. Il ne faut donc pas s'étonner si les diverses Sociétés, réparties sur le territoire Français, entrent, à des époques très différentes, dans la voie des améliorations que leur ouvrent les progrès de la Technique ; la précipitation, en ces matières, risquerait de conduire à de graves déboires, surtout dans une industrie de transformation aussi complexe que la Sidérurgie.

RÉSUMÉ.

In the above report an attempt has been made to determine the total amount of energy which might be recovered from blast furnaces and steel works in France and distributed to the extra high tension lines for light and power purposes.

The author points out that this question is of particular importance to France on account of its deficiency in coal, and that, in addition to the utmost economy possible, every kind of natural power should be utilised such as water power, tidal power, power of small rivers, etc. The metallurgical

industry being one of the largest consumers of coal in France, it is quite natural that such an industry should investigate the question of fuel saving; this, in addition, was of prime importance in order to reduce the cost of iron and steel.

All the calculations have been based on the pig iron production, and the metallurgical works have been divided into three different classes as follows:—

1. Works which are able to realise all the successive transformations of raw materials, starting with coal and ore up to the production of steel, and which operate also coke ovens and Siemens Martin furnaces.

2. Works which are able to carry out all the transformations, but starting from coke and ore, and which do not have any coke ovens or Siemens Martin furnaces; works having Siemens Martin furnaces but no coke ovens are also taken in this second class.

3. Isolated blast furnaces.

For works of the first class the author has taken as an example works having a yearly production of 500,000 tons of pig iron, 300,000 tons of basic steel, 150,000 tons of Siemens Martin steel, and about 50,000 tons of pig iron.

In such works, when equipped in a modern way, the blast furnace gas is sufficient to supply the Cowpers and the blast furnace gas engines supplying the electrical energy required for the running of the works. Four-fifths of the gas from the coke ovens is used for the heating of the Siemens Martin furnaces, reheating furnaces and others, and one-fifth is available for other purposes and can therefore be used for the production of electric power. The author finds that about 90 kW. hours can be obtained per ton of pig iron; this figure might be reduced to 50 kW. hours to be on the safe side.

For works of the second class, namely, without coke ovens and Siemens Martin furnaces, there is no available power for outside distribution.

Coming to the third class it can be reckoned that works operating only blast furnaces have an excess of gas available of about 25 to 35 per cent. of the total production; to be safe the author has taken only 20 per cent., which means 180 kW. hours per ton of pig iron.

Estimates have then been made regarding the possible recovery of heat in the various parts of steel works; such recovery can be made under the three following heads:—

(*a*) Recovery of the waste gas of gas engines.

(*b*) Decrease in the average consumption of gas in the Cowpers.

(*c*) Recovery of the heat lost in Siemens Martin and reheating furnaces.

The recovery of heat contained in the coke at the time of discharge has not been yet realised in a practical way nor has it been possible to recover the heat contained in the slag.

The recovery of the waste heat of gas engines is now realised in many steel works, and large plants are now being installed. Practical experience has shown that it is possible to recover, at the terminals of the turbo-alternator fed by the waste heat boilers, 15 to 16 per cent. of the power of the generators, this is figured out at 50 kW. hours per ton of pig iron.

Regarding the heating of the Cowpers it is generally admitted that 35 to 40 per cent. of the total amount of gas produced by the blast furnaces is required; with a better design of this apparatus it would be possible to reduce to 30 per cent. the amount required to heat the Cowpers, this 5 per cent. saving transformed into electric power would mean at the lowest 40 kW. hours.

The recuperation of heat from metallurgical furnaces has been tried in various countries and would enable one to recover 10 to 12 kW. hours per ton of iron for Siemens Martin furnaces, and 5 to 6 kW. hours per ton of iron for reheating furnaces.

These figures are rather low, and in addition the heat recovery is generally very difficult to realise.

In the case of France, for a total production of 10,000,000 tons of pig iron, the following figures would be obtained : from the general use of blast furnace gas engines the works of the first and third class could supply about 600 millions of kW. hours ; this power could be fed into the extra high tension transmission line in the Northern and Eastern parts of France and would thus be available for general distribution.

If the saving is figured out it is found that about 500 million kW. hours could be obtained from waste heat boilers of gas engines, of Siemens Martin and reheating furnaces and about 400 million kW. hours could be saved by a better design of the Cowpers, therefore a total possible recovery of 1,500 million kW. hours could be obtained ; this would represent about 8 per cent. of the total coal (18 millions of tons) required for the production of the 10 million tons of pig iron under consideration.

The author points out that this figure is a maximum which will never be realised, and that only a part of this saving will eventually be made, as there are many technical and financial questions to be solved in order to increase the recovery of waste heat in steel works.

HEAT ECONOMY AND POWER TRANSMISSION IN THE BEET SUGAR INDUSTRY

DIPL. ING. H. KIND

(1) INTRODUCTION.

Beet sugar and cane have always been keen competitors on the world's market. At the close of the last century, the beet sugar production had developed in a most extraordinary manner, and in 1900 amounted to more than one-half of the world's total production. Since then the conditions have undergone a remarkable change, and the proportion of the cane sugar has increased to such an extent that the beet sugar production now only figures at one-third of the world's production.

If the beet sugar industry intends to reconquer its former position on the world's market, it will have to make very serious efforts, and avail itself of every means to improve the conditions for the production. Modern manufacturing methods will have to be introduced, which guarantee a rapid and systematic treatment of the beetroots and their complete utilization, but first and foremost, improvement of the heat economy and a systematic organisation of the power supply and distribution will have to be aimed at.

The following short sketch deals with these two points, which specially influence the economical works management of a raw sugar mill.

(2) HEAT ECONOMY.

To obtain a correct idea of a heat consuming manufacturing process, a heat balance must be made. For the manufacture of raw sugar, heat is chiefly required for:

(a) The generation of power,
(b) The heating of the juice,
(c) The evaporation and thickening of the juice.

We need not consider the heat required for drying the chips, because not all mills are equipped with such a plant, and we wish to give a general outline of the questions involved. The

empirical figures for the power and heat required are contested even by sugar experts. The units refer to 100 kilos of beetroots. The power required for 100 kilos of beetroots is stated to be 1.2 to 2 B.H.P. It depends primarily on the extent to which a mill has been mechanicalised, *i.e*, to what degree mechanical work has replaced manual labour. Opinions are also divided with regard to the figures for heat consumption. These figures are mostly given in percentages of the weight of the beetroots treated, and average from about 45 to 65 per cent. The difference may be accounted for by the fact that the heat consumption of the auxiliary apparatus and the losses are not always correctly stated. For our present purposes we will assume average values, and a five-fold evaporation as standard. We then have the following balance :—

(a) Power generation	approx.	1,000 th. u.
(b) Heating of the juice	„	15,000 th. u.
(c) Evaporation of the juice	„	6,000 th. u. 4,000 th. u.
Concentration of the juice ...	„	5,000 th. u.
(d) Losses in the machine, due to radiation, leakage, etc.	„	5,000 th. u.
Total	„	36,000 th. u.

We will now investigate the single items of this balance and find out where savings might be made in the interest of the total heat economy.

(a) Let us first consider the heat required for the production of power. Our balance contains the theoretical figure. Older mills still work on the multi-engine system, *i.e.*, they have a number of back pressure engines running in different parts of the works, which drive a group of machines; the exhaust steam of these engines is supplied to the evaporating station. Now, if we figure the thermal loss for old engines at 40 per cent., that means that 600 thermal units are lost in these engines. Savings can be made in the following way :—

(1) By replacing the many single back pressure engines by a single engine.
(2) By employing higher pressures for the steam admission and back pressure.

The advantages to be achieved by the first method are obvious. The thermal efficiency of larger and more modern engines is

decidedly higher. The second method is subject to certain restrictions. The back pressure cannot be increased to more than about 3.5 atmospheres absolute, for the temperature of dry saturated steam at this pressure amounts to 138° Centigrade. Higher temperatures than 120 to 130° Centigrade in the evaporator are avoided if possible. As regards the admission pressure, recent technical developments would permit adopting a pressure of 60 atmospheres absolute, and in the near future, probably even higher pressures. Now, if the total quantity of steam required in the evaporating and boiling station were utilized in the engine, we should have an output for which there would be no practical use. This proves that as long as raw sugar mills cannot combine with other heat consuming concerns, the choice of higher and super-pressures is of no avail. Such a combine would also be very difficult, if not impossible, owing to the very short duration of the sugar harvest. Anyhow, the conditions obtaining in a sugar mill cannot be compared with the much more favourable conditions in refineries. The supply of excess energy to long distance transmission lines will also be impossible in most cases, because such works could hardly put this limited supply of energy to any practical use. Parallel service with other stations would also be unsatisfactory. This teaches us that the super-pressures which are so profitable to other power generating stations, are with few exceptions of no practical use for the raw sugar mills, whose heat consumption for power generation amounts to one-thirtieth of the total heat consumption. The raw sugar manufacturers should, therefore, be careful not to install a plant, which under the obtaining conditions would present no economic advantages, simply for the sake of being able to boast that they own up-to-date equipment. Steam pressures of 16 to 18 atmospheres absolute, at a maximum, at a temperature of 300° Centigrade for the superheated steam, will generally suffice for a really economic service. The savings to be effected with such measures with regard to the power generation amounts to 350 to 400 thermal units at the most, *i.e.*, a little more than 1 per cent. This minimum saving in heat or coal would not justify the very high expenditure involved by the alterations of the plant. However, in section (d) lower down, we shall learn what further advantages these measure may present under certain conditions, and how they influence another item of the heat balance to such an extent that they must be deemed necessary in all cases.

(b) The amount of heat required to heat the juice can hardly be reduced. Rapid treatment and short distances for transport ensure minimum cooling losses, and consequently also a minimum heat consumption for this process, so that important savings can hardly be made.

(c) The heat required to evaporate the juice is an item which has frequently been tackled in order to achieve a reduction of the total losses. It has been suggested to evaporate under pressure in order to avoid the loss of the very considerable amount of heat absorbed by the cooling water in the condenser. It is doubtful if such great savings can actually be achieved, as are frequently estimated; in our opinion this will only affect mills which, owing to the lack of water, are forced to re-cool the cooling water for the condenser. Otherwise the cooling water from the condenser will generally be utilized to heat the flushing water in order to avoid taking steam from elsewhere for this purpose. Practically, the only saving effected is that less pumps have to be driven. The waste steam from the vacuum apparatus in any case passes to the condenser, and its heat content must be booked as loss, if the cooling water of the condenser cannot be utilized.

(d) *Losses.* This is the item of heat balance where the greatest saving can be made. The measures discussed under (a) exercise the greatest influence here. Centralizing the power generation in one engine entails a decided reduction of the length of steam piping. The choice of higher pressures permits smaller pipe sections to be used, and these two factors, supplemented by a really excellent insulation of the piping and apparatus to avoid losses by radiation, can effect a saving of about 2,000 thermal units, *i.e.*, of about 6 per cent. of the total heat consumption. The reduction of the loss factor in the heat balance must, therefore, be aimed at by every manager of a sugar mill.

Now since we have ascertained that a minimum of about 36,000 thermal units are required for every 100 kilos of beetroots, and the initial pressure should be about 16 to 18 atmospheres absolute, at 300° Centigrade, the question arises how this quantity of steam with the corresponding heat content is to be provided. And this is the item next in importance which can be successfully tackled. First, mechanical stokers for the boilers will have to be more widely used; secondly, the steam production must be rendered more economical by employing steam accumulators. It is assumed that the heat of the exhaust gases of the boilers is

utilized in economizers. The design of the mechanical stokers will naturally depend on the kind of fuel available. The employment of heat accumulators will always be advantageous. In raw sugar mills, the load on the boilers fluctuates to such an extent that even boilers with large water chambers cannot meet the sudden demand for steam. Pressure and temperature fluctuations not only disadvantageously influence the manufacturing process but also are the cause of uneconomical heating of the boilers, because the boiler attendant tries to keep the conditions as stable as possible by forcing the boilers. A steam accumulator, on the other hand, can take over the peaks of the steam consumption and thus ensure a steady service and very considerable savings in coal. In view of these difficulties a special type of boiler was designed, called the Winand boiler after its inventor. This boiler is a combination of a vertical tube boiler and large water chamber boiler, supplemented by an accumulator. It requires very little room, is said to follow rapidly the fluctuations of the load, and simultaneously supplies high pressure steam from the vertical tube boiler for the engine, and low pressure steam for cooking and heating purposes, taken from the accumulator. In any case, a steam accumulator will present great economical advantages, no matter whether this accumulator is erected to supplement existing boilers or whether a combined boiler is used. The steam consumption is less, as experience proves, also the running expenses for the boiler room; the boiler efficiency increases and the fuel consumption is reduced. If improvements are to be made at all, the boiler room and its performance will have to be overhauled first.

(3) *Power Generation.* Passing on to the item of power generation, the first question to be dealt with is what type of engine is to be used for the centralised generation of power. Until quite recently the question as to whether the turbine or the reciprocating engine is the more suitable engine was keenly contested. If we review the plants which have been built during the last two years, we must conclude that the decision has turned in favour of the turbine. The only argument which could be put forward against the turbine was its higher steam consumption. We would emphasise the words "steam consumption" because with regard to heat consumption, the reciprocating engine can hardly compete with the turbine, the less so since it has recently been possible to design high-speed turbines, running at 9,000 r.p.m., whose thermal efficiency is exceedingly favourable. Bar

this one point, the practical importance of which is relatively small in the proportion of steam consumption for power on the one hand, and steam consumption for heating and cooking purposes on the other, as obtaining in sugar mills, all other factors are most certainly in favour of the turbine, the advantages of which are the following:—

(1) Small mass, therefore lighter and cheaper foundations.
(2) Smaller and cheaper engine room.
(3) Lower consumption of oil.
(4) Oil-free exhaust steam.
(5) Better regulation.
(6) Smaller fluctuations of the steam consumption at varying loads.

If we duly consider these points, it is quite obvious that the decision could not but turn in favour of the turbine.

Centralised power generation was naturally followed by electrical power transmission. It would be bad practice to have the turbo-generator running in the power house and to drive the different machines from the old time shafting. Individual drives or group drives (especially in older mills) of the machines is modern practice.

As regards the choice of the kind of current and the pressure, we would remark that three-phase current is preferable for sugar mills. In some mills, direct current power transmission is still to be met with; however, this is due to historic development. There are no reasonable arguments which can be put forward in favour of direct current. The chief advantage of the latter, *viz.*, speed regulation without losses, is of no consequence for sugar mills because there are no drives which require any perceptible speed regulation.

On the other hand, three-phase power transmission presents the following advantages:—

(1) The transmission of high outputs over long distances is simpler and generally requires less material.
(2) The design of three-phase motors is much simpler than that of direct current motors, and the former, therefore, require less attendance.
(3) Emergency connections from public supply companies can nowadays only be had for three-phase current, and a conscientious works manager will certainly not wish to be without such a connection.

This short survey proves that practically only three-phase current can be considered for the electrical power transmission in sugar mills. The most recent development fully bears this out. There is scarcely a modern sugar mill which has not adopted three-phase current.

Now, as to the pressures for beet sugar mills, 380 and 500 volts will be found most suitable. The advantage of the latter pressure is, that a saving can be made in the line material owing to the smaller current intensities. However, if this pressure is chosen, the regulations governing H.T. plants must be observed, because the pressure to earth exceeds 220 volts. A further disadvantage of this pressure is that a special transformer has to be provided for lighting, which latter is run on 220 volt circuits.

If on the other hand a pressure of 380 volts is chosen, 220 volts are available as star potential to earth. Beside this, the machines and apparatus for this pressure, which is very widely used, are standard types and can be had everywhere. The capacity of the single motors, even for group drives, rarely exceeds 100 KW, so that this pressure suffices. The control of the voltage drop in a 380 volt supply presents no difficulties.

(4) *Distribution of electrical energy.* The design of the main switchboard of a sugar mill from which the electrical energy is distributed does not differ from that of switchboards used elsewhere. The space allotted to the board should not be too small, in order not to reduce the reliability of the plant. There should be sufficient measuring and recording instruments to enable a sharp control to be kept over the plant. In America, this has been done to such an extent that the works manager can control the complete manufacturing process from his office.

Great care should be exercised in the correct choice of the wiring materials for the motors, starters and switchgear, Bearing in mind the fact that the manufacturing process in a sugar mill is a continuous one, and that a breakdown with consequent stoppage costs infinitely more than could be saved by equipping the plant with inferior material, there is no doubt that the best material is advisable. Cables or rubber conductors run in steel conduit should be used for the wiring.

Open type motors are preferable to other types, but their windings must be specially protected against moisture.

Oil-cooled starters should generally be employed; for motors of higher outputs controller type starters are preferable.

Ironclad gear should be used for the distribution. Incandescent lamps are exclusively used for the lighting. Special fixtures are not required, but watertight fittings are to be preferred.

(5) *Consumption of electrical energy.* One of the chief advantages of electrical power transmission is that it permits the individual drive of the machines to a very wide extent. In new mills this drive should be used whenever possible; in older mills, the group drive will be more to the point for local reasons, because certain groups can be formed which were formerly driven by several engines. The individual drive would probably result in an expenditure which would counterbalance the advantages of the drive.

The introduction of the individual drive has revolutionised matters in the sugar industry, inasmuch as nearly all the reciprocating pumps have been replaced by centrifugal pumps. The adaptability of the electric motor to the speed of the machine to be driven is one of the chief reasons why rotary pumps are now so widely used. The designs of the latter have been so developed to meet all requirements of a sugar mill, that they are absolutely reliable. The somewhat lower efficiency of the rotary pumps as compared with the reciprocating pumps, is of no importance for the power economy of a sugar mill, because the latter works with waste energy. The experience gained with rotary pumps certainly proves, that it was quite correct to provide these instead of reciprocating pumps.

A special field for electric individual drive in a sugar mill are the centrifugal machines, and great savings in the running expenses can be made. Three-phase squirrel-cage motors are best used for these drives, and the experience gained within the last years with these drives proves that they are the most economical. Even direct current motor drives with regenerative braking have not proved so efficient as the drives with three-phase squirrel-cage motors. Another great advantage of these latter is that they require practically no attendance. Of course the rotor resistances and the rotor must be correctly designed, also the flexible coupling.

We therefore strongly recommend the use of the three-phase squirrel-cage motor. It requires little attention, only the lubrication of the bearings having to be looked after occasionally. There are practically no parts subject to wear. The argument that the motor requires a high current at starting is usually not

justified, and it can be considered to be a progress in electrical drives if this type of motor is used in ever-increasing numbers.

Regarding the other drives of a sugar mill, no remarks need be made, as they depend on the local conditions.

RÉSUMÉ.

Un bilan thermique montre quelles mesures doivent être prises afin de travailler avec la consommation de combustible la plus réduite. On recommande l'introduction du travail mécanique dans la salle des chaudières ; l'emploi d'accumulateurs de vapeur, et la centralisation de la production de l'énergie électrique.

Enfin on donne des règles pour le choix du matériel convenable, et pour la transmission de l'énergie électrique.

BLAST FURNACE GAS ECONOMY IN IRON WORKS

K. RUMMEL

I. THE BLAST FURNACE AS GAS PRODUCER.

From the viewpoint of the combustion engineer the blast furnace is a typical gas producer. The main purpose of the blast furnace being the production of iron, the losses of the process of gasification are chargeable to the iron production, therefore the efficiency of the gasification is 100 per cent. The monetary value of 1,000 calories of blast furnace gas is larger than the value of 1,000 calories of the original coal. In big German plants this value of blast furnace gas is—on the average—about 1.2 times as much as the price for the same amount of calories contained in coal.

On the other hand, the blast furnace is not worked by coal but by coke, and the price of coke is, as a rule, *more* than 1.2 times that of coal, referred to the same amount of calories. Starting with such an expensive fuel and in spite of the high efficiency of the gasification, the blast furnace cannot be worked economically as a gas producer. Should it be possible to use coal instead of coke (by blowing coal dust into the Tuyères) or should it be possible to increase the value of the gas (by enriching the blast by oxygen) the gasification process would become more economical. In this case it would be suitable to *increase the fuel* used in the blast furnace, at the same time increasing the iron production and saving fuel by applying lower blast temperatures.

Admitting that these ideas are somewhat fantastic, the relative value of gas to coal and coke should not be neglected, while considering the blast furnace as a gas producer.

II. QUALITY FACTORS.

The above calculation represents an example for the application of rates of value, called "quality factors." The use of these quality factors is recommended in many cases of fuel economy calculations, because they state how much more can be paid for 1,000 calories of a certain fuel, than for 1,000 calories of another fuel. Such quality factors will return frequently in the following statements.

III. THE DISTRIBUTION OF HEAT AND ENERGY IN IRON AND STEEL WORKS.

Fig. 1 Monthly heat and energy consumption of a smelting-work in 10⁶ interm. th. un.

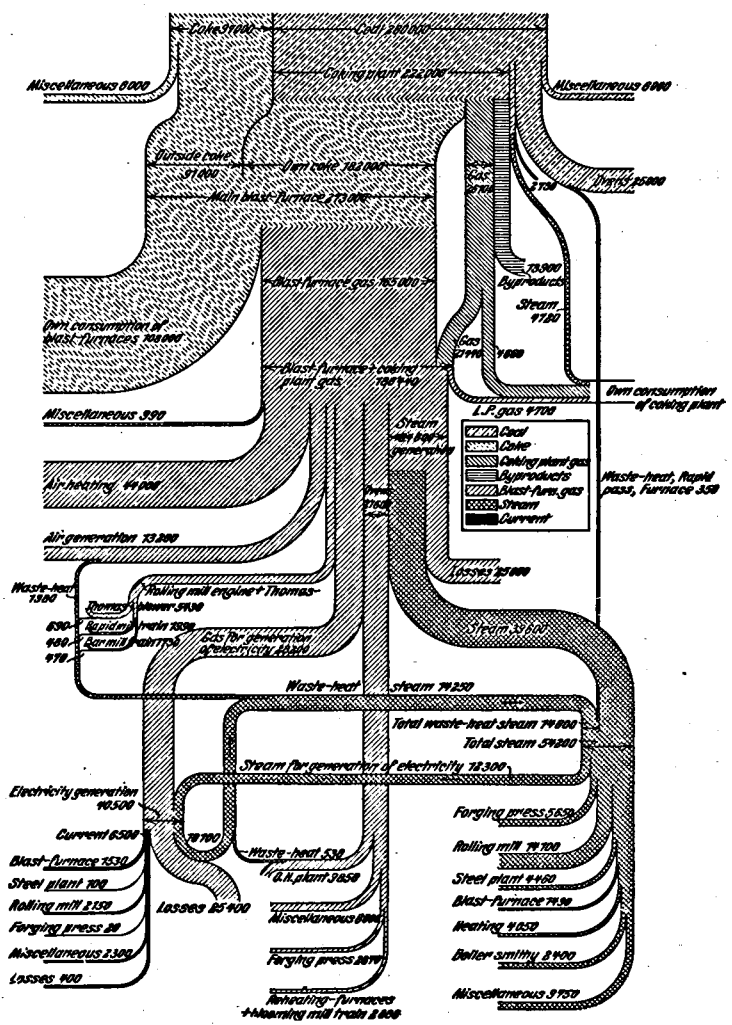
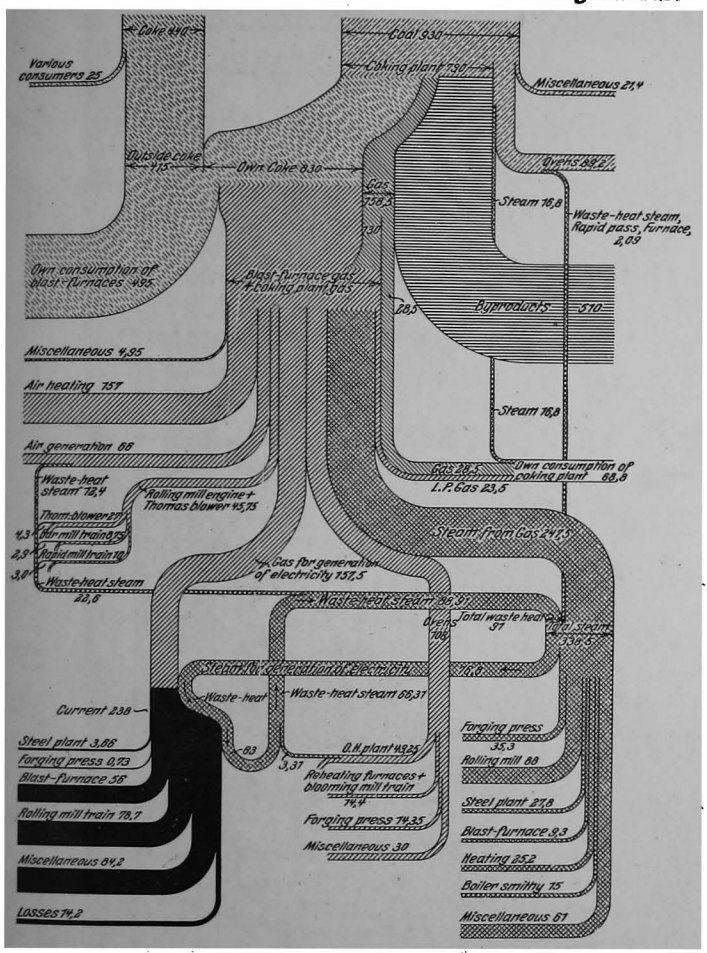


Fig. 1 represents the heat distribution in a plant in the form of a heat balance plan. Fig. 2 shows the same plan except that

Fig. 8 Monthly heat and energy consumption of a smelting-work in 1000 goldmarks.



the quantities of heat have been changed from calories (= international thermal units) to the cost of heat.

A further example of distribution of heat quantities in another plant is shown in Fig. 3. Here another way of representation has been chosen. Still other methods of such diagrams are possible in practical use and sometimes of special advantage, but their reproduction is not suitable for the concise form of literary publications.

Fig. 8 Monthly heat and energy consumption of a smelting-work in 1000 goldmarks.

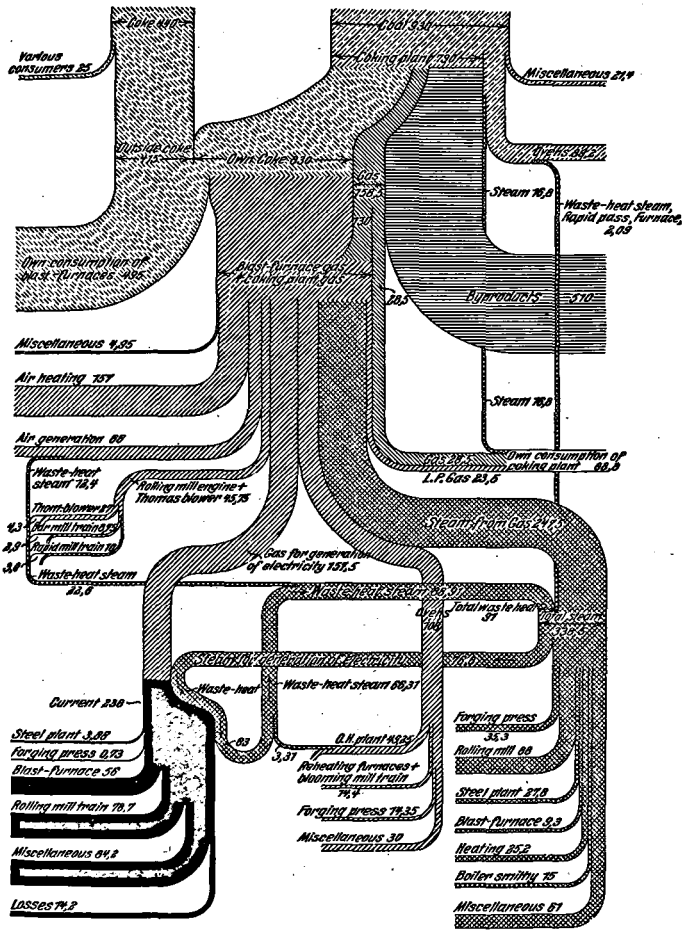


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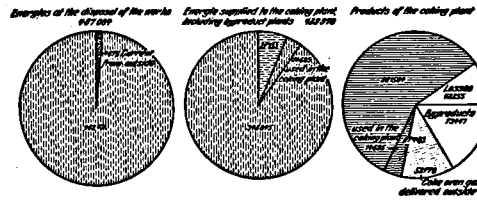
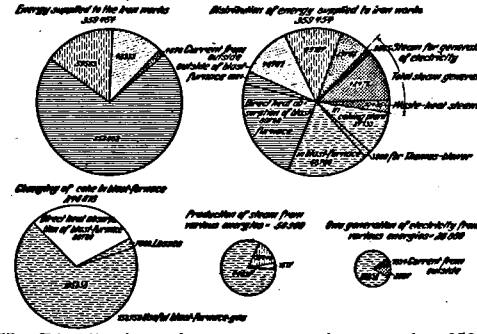
Fig. 3. Heat and energy distribution of a smelting-work in 10^6 intern th.un.

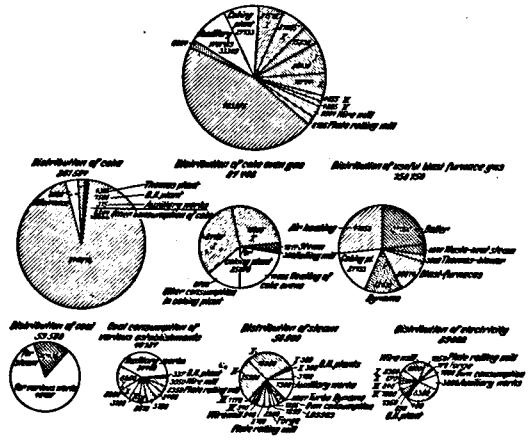
I. Main distribution.



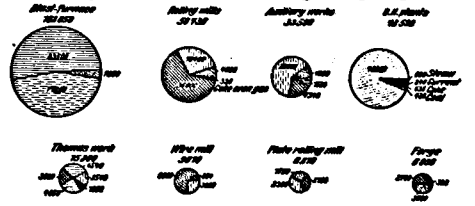
II. Conversion of outside energies into other energies.



III. Distribution of energy to various works, 359454



IV. Consumption of various energies by separate works.



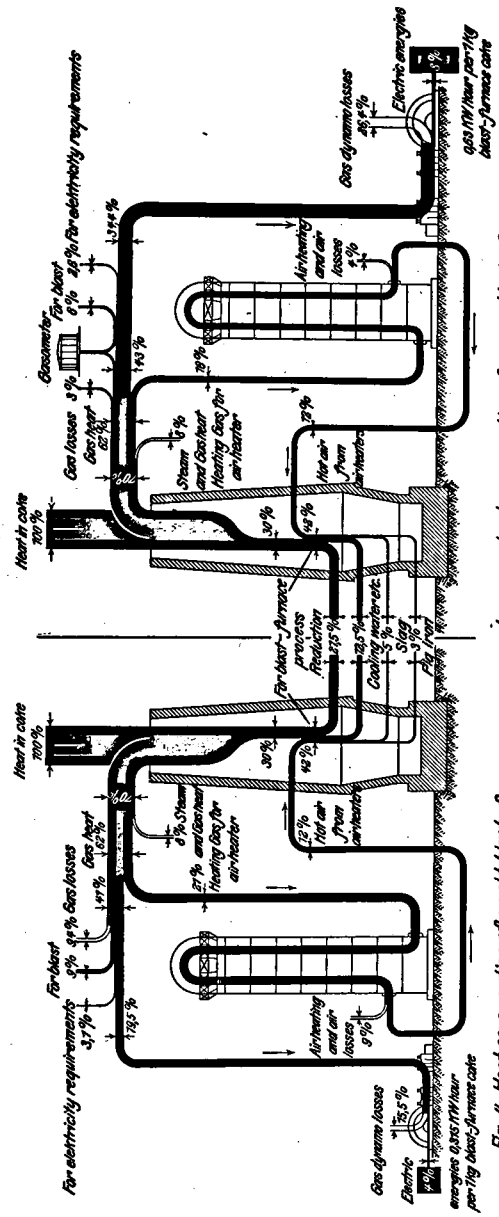


Fig. 4. Heat consumption of an old blast-furnace and heat consumption of a new blast-furnace.

IV. THE DISTRIBUTION OF THE BLAST FURNACE GASES.

The distribution of the blast furnace gas as previously outlined is shown for another plant by Fig. 5.

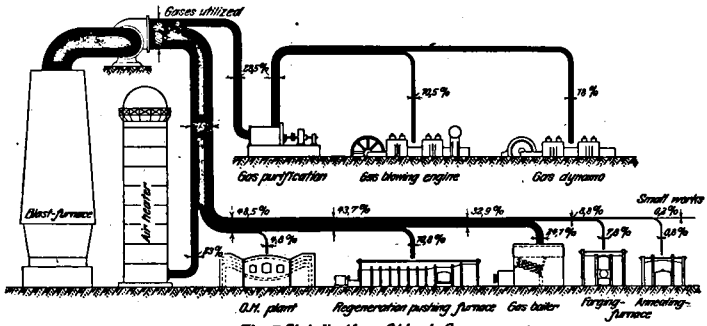


Fig. 5 Distribution of blast-furnace gas.

Fig. 4 shows the change in gas economy that has taken place during the last few years or that is due to come in the near future.

On the left hand side, the former state of the plants is shown, which is neither bad nor particularly good. The right hand side shows the improvement obtained, which means that the energy available outside the blast furnace plant has been doubled. In other words, the amount of surplus gas has been increased by 100 per cent.

V. THE ECONOMICAL APPLICATION OF THE GASES.

The most important question of gas economy is this: Where can the most suitable use of the gases be made? In the engines, in the boilers, furnaces or also for lean gas heating of coke oven batteries? The quality factor mentioned under II. gives some information about this question.

The following figures are such quality factors. They refer to the value or to the price of 1,000 calories of boiler coal free works for big German Iron and Steel plants, if depreciation, interest and overhead charges are included:

Gas engines for generation of electric current without waste heat boilers	1·3 —1·4
Gas engines for generation of electric current with waste heat boilers	1·5 —1·6
Gas blowers without waste heat boilers	1·0 —1·3
Gas blowers with waste heat boilers	1·15—1·5
Lean gas heating of coke ovens	1·3 —1·8
Open hearth furnace heating (mixed with coke oven gas) ...	1·5 —1·8
Heating—annealing—welding furnaces	1·0 —1·5
Boilers with constant gas pressure	1·1 —1·4
Boilers as equalising battery	0·9 —1·1

An example may show how such quality factors have to be calculated. The application is as follows:

When multiplied by the heat value of the gas and the price for 1,000 calories of boiler coal free works, the quality factors indicate immediately according to their definition the price which can be paid for 1 cu.m. of blast furnace gas; thereby the different methods of utilisation can be compared.

VI. THE QUALITY FACTOR OF STEAM TURBINE PLANTS WITH GAS FIRED BOILERS VERSUS SUCH PLANTS WITH COAL FIRED BOILERS.

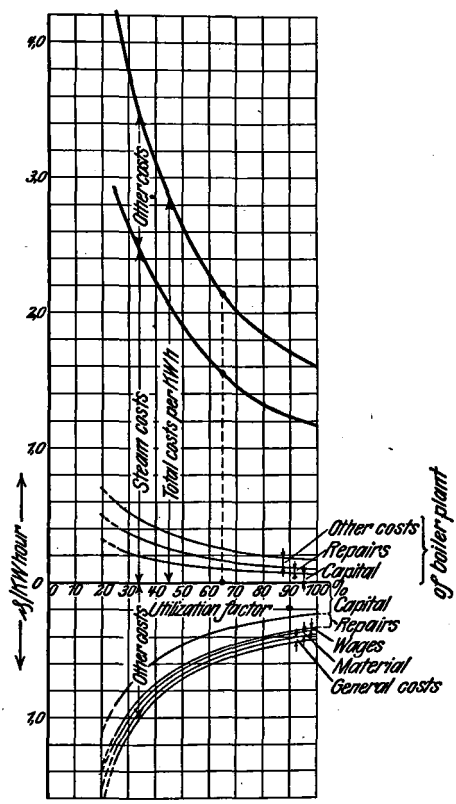


Fig. 6. Costs per KW hour in steam turbine powerplants with gas-fired of coal-fired boilers at medium high coal price.

How to find the quality factor may be shown by an example in section VII. Fig. 6 serves as a basis for determining costs of

one kilowatt-hour in steam turbine power stations with gas fired boilers at various load factors." The load factor (utilisation factor) is determined as follows:

$$\frac{\text{ACTUAL OUTPUT OF THE PLANT PER YEAR IN K.W.-HOURS.}}{\text{Installed KW's.} \times 8{,}760 \text{ hours}}$$

The steam consumption per kilowatt-hour represents actual figures obtained in big plants. These figures are considerably higher than those guaranteed by turbine builders and also

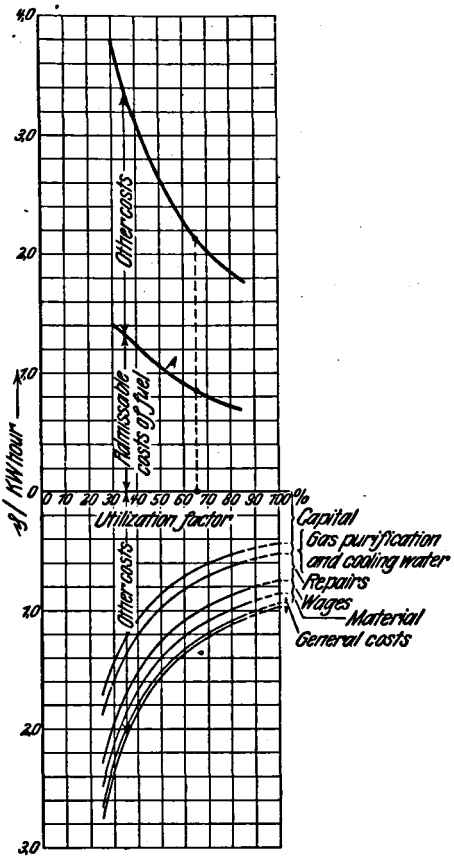


Fig. 7. Admissable costs per KW hour in gas-engine power plants. (Same total price per KW hour as in Fig. 6)

higher than the consumption of many public utility plants. Nevertheless such figures as shown are not so easy to maintain

and require a rather well equipped and well organized outfit. Sometimes the figures obtained in iron works will exceed those of Fig. 6.

In preparing this diagram it has been assumed that 1,000 calories of coal have the same value as 1,000 calories of blast furnace gas or that in comparing turbine power stations and *gas* fired boilers with such plants having *coal* fired boilers, it will be found that the quality factor equals 1. The proof of this fact is not within the scope of this paper. For gas fired boilers serving as equalizing battery for the fluctuations of the available gas quantities it can be shown that the quality factor equals 1.

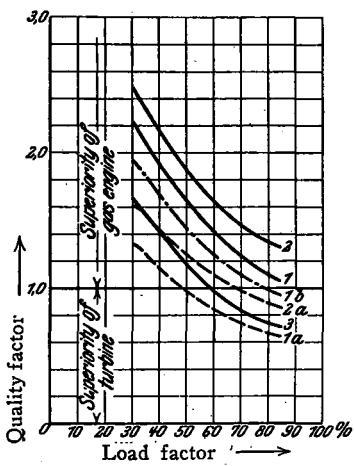


Fig. 8. Index values for valuation of gas in gas-engine work relative to steam turbine work with gas-heated boilers.

(1) Medium high coal price
(2) High coal price
(3) Low coal price
(1a) Medium high coal price and 25 per cent. lower consumption of turbine
(1b) Medium high coal price and 10 per cent. lower steam consumption of turbine
(2a) High coal price and 25 per cent. lower steam consumption of turbine

VII. THE QUALITY FACTOR OF GAS ENGINE POWER STATIONS VERSUS STEAM TURBINE POWER STATIONS WITH GAS FIRED BOILERS.

The quality factor is determined by using the same price per

kilowatt-hour produced in gas engines which has been found according to Fig. 6 for steam turbines. Considering the interest of capital and the working costs of the turbine plant on the one hand and the gas engine plant on the other hand the curve A of Fig. 7 is found. The distance between this curve and the abscissa shows the amount of money which can be spent on the gas necessary to generate one kilowatt-hour without paying for more than one kilowatt-hour in steam turbine power plants. The fuel consumption of gas engines is known. From this we can calculate what price can be paid for 1,000 calories of gas and (since we know the price of 1,000 calories of coal) hence the quality factor for gas engines versus steam turbine power stations with coal fired boilers can be found. This quality factor is at the same time the quality factor for gas engine stations as compared with turbine power stations with gas fired boilers, because the quality factor of coal fired to gas fired equals 1 according to section VI.

Curve 1 in Fig. 8 shows the quality factor figured in this manner for gas engine power stations against gas fired steam turbine power stations for various load factors. Before discussing these curves, the basis of comparison has to be mentioned; power stations with up-to-date equipment and with about 20,000 installed kilowatts are being compared. For gas engines, units of 3,000-4,000 kilowatts nominal load are assumed. It has also been assumed that the gas engines carry a load of about 85 per cent. of the full load and that regulation takes place *by cutting in or out one or more units,* if the full load of the engine is exceeded or if the load of this engine falls below 70 per cent. of full load. Furthermore, for the steam turbine plant it is assumed that there are several units of different size between 8,000 and 3,000 kilowatt nominal load and that the fluctuations of energy be such that the night load of the central station averages two-thirds of the day load and that the Sunday load be about one-third of the working day load. Furthermore, it is assumed that the steam consumption of the turbines per one kilowatt-hour on the switch-board, including all auxiliary engines and the total works consumption be as follows:

Load factor (utilisation factor)	1·00	0·65	0·25
Kgs./kilowatt-hour	6·00	7·10	8·50
[lbs./kilowatt-hour	13·23	15·66	18·74]

It has already been mentioned in section VI. that these figures

are considerably higher than those guaranteed by steam turbine manufacturers. For Iron Works they represent rather favourable values especially because the figures found in practice refer mostly to older works that have been gradually extended in the course of time.

For gas engines a consumption of 3,600 calories/kilowatt-hour (14,300 B.Th.U./kWh.) with waste heat boilers corresponding to about 4,200 calories/kilowatt-hour (16,700 B.Th.U./kWh.) without waste heat boilers is assumed. This figure is also considerably higher than those guaranteed by the engine builders.

In practice, for gas engine central stations without waste heat boilers, values have been found that vary generally between 3,800 and 4,800 calories/kilowatt-hour (15,100 and 19,050 B.Th.U./kWh.) at the switchboard for the kilowatt-hour delivered to other places.

The fuel consumption of the gas engine central station does not depend on the load factor if the plant is regulated by cutting in or out entire units and these units are of the same size.

In Fig. 8 the curves 2 and 3 are shown under the following assumptions: curve 1 meets, with reference to the boiler plant, works and fuel costs, the considerations prevailing in Germany in the year 1913. Nowadays coal, if compared with other costs in Germany, is comparatively dear, whilst in other parts of the world coal is considerably cheaper than shown in curve 1. Curve 2 therefore supposes that, compared with the other costs, the fuel costs (i.e., the price of the coal) is 1.5 times, and in curve 3, 0.67 times as high as under normal conditions. Hence, curve 2 corresponds to present German conditions, curve 3 to the conditions partly existing in other parts of the world. The rate of fuel costs to the other costs for the cases 1, 2 and 3 and in most cases for a rather good load factor of 0.65 is reproduced in the following table.

COSTS OF THE KILOWATT-HOUR IN GAS ENGINE POWER PLANTS.
(LOAD FACTOR 65 PER CENT.)

	Fuel costs.	Other costs.
Case 1.		
Medium cost of coal ...	36·9%	63·1%
Case 2.		
High cost of coal ...	53·6%	44·4%
Case 3.		
Low cost of coal ...	73·6%	26·4%

Fig. 8 shows that, in contrast to the usual perception, the quality factor rises with decreasing load factor. The reason is that for gas engine power stations there has been assumed—regardless of the load rating—a constant heat consumption, whilst in steam power plants of iron works the efficiency depends very largely on the load rating.

In Germany, a great superiority of the gas engine has been found, since with the prevailing load factor of 85 per cent. the quality factor exceeds the value 1. This holds true still more at a coal price higher than that shown in curve 2. Only at as low a coal price as that shown in curve 3 is the steam turbine superior to the gas engine. According to the conditions of each case, the curve of the quality factor will change somewhat. By means of Figs. 6 and 7 it will not be difficult to make the proper considerations for each special case.

Finally, the case has to be examined that the steam consumption of the central turbine station can be diminished by proceeding to higher pressures of about 40 atmospheres (569 lbs.), corresponding to the results of the "Erste Brünner Maschinenfabrik" by improving the thermodynamic efficiency. If we assume a reduction of the steam consumption by 25 per cent. and at the same time an increase of the *total* costs of the boiler plant by 30 per cent. and the turbine plant by 10 per cent., the curves 1a and 2a will be the result. Even without an increase of the thermodynamic efficiency, a reduction of the steam consumption by 25 per cent. could be obtained if we proceed to 100 atmospheres (1,422 lbs.) steam pressure and a superheat of 400°C. (194°F.) (reheating regenerating). It follows that a reduction of the steam consumption by 25 per cent. below the conditions above assumed means death to the gas engine if we do not succeed in improving its economy considerably, for instance, by introducing generally the charging method and by producing steam from the cooling water.

If we only succeed in reducing the steam consumption by 10 per cent., which would be possible by obtaining 40 atmospheres (569 lbs.) steam pressure and 375°C. (257°F.) superheating, the quality factor is even reduced considerably. Curve 1b gives the quality factor for a medium price of coal, as used in curves 1 and 1a, if the steam consumption is lowered by 10 per cent., and if the same depreciation costs like those in curve 1a are assumed.

VIII. THE ECONOMY OF GAS BLOWING ENGINES.

Thus far, gas engines for current generation have been taken up. For blowing engines the same considerations hold true. It is to be noticed, however, that the blast pressure will vary within wide ranges, if the blowing engine instead of being connected to a main blast pipe, is assigned to a certain furnace, or in other words, if instead of *pressure* blowing, *volume* blowing is applied. The latter will be more and more the case. By this method the load of the gas engine is rather unfavourable because, on account of the varying load, the thermal efficiency of the gas engine grows worse. This drop in efficiency can be moderated by adding a waste heat boiler (this will be demonstrated in section x.), yet the heat consumption of the gas engine will be considerably higher, as in section VII., whilst the steam reciprocating engine and the steam turbine or the electrical turbo-blowing engine are less sensible in this respect. The difference in heat consumption between steam and gas driven plants will change therefore in favour of the steam drive, and the result will be in many cases in favour of the application of the turbo-blower, especially on account of the limited local requirements of this simple and comparatively cheap engine. The turbo-blower can be set up close to the blast furnace, resulting in short pipes with small wind losses.

IX. WORKS WITH EXCESS OF GAS AND WORKS WITH GAS SHORTAGE.

In the results thus far discussed it has been assumed that the quantities of gas saved by the use of gas engines could be usefully applied in other departments; this cannot always be done in iron works. Therefore certain reservations have to be made and the most advantageous utilisation of gas has to be considered with regard to the different simultaneous places of application outside the central power station.

In order to determine the highest possible utilisation of the blast furnace gas the total obtainable price for delivered gas must be as high as possible. Taking the quality factor as a basis, the quantity of gas used for each single purpose has to be multiplied by the quality factor for this purpose of utilisation and all these products have to be summed up. If the sum made up for all possibilities shows a maximum, the most favourable utilisation of the gas has been reached.

X. WASTE HEAT BOILERS BEHIND GAS ENGINES.

In the above considerations it has been assumed that the gas engines are equipped with waste heat boilers. This has been done because the arrangement of waste heat boilers behind the four cycle engines is so economical that plants without waste heat boilers should not be installed any more. The fact of the good economy can be shown by a very simple consideration.

Assuming that the steam of the waste heat boilers be again transformed to electrical power (for example in turbines for peak load taking up momentary fluctuations), it follows that the first cost for the installed kilowatt-hour of gas engines with

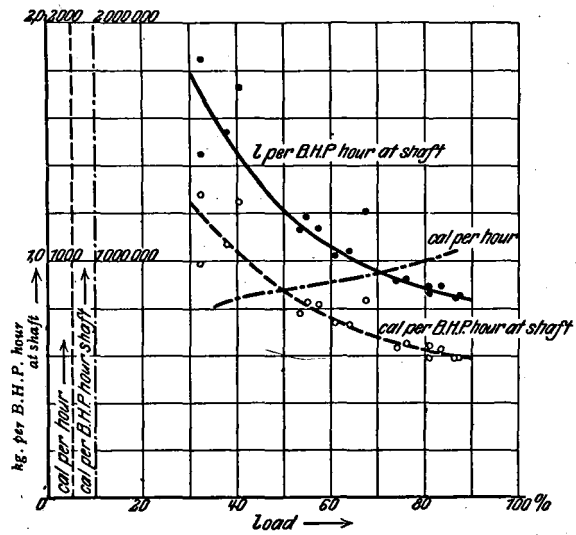


Fig. 9. Evaporated in waste-heat boiler behind gas-engine relative to load of gas-engine.

waste heat boilers are not higher, even a little smaller than those of gas engines without waste heat boilers. The first installation comprises of course the cost of the boilers, but the total power rises; the price of the installed kilowatt-hour will therefore not be higher, but somewhat lower, also the works cost of production of the kilowatt-hour delivered at the switchboard will not increase. The fuel for the waste heat boilers (the exhaust of the gas engine), has been regained without expense. Per kilowatt-hour about 1.2 kg. (2.65 lbs.) of steam can be reclaimed

with an engine running at 85 per cent. full load rating. With this steam, even under unfavourable conditions, for example in peak load turbines, at least 0.15 kilowatt-hours can be generated, the gain of power being therefore 15 per cent. and up to 20 per cent. By this increased power of 15 per cent. gained without any cost of fuel, the fuel consumption of the power station falls from 100 to 100 ÷ 115 = about 86 per cent. (Quality factor = 1 ÷ 0.86 = 1.15). It has to be noticed that the effect of the waste heat boilers behind gas engines falls very little if the load of the gas engine decreases. Fig. 9 shows the results of a test.

Between 86 per cent. and 35 per cent. load, the effect of the waste heat boilers only decreases from 100,000 to 80,000 calories/hour (396,800 to 317,500 B.Th.U./hour), measured in produced steam. This statement is important because it shows

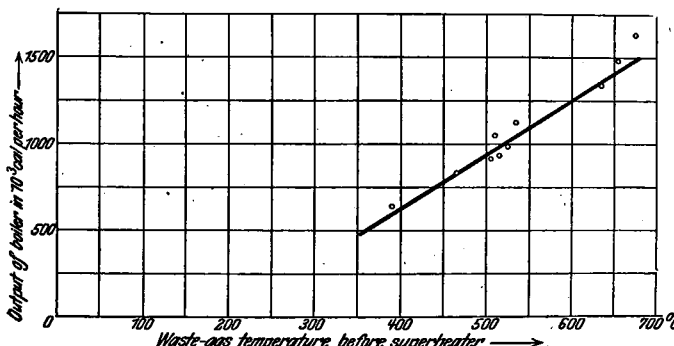


Fig. 10. Output of a waste-heat boiler behind gas-engine dependent on waste-gas temperature.

that if waste heat boilers are used, the curve of relation between heat consumption of the gas engine and the load (which is inherently steeper than that of turbines) is flattened out. If, therefore, waste heat boilers are in use, the gas engine will work with more uniform gas consumption than the gas engine without waste heat boilers, if at the same time the load varies largely.

The effect of the waste heat boilers will no doubt depend largely upon the temperature of the waste gases. Fig. 10 shows this relation for the range from 93 to 97 r.p.m.

XI. REGULATING THE DISTRIBUTION OF THE GAS WITHIN THE VARIOUS DEPARTMENTS, AND THE ACCUMULATION PROBLEM.

Good gas economy required that a very good distribution of the gas be available to the various gas consuming places. This balance can be made either by storing the gas heat in stoves or by storing the gas in steam accumulators or by a boiler, heated by choice by blast furnace gas, or other fuels (oil, coal, coal-dust) or finally by adding as required gas from gas producers with running slag. In this direction a strong development is being made but has not as yet been realised. The following statements are consequently only partially the results of experience and to a great extent they are only of a speculative character and may serve as a guide for future improvement.

About the different possibilities, the following can be said:

1. *The stoves*[1] are nothing else than accumulators. Therefore it is only a matter of course to use them for heating the air as well as for equalising the gas delivered by the furnace. The different possibilities of accumulating are very manifold and their description is beyond the limits of this paper.

The *efficiency of the accumulation*, i.e., the proportion of the accumulated to the delivered peak depends on the construction and the working method of the stoves and is about 70 to 100 per cent. The longer the gas peak lasts the worse the efficiency will be.

The *first cost* is in this case zero because the apparatus is in use anyway.

The *regulation* has to be effected automatically if short peaks of less than half-an-hour's duration are assumed also with regard to the supply of the combustion air. The necessary provisions for it are not very cheap; if peaks for longer time have to be assumed the accumulators can be adjusted to fixed pressures.

Heat storing in stoves is best suited for peaks of half to three hours. If considerable drop in efficiency is admitted this method of accumulation is also suitable for longer peaks. It is then well adapted for equalising the excess of gas due to the difference in consumption between day and night shift.

Also the Sunday peaks can be taken up in this way, but the

[1] See Stahl und Eisen 1923, p. 225 K. Rummel: The accumulation of the excess of gas in blast furnace stoves.

accumulation requires a well organised management and can only be accomplished if the temperature of the air at the blast furnaces is regulated by adding cold air.

2. *Gasometers.*

The efficiency is 100 per cent.

The first cost is rather high.

The regulation is fully automatic.

The range of application is limited on account of the high cost for peaks appearing more frequently than once in 24 hours. To equalise the day and night shift or even the excess of gas, gasometers are not suitable. The cheaper the energy compared with the first costs, the less economical this method will be. For small and often repeated peaks the gasometers are very suitable. If there is an excess of coke oven gas, which cannot be sold at a considerably higher price than blast furnace gas, it is recommended to accumulate coke oven gas instead of blast furnace gas in the gasometers and to equalise in this manner the requirements of power. The gasometers will in this case be considerably cheaper for the same quantity of energy.

3. *Accumulation of steam.*

We have to distinguish between decreasing pressure accumulators (Ruths System) and constant pressure accumulators. In the former, by lowering the pressure, a part of the accumulated water is evaporated thereby giving off some of its heat; in the latter, the accumulated water is heated under full boiler pressure to the temperature corresponding to this pressure in order to be used at times of large steam requirements such as hot feed water.

(*a*) *Accumulators at constant pressure.*

The efficiency is about 95 to 98 per cent.

The first cost is comparatively low.

The regulation is effected by hand or semi-automatically.

Full automatic regulation might be considered, but meets with certain difficulties and is therefore not as yet carried out. Within the limits of peak loads that can be carried by this method, the efficiency of the boiler plant is favourably influenced on account of the greater uniformity of firing.

Range of application.

The effect of the accumulator is limited, according to the amount of the peak to be taken up, by physical relations

especially if the feed-water, as it is mostly the case in iron works, can be heated by other means to about 100°C. (212°F.). If outside the boiler plant no hot water of over 100°C. (212°F.) is used, this system of accumulation can *only be applied to a limited extent* in order to equalise the day and night quantities. If accumulators with decreasing pressure are useless (see under *b*), accumulators with constant pressure should be applied within the limits of their storing capacity.

(*b*) *Accumulators with dropping pressure.*

The *efficiency* is about 95 to 98 per cent.

The *first cost* is somewhat higher than under 3 (*a*).

The *regulation* is fully automatic. At the same time the load of the boiler is regulated to a higher degree and consequently by the higher efficiency of the boilers *considerable saving of fuel is obtained.*

In new power stations of iron works, in which steam is used (which is always advantageous to some extent) or in old plants with waste heat or mixed pressure turbines, these accumulators are very suitable and they are superior to the other types of accumulators (with exception only of the accumulation in stoves within the limits of this type of accumulating). Combination with 3 (*a*) is possible although thereby the simplicity of the plant is unfavourably affected.

4. *Equalisation of fluctuations in combined boilers fired simultaneously by gas and coal (powdered coal) or fuel oil.*

The *efficiency* of the equalisation is assumed to be nearly 100 per cent. The first cost is lower than under 2 and 3. The regulation is simple and is effected by hand but requires a competent staff.

The *range of application* is limited to works with considerable requirements of energy, which cannot be covered by the blast furnace gas alone, having at the same time a great steam consumption. Consumption with 3 (*b*) is possible and has to be judged from the general points of view of the installation of steam accumulators in large power plants according to the particular shape of the load curve of the boiler plant.

5. *Gas producers with running slag.*[1]

The efficiency is 75-80 per cent., if waste heat boilers are used

[1] See Mitteilung Nr. 34 der Wärmestelle Düsseldorf: "Der Abstichgenerator als Ausgleicher der Schwankungen der Gasmengen im Hochofenbetrieb."

behind the gas producers and if fluctuations between half and full load are assumed.

The *first cost* and the works cost form a considerable part of the total gas cost, if the degree of utilisation is small.

The *regulation* is comparatively simple and can be made fully automatic though this has not as yet been done practically. The range of application is limited to works with unusually high

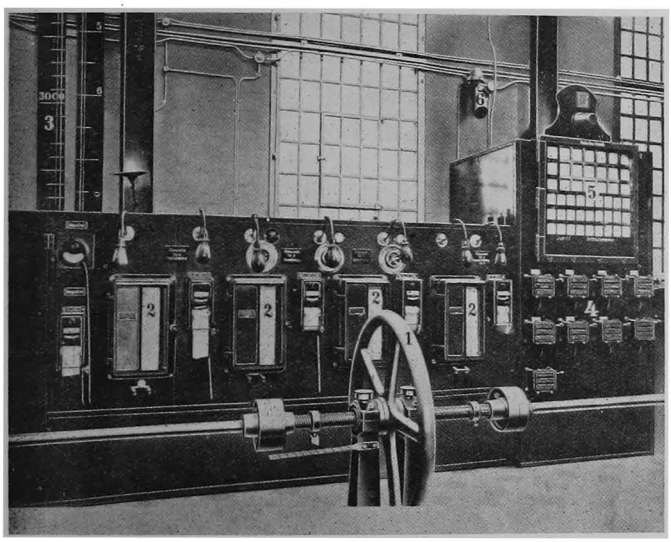


Fig. 11. Switchboard for distribution of gas.

(1) Wheel for regulating the throttle valves in the main pipe.
(2) Pressure and volume recorders for the main distribution pipes.
(3) Scale of the gas holder.
(4) Signals to the consumers.
(5) Table for signals from the consumers.
(6) Acoustic apparatus for signals from the blast furnace.

requirements of energy beyond their own production from blast furnace gas.

6. Still another method of equalisation is to deliver power outside, usually as electrical energy. These means are but seldom applied, first of all on account of the difficulty of reconciling the various interests. Nevertheless this method will work out all right in thickly populated countries.

XII. METHODS FOR GOOD DISTRIBUTION OF THE GAS IN THE WORKS.

Apart from these more or less automatically working accumulators and methods of equalisation, a well arranged regulation between supply and demand cannot be forgotten. Each department consuming gas must first of all do its best to take energy as equally as possible and in this direction much can be obtained. This shows the value of easy reversing of the valves of the stoves. Between the time in which the gas is shut off from the stove and the opening of the valve of the next stove, a considerable time (between three and eight minutes) is wasted by the reversing of the air valves. During this time the stove needs no gas and causes an excess of available gas or a peak. It is therefore best to shorten the time of reversing the valves as much as possible, for instance, by special quick closing valves or by studying the process of reversing.

Other methods include the well organised distribution of work so that particularly high power and heat consumption do not coincide. It is very convenient to install a special station (see Fig. 11) for the total distribution of the gas; in this, all variations in the delivery and the requirements of gas are controlled by signals or by telephone. For important places, a special telephone system has to be arranged independent of the other telephones. In such a control room a number of registering instruments is arranged so as to give a complete view of the pressures and quantities of gas in individual sets of pipes. Important places of measurement in remote departments transmit their information electrically to the control room. In the individual departments the instruments are protected in small control rooms; they are in rows, side by side as shown in Fig. 12. The small instrument houses are standardised. The above mentioned control room is occupied day and night by a sort of switchboard attendant who decides according to given instructions and exact knowledge of the requirements and the method of working of the single departments, what quantity of gas is to go to each department at any moment. Such control rooms have proved very successful.

In connection with all these questions, a discussion of the economy of the coke oven gases would be very profitable on account of its relation to the blast furnace gas economy.

Unfortunately, such a discussion is impossible here on account of the limited space available. At any rate the above considerations will throw some light on the importance, development

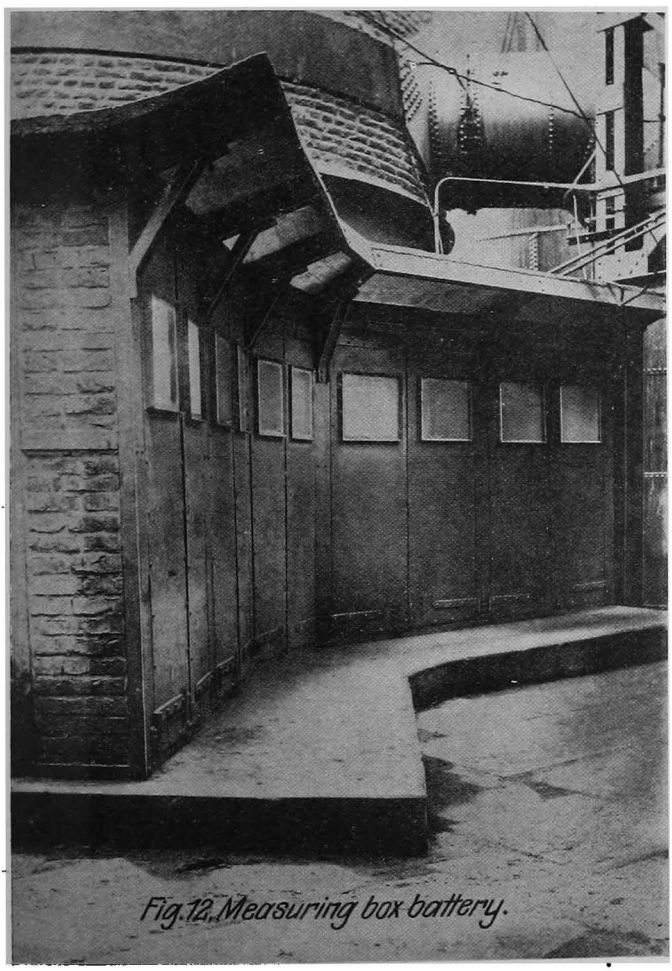


Fig. 12. Measuring box battery.

and the future prospects of economy of blast furnace gas and will show that the question is, like everything else in technical science, progressing continually.

RÉSUMÉ.

Considérant le haut fourneau comme un gazogène l'auteur établit des " coefficients qualitatifs " indiquant la valeur de 1.000 Cal. gaz par rapport à 1.000 Cal. charbon. Il examine le bilan thermique d'une usine métallurgique et en particulier la part prise par le gaz du haut fourneau dans différentes sortes d'usines.

Les possibilités d'amélioration sont ensuite mises en évidence, la fixation des " coefficients qualitatifs " est illustrée par l'exemple d'une centrale de moteurs à gaz avec coefficient d'utilisation variable. Il en déduit sous quelles conditions le moteur à gaz est supérieur resp. inférieur à la turbine à vapeur, même étude pour les soufflantes à gaz et enfin sur l'application des " coefficients qualitatifs " au rendement économique total des gaz du haut-fourneau dans les usines métallurgiques. Cette description est suivie d'une considération sur l'économie réalisée par les chaudières chauffées par les gaz d'échappement des moteurs à gaz. Des remarques détaillées se rapportent à l'équilibrage entre la production variable de gaz et la consommation également variable, mais influencée par des conditions différentes.

A ce sujet le problème d'accumulation de la chaleur est considéré en détail, soit les frais de première installation, le rendement, la simplicité, le réglage et les domaines d'application. Pour terminer, les mesures à prendre pour obtenir une bonne distribution des gaz sont décrites.

GERMAN PRACTICE IN EXHAUST STEAM ENGINEERING.

H. TREITEL

(*a*) The Problem of Exhaust Steam Engineering.

The pressure of steam is reduced either by throttling or else in a prime mover. When steam is throttled its heat content is not altered, whereas in the other case the thermal loss is balanced by a gain in energy. The total heat in the steam at the end of the process is a minimum when the efficiency of energy conversion is a maximum; in the case of a machine working with a condensing plant producing the highest possible vacuum, this minimum is still about 600 kg. cal./kg. (1160 B.T.U. per lb.). Throttling is a waste, because the opportunity of producing energy is missed. *What exhaust steam engineering aims at is: The conversion into useful work of the whole available thermal gradient.* Whereas there is considerable scope for raising the initial pressure, the lower limit is given. It will be shown in the following by what means and to what extent mechanical engineering and German industry in general have been able to profit by the above considerations.

(*b*) The Mechanical Engineering Side of the Problem.

1. *Machines for the Supply of Steam Heating Systems.*

Back-pressure Machines.—In order to avoid condensing by cooling water, the heat of the exhaust steam should be transmitted to substances of a manufacturing process. The most favourable condition would be that the steam delivered after expansion in a prime mover with the required output be, at all times, sufficient for boiling, heating, drying, etc.; but this condition is seldom realised. When more steam is required, which is the simplest condition, the back-pressure machine is utilised to advantage. It has always been used in sugar factories, an industry that was probably the first to develop systematically ideas of heat economy. The old practice in sugar factories was to decentralise, that is, to install back-pressure machines delivering steam at about atmospheric pressure into the last stages of evaporators. Gradually preference was given to centralisation with a single back-pressure

machine to satisfy the whole demand. Progress is being made in the application of back-pressure turbines, working at a higher range of pressure and connected to simplified evaporators; quite recently, vacuum stages for evaporators have been entirely abandoned. Similar conditions prevail in other industries, for instance, in dye-works. For most conditions, reliable data have been collected privately or have been published regarding the amount of steam and the required power for the article produced. Thus an estimate can be made as to how far the live steam pressure must be raised for a specific manufacturing process in order to satisfy the power demand from a back-pressure machine. As an instance of a large back-pressure turbine, a machine may be cited with a capacity of 4,200 kW. taking 42,000 kg. (about 93,000 lbs.) of steam per hour, which is delivered at a back pressure of 1·5 atm. (21·3 lbs. per sq. in.) absolute.

Vacuum Heating.—The energy head extends into the range of vacuum, with the simultaneous use of exhaust steam, in cases and at times when it is possible to employ vacuum heating. Many machines for this purpose are in operation, but steam turbines are not very applicable. The nature of the heating process involves periodic application, and during such times the heat economy is good.

Bleeding Engines.—In some industries the amount of power required, either temporarily or continuously, exceeds that which can be produced with the demand for heating steam. Those are the conditions for which bleeding machines are the most suitable. They were used first in Germany. The first piston engine supplying steam at constant pressure from an intermediate stage with automatic pressure regulation was run in a brewery at Munich, in 1904; the first bleeding turbine was installed, under the supervision of the author, in textile works near Berlin, in 1907. The introduction of these machines was originally hindered by patents, which have since expired, and the machines are now being used very extensively. Of the total number of steam turbines in sizes up to 12,000 kW., supplied during the last five years by the largest manufacturers in Germany, no less than 43% were for the use or delivery of low-pressure steam. Special care must be taken in the design of reducing turbines on account of the uneven distribution of load between the high and low-pressure parts, depending on the fluctuating demand of steam. A stable steam pressure at the point of bleeding, unaffected by variations in load and in the demand for steam, are conditions of many

manufacturing processes. The governing device must be designed to meet these conditions. The speed governor is therefore arranged to control the steam inlet of both the high-pressure and the low-pressure parts simultaneously and in the same sense, whilst the pressure regulator adjusts the admission of steam at both points, also simultaneously, but in opposite ways. For more stringent requirements, the pressure regulator is of the diaphragm type.

The general progress in the construction of steam turbines, which has led to thermo-dynamic improvements in the high-pressure stages, has largely affected the design of bleeding and back-pressure turbines; they are now equal to piston engines, which formerly were considered superior. The size of individual machines has increased considerably. There are several works, chiefly in the chemical industry, with bleeding turbines having an output of 6,000 kW. and delivering 43 tons of steam per hour at a pressure of 4·5 to 6, atm. absolute (64·0 to 85·3 lbs. per sq. in.). Turbines which, in winter, deliver for heating purposes practically all the steam that can be bled and are operated with a condenser in summer, when only a small amount of steam is bled, are, during the main heating period, connected to an auxiliary condenser for condensing the discharge from the glands which passes through the low-pressure cylinder. Another solution for reducing the energy required by the condenser auxiliaries, when delivering the maximum quantity of back-pressure steam, is to admit air into the suction of the cooling-water pump, so that no water is circulated and to remove the small quantity of steam creeping through the intermediate gland by means of a water-jet air pump.

Bleeding Back-Pressure Turbines.—Bleeding turbines are often installed without condensing plant and are then operated also as back-pressure turbines. They are used in factories with systems worked at two different pressures, using back-pressure steam in one system and bleeder steam at a higher pressure in the other. During the periods of maximum demand for high-pressure steam, there may be an insufficiency in the low-pressure system, and to make this good, a supply of steam is admitted through reducing valves controlled by oil-pressure servo-motors and very accurate in operation. They form a good substitute for the unreliable reducing valve generally to be had in the market.

Double Bleeding Engines.—In certain instances, where there are two heating systems at different pressures, it may become impossible to avoid condensing plant when the demand for heat does not coincide with the power demand. For such conditions multiple

cylinder turbines have been developed, delivering steam from two different stages, which are chosen according to the requirements of the particular industry. The pressure at the first bleeding point is from 6 to 8 atm. (85·3 to 113·8 lbs. per sq. inch. gauge); the boiler pressure should be high enough to make the conversion of energy in the high-pressure stage worth while. An arrangement used in pulp mills consists of a bleeding turbine and a back-pressure turbine both on the same shaft. Both turbines are fed with live steam from the boilers, and are governed in such a manner that the pressure at the two points from which the supply of steam is taken remains constant when the load fluctuates; on the other hand, the speed should not be affected when the quantity of steam delivered by the turbine varies. Therefore all three impulses of the control gear are arranged to act simultaneously on to a common system of levers; the design is derived from that used in Germany on the improved type of bleeding turbines. In another instance (paper works), a bleeding back-pressure turbine is coupled to a condensing turbine. A peculiarity of this set is that the coupling can be disconnected, so that the condensing part can remain at a standstill when not wanted; thus the no-load losses for this part of the plant are avoided. If the demand for heat is small compared with that for power, large condensing turbines are installed and, in addition, a reducing turbine of one of the types referred to, which is regulated to deliver steam at a constant steam pressure; the energy it supplies varies according to the demand for steam.

2. *Machines for Feeding Hot Water Systems.*

In some industries—for example, in chemical works, wool-washing and other cleaning processes—there is a very large demand for hot water. Here, the ordinary condensing plant is used for heating water, its circulation being choked either by hand or automatically under the control of thermostats. Storage tanks for equalising the supply and demand are placed between condensing plant and the point of consumption. Storage takes place periodically, and during this time the plant will run with an artificially reduced vacuum, but otherwise with a maximum vacuum. This arrangement is also suitable for small plant such as is required for slaughter-houses, baths, hospitals, etc.

3. *Machines for Working at the Lower Range of Pressure.*

The problem of the production of energy in the lower part of the pressure gradient is one that has been solved long ago by means

of low-pressure and mixed-pressure turbines. As in other countries, numerous machines of this description have been installed in German mines and iron-works, where there is little other use or only temporary use for the exhaust steam from winding engines, rolling mills, etc. By means of very sensitive governors and proper dimensions of the low-pressure part, it has become possible in Germany to do away with nearly all accumulators, which are generally quite ineffective; for new plant they are no longer provided.

(c) Power Economy as Affected by the Utilisation of Exhaust Steam.

Decentralisation.—Power economy in Germany has assumed a distinct peculiarity on account of the many varied systems described above for the utilisation of exhaust steam. On the one hand we see the large power supply undertakings absorbing the small independent power stations. These are not kept running unless their existence can be justified for the purpose of assisting the large base load stations, either at times of peak load, for power factor improvement, or for supplying heat. On the other hand, progress in decentralisation can be observed. Numerous industrial concerns find that they can themselves produce electrical energy at a lower cost by combining the production of power and heat. In the case of back-pressure plant it becomes more profitable to produce power as well as heat, when the power load exceeds 50 H.P.; in the case of bleeding turbines the minimum power load that can be produced profitably is about 300 H.P. A textile factory, for instance, with a large demand for heat, used to purchase power, but was able to save the whole of the expenditure on electrical energy, without increasing its coal consumption, after installing the necessary machines and high-pressure boilers. This change in methods of operation is very desirable from the point of view of national economy. On the other hand, wherever there are industries that do not require exhaust steam, it is equally justifiable for these to shut down their own stations. The consequence of this development is that, as far as the market in Germany is concerned, turbines for *industrial* purposes are only in exceptional cases of the ordinary condensing type.

Linking up of Power Stations under Common Control.

A considerable improvement in the loading of back-pressure turbines can be obtained by electrically linking up all available power stations. There is a group of lignite mines in Central Germany,

for instance, where the power stations of six pits, with a tota capacity of 20,000 kW., are joined to a common high tension rin main. The surplus energy is sufficient to supply a network witl mains of a total length of 800 km. (497 miles), which supplies 30 villages and towns in addition to the local demand of the pits Apart from ordinary difficulties of operating power stations i parallel, new governing problems have to be solved in order t make full use of the power obtainable from back-pressure opera tion. The very frequent short-circuits experienced in open work ings are localised by a selective protective system. The inter connection of these power stations has worked satisfactorily, an the remaining 3,000 kW., still produced by condensing machines will very shortly also be obtained from back-pressure plant sup plied with steam from high-pressure boilers.

Wayleaves.—The difficulty of obtaining permission to cross pub lic roads or privately owned property with steam pipes or electric conductors used to be sufficiently discouraging to render a local interchange of surplus heat or surplus electrical energy almost im possible. The necessity of effecting fuel economy and the wide spread interest that has been taken in all matters referring to heat economy for the last six or seven years, has made the saving of coal an officially acknowledged matter of public interest, so much so that owners of roads and property may be compelled by law to grant the necessary wayleaves if it can be proved that their refusal stands in the way of an appreciable saving in coal. Within the last few years several cases have been known where manufacturers were enabled to link up parts of their works by crossing other people's ground or by carrying their mains under public roads. In some cases the works thus connected are about 500 m. (1,640 feet) apart. In Bavaria, the Government coal office has the right to insist on improvements wherever the heat economy is not satisfactory.

The Purchase of Supplementary Electrical Energy.—The result of this development is that electricity supply undertakings lose the demand of certain groups of consumers. A connection to the supply mains is, however, essential even for works that produce their own current; they must be able to rely on an independent source of supply, both as a standby and in case their own demand exceeds that which can be obtained from their back-pressure plant. From the point of view of heat economy this interchange of energy is undoubtedly good, although it is somewhat in opposition to the interests of the supply concern, and difficulties in

running many private power stations in parallel may be experienced. These difficulties have been overcome in several instances by sub-dividing the plant in the factories, so that individual machines, or groups of machines, can be switched either on to the works' network or the public supply mains.

The Sale of Surplus Electrical Energy.—Cases exist where, instead of having to buy a supplementary supply, factories are in a position to sell their surplus electrical energy, the production costs of which are naturally very low with back-pressure plant. The price of this current will vary widely for sundry reasons, such as the available amount, whether the demand is steady throughout the year or intermittent, the time of the day or season of the year. Supply concerns still often refuse to consider propositions of this description, although they are matters of public interest, a fact which is being continuously and emphatically advanced. A remarkable example was set by an official authority in South Germany during the time of great coal scarcity. For every kilowatt-hour delivered into the public supply mains by private industrial concerns, the authority in question supplied one kg. of good coal. Favourable conditions for the supply of surplus energy exist in sugar factories more than in any other industry. The sugar harvest happens to coincide with the low-water season of public water supply stations. Where water power is developed in mountainous districts, the scarcity of water during the winter months is compensated by the favourable conditions for the supply of power from heating steam plant; whereas in summer a sufficient supply of water is available and no power from steam plant. This coincidence has formed the basis of projects laid out on a large scale, which, however, have not yet been realised.

Power Factor Improvement.—Lively discussions have taken place on the use of induction generators, which can be switched in like motors. The idea was to facilitate the linking up of a large number of small works for the supply of surplus energy. The available surplus output of these generators is, however, intermittent and low, according to the demand for exhaust steam. The practical effect of asynchronous generators in the circuit of a general supply station would therefore be a reduction in capacity, owing to the increased wattless current, rather than an increase in capacity, unless the newly developed compensated induction generators are used. Preference is given, therefore, to synchronous generators carrying a steady and full kilovoltampere load. When the demand for exhaust steam is small, these sets feed a wattless

current into the network, which is paid for according to a special tariff. As an extreme case, mention may be made of the installation of a rotary condenser with a capacity of 7,000 kVA. for improving the transmission of a line 70 km. (43·5 miles) in length. At the time this was installed there was a scarcity of coal, and it was therefore impossible to consider a power station at the point of consumption. The rotary condenser is driven by a back-pressure turbine without raising the coal consumption. The turbine is connected to an existing boiler plant originally used for the supply of steam to gas producers. It may be looked upon as a reducing valve from which power is obtained approximately equivalent to the no-load losses of the rotary condenser. The latter figure is about equal to the saving in energy that is effected by a reduction in the losses of the transmission line. But apart from this, about 40% more current can be transmitted over the line by the arrangement.

Public Supply of Heat.—In conclusion, reference should be made to cases complying with the often repeated claim for power stations to be placed near a market for heating by steam and water. The oldest plant of this kind is at a swimming bath in Stuttgart (1906). These installations are remarkable for the use of the condensing plant for the supply of warm water to buildings at a distance, and for the delivery of bleeding steam from turbines to satisfy a demand in the immediate neighbourhood. The number of stations supplying heat is still very small.

(*d*) MEANS FOR IMPROVING THE THERMAL GRADIENT.

Increase of Pressure.—Anyone considering this question from the standpoint of heat economy and operation will naturally endeavour to avoid the process of condensation with bleeding machines running condensing by using the back-pressure system. The use of higher live steam pressures, which has become possible by the improvements in modern boiler construction, has greatly assisted this development. As early as in 1909, boiler works were called upon to produce a boiler for 18 atm. (256 lbs. per sq. in.), intended for a back-pressure steam engine delivering steam at 5 atm. (71·1 lbs per sq. in. gauge). The plant was installed at a weaving shop in Bavaria. To-day the upper limit of pressure for standard boilers is 35 atm. (497·8 lbs. per sq. in.). The power production in a pulp mill is being rearranged for a single back-pressure machine supplied with steam at 30 atm. The turbine reduces this pressure to 8 atm. (113·8 lbs. per sq. in. gauge), at which

pressure steam is delivered to the digesters, the fluctuating demand of which is equalised by a Ruths accumulator. It is a remarkable fact that for this plant the cost of power is no greater than are the production costs of the same amount of water power.

In chemical works, where the evaporating process necessitates the use of live steam for heating, the conditions were not favourable in comparison. Here also, however, the improvements in boiler construction have led to the introduction of modern back-pressure plant or to the use of high-pressure turbines exhausting into existing steam mains.

Lowering of Back Pressure.—As a rule it is a simple matter and one that can sometimes be effected almost without expenditure, to lower the pressure of the manufacturing steam. Frequently, it is merely a question of overcoming prejudice and tradition. The tyranny of foremen has to be overcome; efforts in this direction were successful as soon as qualified engineers were given a free hand. By increasing the size of pipes and heating surfaces it was possible to reduce pressure losses. With the assistance of manufacturers of textile machines, the heating plant at dye and bleaching works was rearranged for a single heating steam pressure of 2 atm. (28·4 lbs. per sq. in. gauge). In many quarters this is still considered to be impossible.

Three Pressure System.—In cases where the machines are required for a moderate initial pressure only, and for exhaust steam operation, for instance, in connection with winding plant, rolling mills, presses and steam hammers, the pressure range can be extended upwards by adding a high pressure machine, and downwards by using mixed-pressure turbines. A three pressure system of this kind was first introduced at a pit in Westphalia. The back-pressure turbine here receives steam at 20 atm. (284·5 lbs. per sq. in.) pressure and 350°. C. (662° F.), and after expansion delivers this steam at a pressure of 10 atm. (142·2 lbs. per sq. in. gauge) to the medium pressure pipe work; the quantity of steam supplied in this manner is 36,000 kgs. (79,366 lbs.).

Power Production from Steam Vapour.—One of the largest heat-consuming industries in Germany is that of lignite briquette manufacture; it is estimated that a total of about 4,000 tons of water per hour are evaporated in Germany out of the raw material. Experiments have been commenced recently on a large scale to obtain not only energy from the steam before it is used for drying, but further to utilise the heat contained in the evaporated moisture for power production. An interesting feature, from an engineering point of

view, is the use of low pressure exhaust steam turbines operating with steam at an initial pressure of 0·3 atm. abs. (4·3 lbs. per sq. in.). The vapour, which contains a large amount of air and dust, has a temperature of 90° C. (194° F.) when leaving the dryers. A temperature drop to 70° C. (158° F.) is required to separate air and water; the remaining sludgy condensate is then used for evaporating pure steam suitable for use in the turbine. The remarkable feature of this scheme is that an intermediate part of the energy head is employed for a manufacturing process.

Improving the Rankine Cycle.—The improvement of the Rankine Cycle, commonly known as the regenerative cycle and realised by bleeding steam for feed-water heating, has hitherto found a more rapid application in public power stations than in the manufacturing industry. The reason is that the large quantities of condensate obtained from the heating surfaces possess high temperatures and, if economisers are used, can be returned to the boilers without further pre-heating. In Germany, it is considered too complicated to bleed the large prime movers, and the tendency is to provide for a separate bleeder turbine for supplying steam at intermediate pressures kept constant by regulating devices.

(*e*) Exhaust Steam Engineering and Acceleration of Production.

Accumulators.—The engineering progress described above has brought about a reduction in the coal bill, without, however, at the same time producing facilities in operation. Factories demand power and heat, without regard to the steady and therefore economical production of the same. In trade it is necessary to provide for warehouses between the producer and the consumer; in a similar manner it is necessary to equalise supply and demand by the provision of an accumulator between boilers and machines on the one side and the points of consumption on the other side. As a means of equalising peaks and dips, lasting one hour or more, the Ruths accumulator has raised a large amount of interest and has already been installed in many places. Evidence of the popularity of the idea of heat storage in Germany is to be found in the extensive literature on the subject. Apart from the Ruths accumulator, which operates with pressure variations, interest is shown in accumulators connected to the water space in boilers. The usefulness of these accumulators is, however, limited to small steam peaks alternating with periodical drops in load. The Ruths accumulator represents the last stage in the development of

exhaust steam engineering, which may be put briefly as follows: Continuous improvement to efficiencies of individual machines and equipments—interlocking of power and heat economy—acceleration of production by avoiding retarding processes and by devising the best conditions for the production of both steam and energy. This alone gives exhaust steam economy an influence which reaches beyond the coal bill, an item which in many industries does not exceed a few per cent. of the total production costs. Exhaust steam economy thus becomes the determining factor of production.

(*f*) The Mental Powers Furthering the Development.

In Germany the development was brought about by the large electrical and mechanical manufacturers. These firms were the advisers and instructors of the industry, including electricity supply concerns, on all questions relating to heat engineering. In other countries it is considered the duty of the independent consulting engineer to solve the engineering and economical problems. In Germany the manufacturers have become accustomed critically to study the technical and economical requirements of clients. The choice of machines, the connections and regulation of steam circuits, are becoming more and more complicated, especially when boilers working at different pressures and governed accumulators are introduced. There are but few clients that are able to give accurate data on the demand for steam and power over a given time. When preparing propositions, the contractors must therefore make their own careful measurements of the steam produced and consumed at each point on typical days. In several instances turbine manufacturers undertook to build the complete industrial power station with the entire complicated plant for the economical use of exhaust steam.

It is only a few years ago that large industrial concerns have commenced to engage their own specialist for heat economy; to-day, even small industrial combines, such as those for brickworks and potteries, glass works, and lime production, have organised their own departments for dealing with these questions; they exert a valuable and instructive influence by spreading experience gained in other quarters. It is not likely that, even in small works with a purely commercial management, any departure from commonly approved principles as to efficient exhaust steam economy will escape their notice.

The fruit of these labours will finally ripen when economic conditions in Germany have become steady and the factory owner no longer puts aside expert advice with the argument that the speculative risk connected with the expenditure on raw material is sufficient to reduce to a position of small importance all other questions, such as savings in coal consumption and acceleration of production, questions which involve capital outlay.

RÉSUMÉ.

L'auteur passe en revue les constructions mécaniques et les méthodes appliquées en Allemagne pour transformer toute vapeur d'échappement disponible en force motrice et pour éviter les pertes causées par la condensation de la vapeur. Il décrit les procédés employés pour augmenter la pression et démontre combien ces progrès ont influencé, grâce à leur vaste application, la production d'électricité en Allemagne ainsi que les méthodes de la production industrielle.

FUEL ECONOMY AND THE MEASUREMENT OF HIGH TEMPERATURES.

Sir ROBERT HADFIELD, Bt., D.Sc., D.Met., F.R.S., M.Inst.C.E.

SYNOPSIS.

SECTION I. INTRODUCTION.

Importance of fuel economy during the late War and the post-war period; the latter especially in connection with the reduction of manufacturing costs.

Brief reference to past work including the investigation by the Federation of British Industries and work carried out at the Works of Messrs. Hadfields Ltd.

Knowledge of the temperature distribution in fuel consuming plant, one of the most important factors in the study of fuel economy.

The comparative deficiency of knowledge of the effects of high temperature and the importance of research in this direction.

Modern methods of pyrometry and some difficulties in their application.

SECTION II.

SURVEY OF THE FIELDS WHERE PYROMETRY HAS ENABLED ACCURATE HEAT BALANCES TO BE OBTAINED.

(a) Steam Boilers. A field for fuel economy to which much attention has been devoted during the last 50 years, and one that lends itself to accurate scientific measurement on the various items of heat balance.

The scientific possibilities of boiler development are discussed as foreshadowed by the work of prominent pioneers on the subject. Major industrial developments have followed the perfecting of engineering appliances ancillary to the main agent. A brief outline is given of the main developments.

Plant and practice of modern times require refinements in methods of measurements. A brief outline of the salient methods of determining efficiency is given, and the determination of heat lost in the waste gases as revealed by pyrometric and analytical observations of the composition of the gas is the key to the attainment of complete combustion and the proper passage of the gases through the boiler system. Losses due

to unburnt combustible, radiation and conduction from the settings are reviewed.

Limits of accuracy narrowed on temperature measurement rather than on the measurement of fuel energy and the water evaporated. Sources of error reviewed.

The high temperature aspect in boiler operation. Modern tendencies moving towards larger units and outputs call for greater combustion intensities. The relation between temperature and calorific intensity. Variation of calorific intensity with character of fuel. The position of modern research into the constitution and properties of solid and gaseous fuels and its bearing on this question. Directions in which developments may be looked for in regard to improved intensities. Present limitations of materials for refractories and grates. Non-scaling steel.

(b) Forge Furnaces and Furnaces for the Heat Treatment of Steel. Relation between temperature distribution and fuel economy. Errors in determination of temperature distribution in flame furnaces. Flame temperatures and furnace efficiency. Influence of selection of fuel. Effect of recuperation and regeneration. Present position of regenerative and recuperative practice.

Heat transmission problems in furnaces; directions in which developments looked for. Relative influence of radiation and convection. Review of items of heat balance. Question of load.

(c) Open Hearth Furnaces. Review of items of heat balance. Present position of high temperature measurement in steel making.

SECTION III. TEMPERATURE COLOURS.

Estimation of temperature by eye. Both colour and brilliancy are operative. The latter not reproducible in the ordinary form of Temperature Colour Chart which is therefore under a disability, especially at the higher temperatures.

The Author's Temperature Colour Chart; its method of preparation and manner of use. Tests of this chart by practical observations. Some reservations regarding its use. Colour blindness. The description of temperature colours.

The artistic aspect of temperature colours.

SECTION IV. CONCLUSION.

SECTION I.

INTRODUCTION.

It was with considerable pleasure that the author accepted an invitation from the Federation of British Industries to present a paper on the subject of Fuel Economy to this important Conference.

Both from the point of view of conservation of our fuel resources and also what is perhaps of greater consequence at the present time, the efficient and economical operation of fuel consuming plant, the subject is of the highest importance. This is true either of power generation or of manufactures such as the one in which the author is particularly interested, namely steel manufacture.

The author was specially asked to refer to the subject of High Temperatures, a matter quite appropriate in this connection, since the question of fuel economy is largely concerned with the control of the operating temperatures. As the subject of the present paper the author thought, therefore, that the progress of fuel economy might be reviewed, especially referring to the part played by measurement of temperature as a means of investigation and control in this connection.

Although some of the observations made apply more particularly to plant for the manufacture and heat treatment of steel, the author feels they may nevertheless be of interest to power engineers, since the principles of fuel economy are not restricted in their application.

THE FUEL RESEARCH BOARD.

During the late War the question of economy of fuel naturally became a problem of first importance. Under the joint stimulus of the Coal Conservation Committee and the Department of Scientific and Industrial Research, the Fuel Research Board was instituted by the Government in 1918 as a national research organisation for the study of fuel problems. The Board have since undertaken quite a wide field of useful enquiries, and have built at Greenwich a well-equipped station for practical experimentation.

Much credit is due to Sir George Beilby, F.R.S., the former Director of this Research Board, for his work in the past,

including the " James Forrest " Lecture delivered by him in 1921 to the Institution of Civil Engineers on " Fuel Problems of the Future," which was of great interest and should most certainly be read by all those engaged in the study of the subject of Fuel; also to the present Director of the Board, Dr. Lander, who is continuing the valuable work at the Greenwich Research Plant; and to Professor W. A. Bone, F.R.S., to whom the author has been specially indebted for much useful help and guidance in the direction of the scientific study of Fuel Economy questions.

In their report for the years 1918 and 1919 the Fuel Research Board indicated that there existed a considerable knowledge of the methods of fuel economy which could, by means of suitable organisation, be made available to the industries generally, an opinion at that time shared by many of the more prominent workers in the field.

Several large industrial concerns had already made considerable progress in this direction. Organisations of a co-operative character have been established by manufacturers in several Continental countries for the purpose of promoting the economical use of fuel.

THE WORK OF THE FEDERATION OF BRITISH INDUSTRIES.

In this country, and as regards direct practical applications and improved methods, the Federation of British Industries took the lead by establishing a special department to furnish manufacturers with technical advice and assistance on fuel questions. The work of that department, which is now in the fourth year of its existence, has been devoted in the main to questions of steam raising and gas producer practice.

The Federation appointed in Dec., 1919, a Fuel Economy Committee, of which the author is chairman.

Under the guidance of its technical sub-committee, with Professor W. A. Bone, F.R.S., as Chairman, ably assisted by Mr. G. W. Andrew, the technical assistant, and Mr. W. Prescott, considerable success has been achieved as the result of much devotion and attention in the carrying out of the programme of the Council.

The work already accomplished has been of an extensive and varied nature. Enquiries have been made into the more

common errors of manipulation, major questions of development, and the more intricate matters dealing with accessories and control appliances. Research work of a general character has also been carried out on such problems as the generation of producer gas, the efficiency of boiler and steam pipe lagging, and methods of effecting fuel economy.

The Federation also publish the Fuel Economy Review, which is specially devoted to disseminating knowledge and fostering interest in the subject.

Finally, an important function of this organisation has been the help that it has been able to give manufacturers in facilitating the interchange of relevant statistics.

The author's firm, Messrs. Hadfields Ltd., of Sheffield, applied themselves to the problem on their own account and by scientific study of the subject, and with the intelligent co-operation of the workmen were able to achieve considerable economies. The author has referred to this and given some particulars in his Presidential Address to the Society of British Gas Industries in 1918.

THE IMPORTANCE OF HIGH TEMPERATURE RESEARCH.

As previously mentioned, one of the particular factors to be taken care of in all questions of fuel economy is the obtaining of an accurate knowledge and control of the temperatures involved. The study of high temperatures is a subject in itself as so well pointed out by a distinguished authority, Dr. E. F. Northrup, of Trenton, N.J., U.S.A.

Our knowledge of the properties of matter of all kinds at high temperatures is of the scantiest nature compared with that which has been derived from observation at normal everyday temperatures. Dr. Northrup points out the very fruitful field of research in this direction, and indeed it seems in the highest degree desirable to improve our knowledge in this way if only so as to understand better and to be able to control effectively what is going on in the way of chemical and physical reactions in high temperature plant.

THE USE OF PYROMETERS.

However, the author does not propose to digress into its ramifications remote from the present subject. Means for the

accurate measurement of temperature have made considerable strides in the last 20 years, and at the present time there are available efficient pyrometric appliances of various forms and types, adapted, except in some specially difficult circumstances, to practically every requirement. It is not necessary to go into the question of their nature and mode of application. Those interested will find an excellent literature on the subject, and if contemplating the use of pyrometers, or improving their existing installations, they cannot do better than place themselves under the advice of one of the firms who make a speciality of these appliances.

It should be added here that the world generally is greatly indebted to that able French scientist, Professor Henri le Chatelier, F.R.S., for much of the advance which he helped to bring about in this direction.

As showing its importance the Symposium held by the American Institute of Mining and Metallurgical Engineers in September, 1919, required a volume of 700 pages for the report of its proceedings. This Symposium followed the lead set by our own Faraday Society which had previously held, during the occupancy by the author of the Presidential Chair in 1917, a General Discussion on this subject; this was, in his opinion, one of the most successful of the symposia which have formed a prominent feature of the activities of that Society.

As regards the difficulties referred to in the measurement of temperature, these are rather concerned with the means of applying the pyrometer. Although accurate in themselves, and by the use of optical and radiation pyrometers we are able to cover the whole range of temperature involved in manufacturing processes, pyrometers cannot always be applied so as to give a true indication of the temperature of the object. In the case of steel manufacture there is flame which either in the case of the optical pyrometer by its luminous effects affects the readings, or in the case of the thermo-electric pyrometer, may cause the thermo-couple to be heated above the temperature of the object. The temperature in the interior of a large mass if inaccessible to a thermo-couple, is more or less a matter of conjecture; it is not always possible to circumvent these difficulties.

It cannot be too much emphasised that this type of apparatus, i.e., the thermo-electric pyrometer, actually measures not the temperature of the heated object under investigation but of its

own couple. It is in the art of its use necessary to see that the two are in thermal equilibrium with each other.

Finally, on the subject of temperature measurement it should be emphasised that the accurate operation of pyrometers requires considerable intelligence, and, in fact, a knowledge of the scientific principles underlying their use. In the author's firm, where the heat treatment processes have now been under pyrometric control to their great advantage for the past 25 years, it has been found necessary to devote a special laboratory to their care and maintenance under the charge of scientific assistants.

With these preliminary remarks the author proposes to proceed in Section II. with the discussion of the subject from the point of view of fuel economy, endeavouring to draw attention to certain important applications of temperature measurement in this connection.

SECTION II.

A SURVEY OF FIELDS WHERE PYROMETRY HAS ENABLED THE ACCURATE HEAT BALANCES TO BE OBTAINED.

The following remarks are necessarily confined largely to generalisations, based on a wide experience of practical investigation, as to the nature of the problems met with in studying the fuel economy of the appliances mentioned, and as to the methods by which they may be attacked. In a survey of this kind, and of such a wide field, it is not possible nor desirable to go into any considerable degree of detail. No attempt has therefore been made to illustrate the remarks by descriptive matter or test data.

(*a*) STEAM BOILERS. SCOPE FOR ECONOMY IN MODERN BOILER PRACTICE.

The accurate determination of heat balances of boiler plant as well as fairly complete tests made for a variety of reasons, has raised this branch of fuel economy to the forefront amongst the latest efforts to reduce the waste of our greatest national mineral asset. If the results of test runs may be taken as an index of the practical limits so far attainable, then the absolute fuel consumption of the boiler room cannot be reduced much beyond something of the order of 10% of the present consumption. There is, however, a much larger margin still to

be recovered in many installations if we consider that quite average practice leaves 25% of the original heat of the coal capable of being utilised.

It is proposed in this survey to discuss in particular those directions in which the tracking down of the heat units depends upon some form of temperature measurement, and to show what bearing our main theme has upon the accurate determination of the heat balance. Since the first introduction of steam raising, efforts have been made to study the economy of new developments by test runs. In particular, quite early efforts were made under the patronage of the Industrial Association of Mulhouse, in France, to carry out numerous trials on the steaming efficiency of the steam boiler.*

Since that time authoritative bodies in this country and abroad have drawn up comprehensive codes for boiler testing, and the general subject of fuel control in boiler rooms has been receiving increasing attention at the meetings of technical organisations. It is proposed to outline these remarks from a dual aspect, one, the carrying out of such routine tests as may ensure continuous control, and the other, the reviewing of certain directions in which further scientific development of boiler plant may take place.

PAST DEVELOPMENTS.

The developments of the boiler as a thermal machine have been relatively few. The earliest types of boilers were little more than containers, for example, the Haystack boiler of Newcomen (1720), the Wagon boiler of Watt (1770). The first internally fired boiler, the Cornish, appeared in 1810, and its natural descendant, the Lancashire, in 1844. The latter for the reason of its great reliability, simplicity and low upkeep charge, still maintains a popularity in this country. The many developments of the firetube boiler have been gleaned from a wide field of engineering experience, an important part of which field has been the very searching conditions of marine practice.

The progress of the water tube boiler has been closely associated with the development of the mechanical stoker, a com-

* A very interesting account of the history of these early attempts was recently made by M. Kammerer: "Standard Method for Boiler Trials," read at the Congress of Industrial Heating, Paris, 1923, to the English translation of whose paper the reader is referred. See "Fuel Economy Review," Vol. 3, No. 3, December, 1923, page 3.

bination called for in modern practice by the utilisation of low grade fuels and high superheat. The development of the economiser, an appliance almost as old as the Lancashire boiler itself, together with the superheater, has prolonged the reign of the cylindrical boiler. These major developments have followed the perfecting of engineering appliances ancillary to the main agent. The most notable attempt of recent times has been the experimental study of the mercury vapour boiler, but the scarcity of working fluid seems to put such a development out of the court of practical affairs.

TWO MAIN PRINCIPLES FOR FUTURE DEVELOPMENTS.

Perry put forward the view 25 years ago[1] that the bulk of the working fluid which is used in power production by steam was absurdly large. He indicated that the " best boiler would probably be one in which a flame or hot gas tube surrounds or is surrounded by a water tube, with gas and water flowing fast in opposite directions."

The idea that at the surface of contact between a fluid and a solid there is a " dead " film of relatively stationary fluid, which becomes thinner as the velocity of the fluid parallel to the surface increases and breaks away eventually at very high velocities, has long been appreciated. The first mention of its existence was made by Peclet in 1844. Nicholson[2] following the suggestion of Osborne Reynolds, demonstrated the effect of high gas velocities in destroying this film and thereby increasing the rate of heat transmission. He put his ideas into practice in a boiler of which a lucid account is given in Bone's " Coal and its Scientific Uses."[3]

Dalby[4] has demonstrated theoretically that, making use of heat transmission by radiation from a source at 3,000°F. to a boundary surface at 800°F., an equivalent evaporation as high as 134 lbs. of water per hour could be obtained for each square foot of heating surface. The principle received industrial application in the Bonecourt Surface Combustion Boiler erected at Skinningrove in 1911; this gave an efficiency on a net basis of the heat in the gaseous fuel used of 92·7%[5] though

[1] " The Steam Engine," by John Perry. McMillan & Co. 1909.
[2] Mem. Lit. Phil. Soc., Manchester (1875). Vol. XIV. Page 7.
[3] " Coal and its Scientific Uses," by W. A. Bone. Longman, Green and Co. 1918 Page 211.
[4] Proc. Inst. Mech. Eng., 1909. Page 923.
[5] " Coal and its Scientific Uses." Page 465.

the evaporation only reached 14·1 lbs. per square foot of heating surface per hour. Rates of evaporation are still far behind that theoretically realizable as a maximum, but developments are moving on progressive lines in these directions. The difficulty at present is the danger of burning away the material of the tubes themselves. Hence, either improved means of circulation must be provided or some non-scaling material must be found. The latter is a question for the metallurgist, and the progress made in this direction is referred to later.

The laws governing the production and transfer of heat are generally well known, but improvement of design will also follow the development of quantitative data in regard to the co-efficients of heat transfer and equations necessary for the solution of any specific problems.

DEMANDS FOR THERMAL MEASUREMENTS IN MODERN PRACTICE.

The modern boiler house has become a factory in itself devoted to the manufacture of steam, equipped with numerous auxiliaries, including possibly air-heaters, and induced draught fans. There are also a multitude of other appliances and recording instruments whose function it is to keep going a constant enquiry into the thermal efficiency of the plant. These final developments of plant and practice of modern times require a refinement in methods of measurements. Fortunately for each boiler the approximate determination of its performance is a simple matter.

DETERMINATION OF EFFICIENCY.

The main criterion of efficient boiler operation is the evaporation per unit of fuel fired. This remained in the earlier years of boiler history a question of weight or volume evaporated, and pressure, together with the weight of the fuel fired. Apart from other aspects, the rapid growth in the size of the boiler unit, and the increasing use of the superheater, made it imperative that our standard of estimating boiler performances should be raised. To instance the present limits of these developments we may say that there are in America water tube boilers recently equipped or proposed, capable of evaporating 400,000 lbs. of water per hour, and they are to work at a guaranteed efficiency of 85%.

EFFECT OF LOAD ON EFFICIENCY.

Most of the published data in recording the tests of boiler performance have been made under favourable conditions. The type of test which is most valuable for the purposes of fuel economy is that which covers the boiler operation under normal conditions, for it is often found that the operating conditions, particularly in regard to load, have a far greater effect on the efficiency of the boiler than may be obtained by minor modifications of the plant itself. It cannot be over emphasised that a steam boiler, like any other machine, will work most efficiently under a particular load. Those familiar with routine testing are well aware of quite considerable variations due to such a class of circumstances. It is thus evident that much stands to be gained by the practice of constantly controlling operations of the plant by measurements of this kind. Movement is growing rapidly and invading those plants where hitherto the only means of control has been a watchful eye on the pressure gauge, the water gauge, and the blow-off valve.

LIMITS OF ACCURACY.

The basic measurements of boiler evaporation are, the weight of the fuel, its heating value, the weight of water evaporated, and its heat capacity. It is in the estimate of the heat capacity of the steam that the need for accurate thermometric measurement arises. Much fundamental work of the highest rank has been devoted to the absolute measurement of the heat content of steam, and there are available steam tables, the accuracy of which is within the desirable limits for practical purposes.

The error in the measurement of the temperature of the steam is not large, and in fact there are many other aspects of the subject where less accuracy is permissible. The accuracy of the observations depends rather upon getting the true average of the fluctuations. There are refinements for determining such values as the moisture in the steam in which thermometric measurements are necessary, e.g., the throttling calorimeter, but these matters are common knowledge.

Again, for routine records of steam plant efficiency seasonal variations of the temperature of the feed water and make-up must be observed. This calls for recording instruments of which fairly reliable types are available, notably those based on the principle of the relative expansion of a metal spiral, the

movement being communicated to a lever magnifying attachment recording on a rotating disc chart. It is even within the limits of normal accuracy to place such an instrument within a feed tank.

In order to be within desirable limits of accuracy, say $\pm 0{\cdot}5\%$ on the final efficiency, it is only necessary to know pressures and temperatures to within a few units (lbs. per square inch and °F.) for there are other directions in which larger errors may creep in more readily, namely, in the estimate of the heating value of the fuel (sampling difficulties), volume of water metered, etc., and with multiplicity of factors there follows multiplicity of error.

THE HEAT BALANCE.

It is not sufficient to know merely the efficiency of the boiler under any given load. If we are to take the accurate heat balances as our means of pursuing our object, then a knowledge of what has become of the waste heat is necessary.

It has been said by some authorities that efforts to obtain what they described as a cumbersome heat balance are unnecessary, implying that the determination of the thermal efficiency of the boiler (or the boiler and its auxiliaries) in terms of heat in the form of steam raised as a ratio of the gross calorific value of the fuel, is sufficient for either control or development purposes. The author does not however, subscribe to this point of view, for it is only by turning the loss into useful heat that improvements in efficiency can be obtained, and it is readily possible to arrive at a sufficient estimate for practical purposes of the various channels of waste heat.

THE CHIMNEY LOSSES.

Of these losses the greatest is the chimney loss; it is made up of the loss of sensible heat of the waste gases, and the loss of heat as unburnt combustible. The former may vary anything between 10 to 25% of the heat supplied. The latter may even be of the order of 10% in bad practice. It is in the determination of the losses of sensible heat in the products of combustion that the measurement of the temperature of the waste gases becomes all important. Accurate pyrometry (using these words with a full sense of their meaning), and a thorough survey of the question of stratification of the gases in the flues, are of paramount importance if the full value of its

important aid to economy is to be realised. This question of stratification has been exhaustively explored by the engineers of the United States Bureau of Mines, and their observations are reported in Bulletin No. 97. Knowledge of the composition of waste gases in combination with pyrometer measurements is the key to complete combustion, and of the proper passage of the gases through the boiler system, thereby ensuring that the maximum opportunity for heat transfer has been made possible. Satisfactory controlling instruments for this purpose, namely, CO_2 recorders, and recording pyrometers are now available. Carbon monoxide recorders are also available, but it cannot be said that their use is yet appreciable in extent.

THE USE OF TIME SAVING GRAPHICAL METHODS.

By the use of graphical methods the results of the pyrometric measurement and gas analysis may rapidly be converted into terms of heat lost. A series of curves showing the relation between CO_2, the excess air and the temperature of the gases having been plotted for the range of composition of the coals commonly in use at a given installation, it only becomes a matter of brief reference to these. The laborious calculations otherwise involved are finished with once the charts are prepared. For quite a wide range of heating value of the fuel, say from 11,000 B.Th.U. per lb. to 14,400, the possible error is of the order of 1% and does not exceed 2% of the total heat input to the boiler, a result quite within the requirements of practice. Charts of such a character were exhibited by the author's firm, Messrs. Hadfields, Ltd., Sheffield, at the Institution of Mechanical Engineers in June, 1921. The Fuel Department of the Federation of British Industries also published charts for the same purpose in the Fuel Economy Review for February, 1923.

ERRORS IN PYROMETRIC MEASUREMENTS ON GASEOUS STREAMS.

It need hardly be pointed out that any scientific instrument is valueless unless the necessary care in use and periodic check of accuracy is carried out. This applies in particular to the thermo-couple type of instrument. There are other types of instruments which may be used, notably mercury thermometers, protected in an iron sheath—but for routine work on large installations there is, in our opinion, no type to equal the thermo-couple type. The recording or indicating instrument

may be placed at the most convenient point, and it is only a question of wiring up to enable observations to be taken at any number of selected points.

In measuring the temperature of hot gases surrounded by colder surfaces with a pyrometer, the temperature indicated by the instrument is always too low, for although heat is imparted to the exposed element by the hot gases, being taken up by convection and conduction of the sensible heat in them, heat is also lost from the measuring instrument to the colder walls of the furnace by radiation. There is also the possibility of heat loss by conduction along the pyrometer rod. The rates of conduction and radiation and the error are diminished as the element is made smaller, but strictly speaking, for absolute accuracy, observation would have to be extrapolated to an instrument of insignificant size. The chief cause of such discrepancies arises from the necessary protecting tubes which must be used to protect the vital parts of the pyrometer. Actual errors vary with conditions. The United States Bureau of Mines investigation found 20°F. to be the average error in boiler flues.

On the other hand, the error due to stratification of the gases may be of the order of 1% of CO_2. Thus it may be seen that such an item of the heat balance does not compare in accuracy with the limits obtainable in the cases of the values for evaporation efficiencies. A necessary safeguard is an exploration of the stratification in the flue at which the observations are to be taken. This applies both to the observations of temperature and of gas composition.

UNBURNT COMBUSTIBLE.

Soot losses although appearing in the heat balance directly as of minor value, operate in a major and indirect manner by reducing heat transmission through boiler plates or tubes, or through flues, and this adverse influence is reflected in increased losses as revealed by the temperature of the waste gases.

Losses in unburnt combustible in the ash of a boiler furnace fired with solid fuel are commonly in the region of 2 to 3%, but may extend to as much as about 10% under unsatisfactory conditions. Such losses, however, come in a different category, and are generally due either to unsuitable fuel or to over driving.

OTHER LOSSES.

As to the amount of loss of heat by conduction, convection and radiation from the settings, this is usually in practice arrived at by difference, but for the accurate estimation of relative losses in various parts of the installation some form of thermometric measurement is necessary. Such observations do not fall into one's general scheme of routine control. They constitute a field for separate investigation and become essentially a question of initial design and construction. It is, however, a field in which much data of an absolute type is required.

There are two main methods of attacking the subject on an industrial scale, one by the use of some form of radiation calorimeter, and the other by determining the temperature of the surfaces, and from a knowledge of the emissivity constants of the materials and the convection conditions of the surrounding atmosphere, to calculate the heat lost by these means. In a paper before the Iron and Steel Institute in 1919* a method was outlined which gave sufficiently satisfactory results from the practical standpoint. The chief difficulty in the second method is in obtaining contact instruments which when used do not become erroneous. This branch of the subject is of more importance in furnace work.

FUEL EFFICIENCY.

There is an important aspect of the data as regards the heating value of the fuel to be borne in mind. By the determination of the calorific value of the fuel by the usual calorimetric methods the gross value is usually taken, as the determination of the net value involves more complicated analysis—the estimation of the hydrogen. It is often found, however, that the usefulness of a fuel, other things being equal, is not *pro rata* with its heating value as thus determined. This is especially so in the case of furnaces. The author has observed instances where a fuel has given superior results far in advance of any improvement in calorific value. The factors involved are dominantly the clinkering and caking porperties of the fuel in the cases of solid fuel, which determine the rate and completeness of its combustion.

* Hadfield and Sarjant, "Fuel Control in Metallurgical Furnaces." Journ. I.S.I. II., Vol. C. Page 61 (1919).

Damour* has dealt with this subject and suggested that a "utility value" be determined for each fuel by reason of the variable conditions of combustion and operation inherent in furnace practice. He makes the plant itself virtually the calorimeter, and measures the consumption of fuel giving the same production and thermal effect in a given furnace. Presumably the principle applies also in the generation of power. There is much to be said for this method from the practical standpoint. It involves particular attention to those aspects of the heat balance on which we are attempting to focus attention. It gives a direct index of the combustibility and suitability of the fuel, and evaluates a factor not readily estimated by any other method. However, it also involves a knowledge of temperatures of combustion, a subject about which all too little is known.

THE HIGHER TEMPERATURE ASPECT IN BOILER OPERATION.

Higher efficiencies in a given plant are to be attained by higher combustion intensities. Excluding the slight changes in the specific heat of gases with change of temperature, the efficiency of any furnace system is given by the ratio of the difference between the initial and final temperatures of the heating gases to the initial temperature. There is thus available by the measurement of two temperatures a ready and rapid means of determining efficiency. The significance of radiation and turbulence in this respect has already been indicated. The relative calorific intensities of powdered fuel, oil, coke, gaseous fuels and a wide range of bituminous fuels are appreciated in a general manner by the effect of their combustion on the refractories of the combustion chamber. In the Iron and Steel Institute paper cited, one of the tables shows the relative volumes of air necessary to produce 1,000 B.Th.U., and a table of calorific intensities of gaseous fuels of varying composition. The former values showed only a 10% variation in the selected coals—a difference instancing the fact not realized as frequently as it might be in practice—that with known combustion conditions the input of air is a fair index of the heat input. But any increment of calorific intensity is of greater significance because the gradient of temperature of the gaseous heating medium to that of the medium heated determines the rate of heat transmission. In order to clarify our views on this important

* "Le Chauffage Industriel et les Fours à gaz."

question it is necessary to consider the mechanism of the combustion in a boiler furnace from two aspects, one, the generation of gas from the fuel, two, the combustion of the volatile combustibles produced, for approximately only half of the air necessary for complete combustion is used in the gasification process. Thus the considerations which apply to producer gas generation apply in any furnace fire.

THE CONSTITUTION OF THE FUEL.

In recent years much more attention has been given to the constitution of the fuel itself, and whilst the incentive to this study has been the need for improved methods of the carbonisation of coal the knowledge gained has an important bearing on our problem. The behaviour of the macro constituents themselves on being heated determines the burning properties of the fuel, and if more attention were devoted to this aspect of the subject, the question of the selection of fuel for specific purposes would become a much more simple matter. A simple coking test on the fuel tells one much as to the probable behaviour of a coal in a furnace.

The determination of the volatile matter has long been regarded as a test almost as important as that of the ash and moisture, and more recently the relative values of the fixed carbon, the volatile matter and hygroscopic moisture have entered into the bases of classification. Reference is made rather to an inspection of the physical character of the coke produced, considered in conjunction with the quantitative data.

The characteristics of " swift," caking, non-caking or neutral fuels all have their explanation in the nature of the various macro-constituents of the fuel. There are questions of size which also determine the resistance of the fuel bed, but this is controllable by its thickness. A research is needed into the necessary combustion space required for the combustion of British coals at various rates of combustion and for varying proportions of excess air on the lines carried out on American coals by the U.S.A. Bureau of Mines and reported in Technical Paper 137.

The Fuel Research Board in this country has publicly welcomed suggestions, so that the foregoing proposal might well be considered by them, as it could very well be run in conjunction with the present chemical survey of our coalfields.

FLAME TEMPERATURE.

Until there are accepted means of determining the true calorific intensities of fuels it is necessary to judge of these values by taking the ratio of the total available heat of combustion of the fuel to the heat capacity of the products of combustion. That this figure is much in advance of the true flame temperature is well known. The experimental attempts to measure flame temperatures have been necessarily confined to laboratory experiments in which the conditions of works practice are not entirely reproducible. The temperature as given by an optical pyrometer will depend on the thickness and density of the flame as well as upon its reflecting and absorbing powers.

An approximate method for determining the true flame temperature based on the experiments of Von Helmholz on the radiation from flame has been demonstrated by Bone.[1] The values of relative calorific intensities of gas-air flames thus determined fell within the same range as the experimental determinations of Féry and others.[2] However, Féry found values for the bunsen flames of coal gas varying from 1710° to 1870° for various air adjustments. In a small experimental furnace at the author's laboratories there has been obtained a temperature of 1800° with Sheffield city gas, and even as high as 1700° by the single use of a blast burner of his own design coupled directly to the low pressure gas supply, the realisable calorific intensity depending upon the manner of mixing the gas and air.

THE NEED FOR IMPROVED MATERIALS OF CONSTRUCTION.

The utilisation of high calorific intensities in boiler operation depends upon improvements in the material of which the furnace chamber is constructed, i.e., both refractories, and metallic materials. It calls for the provision of a double wall to the furnace chamber, refractoriness being the primary consideration for the inner lining, heat insulation that of the outer; it has not yet been found possible to obtain in one and the same material the maximum development of these two properties. It has been pointed out that there is a limit to the practical

[1] "Coal and its Scientific Uses," Page 260.
[2] "Measurement of High Temperature," Burgess and Le Chatelier, Pages 338, 485.

intensities of evaporation by reason of the failure of the tubes in the case of water tube boilers.

The application of the air heater to boiler plants is a growing development, though at present it appears that the range of actual improvement in efficiency is in the region of 5%. But further application of this type of accessory to increase the output of steam will be more readily possible when the use of special non-scaling materials becomes general practice on mechanical stokers. The fusion ranges of the low grade fuels often burnt on such appliances have to be considered, but the running of a fusible slag through the bars is no disadvantage if such bars are not attacked by the fused ash. Indeed the lines of progress mentioned call for special improved materials in all directions, and with high rates of evaporation should become an economical proposition.

Engineers will therefore be interested to learn that as regards the provision of steel capable of withstanding high temperatures, this is now an accomplished fact.

This advance has been due to the important research work carried out over many years by a group of eminent French Metallurgists, including Mr. Chevenard, of the Commentry Fourchambault et Decazeville Company, also Messrs. Guillaume, Fayol, Muguet and Girin. The rights to manufacture within the British Empire what is known as the "A.T.V." material have been placed in the hands of the author's firm, who are themselves also further trying to improve and develop these special products.

This material is not only practically non-scaling at temperatures up to or even exceeding 1050° Centigrade, but is also resistant to the action of the sulphurous products of combustion, in this respect comparing favourably with the more expensive materials of the non-ferrous type known as Nickel-Chromium Alloys. The steel also possesses remarkably high strength and tenacity at even up to about 900°C., at which, as is well known, the strength of ordinary steel is practically negligible. This is another factor of considerable importance because steel intended for use at high working temperatures must remain rigid.

This material has already found a considerable variety of uses, two of which are illustrated in the accompanying Figures 1 and 2. Figure 2 demonstrates very clearly its non-scaling characteristics as compared with ordinary steel. Its use for

the specific applications referred to above, especially for Recuperator Tubes which can be produced in the form of castings, is being seriously considered, and a number of articles of different types are being put to practical test. It is fully expected that they will lead to material improvements in the operative efficiency of furnaces.

(*b*) FORGE FURNACES AND FURNACES FOR THE HEAT TREATMENT OF STEEL. TEMPERATURE MEASUREMENT AND FUEL ECONOMY.

In furnaces of this type the measurement of temperature is an all important factor. The metallurgical requirements demand almost rigid conditions of temperature distribution. This is also happily in the interests of fuel economy, going a long way towards reducing controllable operation losses.

Advances in this branch of fuel economy have in the past largely been on empirical lines—necessarily so by reason of the complicated character of the subject. In the design of the plant itself, progress has had to follow almost on lines of guesswork, each step having to be proved out under the confusing conditions of practice which often vary considerably from place to place. There is not always that close co-operation between the user and the designer that is necessary to enable the latter to take into account more precisely the influence of the many variable factors met with in practice. In recent years, however, notable efforts have been made to put the technology of furnace design and practice on a more rational basis. The pioneer work of Groume Grjimailo* dealing with the study of the flow of hot gases in furnaces is now becoming more generally known, and the leaven of this knowledge is working. The fundamental laws of the radiation, convection and conduction of heat are more or less understood, so are fundamental essentials in regard to gasification and combustion. The need of the moment is the application of this existing knowledge to the practical problems of the works.

Consideration of the applicable law of probability will answer whether "hit and miss" or systematic methods are to be the more successful.

In this paper the author wishes to avoid separating those methods of measurement which require the use of instruments

* W. E. Groume Grjimailo, "Fours à Flammes," French Translation by L. Douglatch and A. Rothstein. Dunod & Pinat, Paris. 1914.

of precision, and systematic methods undertaken by that most wonderful of all instruments, the human faculty. In the practical affairs of a works where the operative factors are many and varied we regard the former rather as an aid to and not as a substitute for the latter.

The individual, for example, using the pyrometer, the pressure gauge or the CO_2 Recorder must temper his faith in the infallibility of his tools with his own observational capacity. Accordingly in pursuing the aim for measurement rather than guesswork we all look forward to the day when it will be possible to have furnace practice on as precise a basis as that now possible in the boiler room.

FURNACE EFFICIENCY.

For common purposes of comparison it is the rule to judge of the operation of a furnace in the rather approximate terms of tonnage output and fuel consumed, but for the more detailed study of cause and effect which is to point the way to methods of economy means analogous to those described in the section on steam boilers must be used. There is sometimes confusion as to what is understood by the efficiency of a furnace. Richards* has distinguished between what he calls the "generic efficiency" and the "specific efficiency," the first, referring to furnaces "in which the object is to maintain a certain temperature for a certain time with a minimum consumption of fuel, and the second in which the object is to perform a certain thermal operation with the smallest consumption of fuel."

Again the relation of the furnace to the shop conditions is often a prime factor in deciding its operation; its efficiency then has to be judged in a general sense. The best "general efficiency" may not be consistent with the best "thermal efficiency." The aim of furnace design and operation should be to reconcile the two. Thus in heat treatment it is often realised that a particular operation is thermally inefficient. In fact, there are probably millions of tons of coal used annually for operations in which the thermal efficiency of the process, expressed as heat utilised in the material heated to the total heat input is less than 15%. The inversion of this figure to represent the heat wasted rather than the heat used is perhaps far distant, but not impossible in certain cases.

* J. W. Richards, "Metallurgical Calculations," Page 104.

TEMPERATURE MEASUREMENT IN THE FURNACE.

In determining the temperature of gaseous streams the radiation from hot material in the furnace introduces an element of uncertainty, but as regards the hot materials themselves, the optical pyrometer is a safe guide; where its use is not expedient, since it implies a more skilled control, recourse must be had to the naked eye. The lag in the thermo-couple type of instrument and the correct placing of the instrument in the furnace are points of importance already referred to. The flow of hot gases must be taken into consideration, and the effect of radiation from hot surfaces. As regards temperatures in the interior of the material heated, this is a subject about which more quantitative data of a general type is required. It is perhaps surprising that considering the importance of the subject more efforts to correlate the useful methods of a Fourier analysis with experimental data have not been made. Contributory reasons have been probably the facts, that it is relatively a simple matter to ensure uniformity in temperature by soaking, and that such treatment is often demanded by purely metallurgical considerations. Further, the soaking times necessary may be judged in quite a ready manner from rates of heating and observations of behaviour in forging or rolling in cases where the material is worked down.

FLAME TEMPERATURE AND FURNACE EFFICIENCY.

The bearing of flame temperature and temperature drop of the hot gases on the rate of heat transmission has already been discussed. It applies with even more importance in furnace operation, for to arrive at the dimensions of the working chamber for any given load the heat transmission factor must be known. This has generally been arrived at for any given class of furnace in an empirical manner, from experience in the performance of previous furnaces. To obtain a quantitative expression of the fundamental laws governing the flow of heat from the hot gaseous stream to the medium heated is a complicated problem. The Russian scientists Groume Grjimailo and Yesmann have attempted to solve the problem from the analogy of hydraulic flow. They take as the starting point a temperature drop arrived at from general observation, calculate the flow of hot gases necessary to heat the charge, and then

* Loc. cit.

from formulæ based on laws of hydraulics fix the furnace dimensions necessary to make the heating fluid completely bathe the charge. Verdeaux† has also studied the influence of the thickness of the stream and the velocity of the gases. Thus he found that in a normal heating fluid the thickness of the truly active current is limited to a region of 200 mm., or 8″. There exists an analogy in the case of the fire tube boiler in regard to the diameter of the tubes, or the " hydraulic mean depth " of the gaseous stream. In regard to the second factor Verdeaux found that " the influence of velocity improves convection and counterbalances the effect of a shorter period of action."

The temperature gradient in the furnace is thus the chief criterion of its operation. It may be governed by limiting conditions demanded by the process. For example, in the heating of ferrous metals excessive intensities are at times harmful. Thus in heating high carbon steels a " soft " flame and reducing conditions are essential, which again in the present state of knowledge is purely a question for the eye of the operator. The manner of mixing of the combustible gas and air governs these conditions to a large extent. Delayed mixing, by which the natural effects of convection flow are made use of by suitable spacing of the ports, is an advantage in this type of flame; or means may be taken to bring about an induction of the cooler burnt gases in the furnace into the hot stream. A certain amount of viscous drag and convection eddying is inseparable from a slow moving bulky flame, and gives the desired " roll " to it. In general it may be said that flame intensity in furnaces depends primarily upon physical questions of fluid flow. The total input of heat and the maximum realisable flame intensity must of course be determined by the chemical factor of the composition of the gas.

The natural speed of flame propagation, to which much attention has been devoted of late in connection with mine explosions, must of course also be a governing factor, particularly in flames rich in hydrocarbons, in which the secondary " water gas reaction " results in the formation of relatively high proportions of slow burning carbon monoxide. However, the main desideratum of the " reducing flame " referred to is the free carbon, particles of which burn slowly because of the

† Revue de Metallurgie, 5, 312 (1920).

relatively large volumes of air that they must come in contact with for combustion, and the reduced mass action effect of the oxygen in the tail of the flame.

SELECTION OF FUEL.

By suitable adjustment of combustion chamber dimensions to those of furnace chamber, practically any fuel may be applied to any given furnace problem. It mostly happens that the choice of fuel is governed by local conditions of supply. But the best economy is obtained by adjusting furnace conditions to make use of the highest calorific intensity the fuel is capable of giving. Certain fuels lend themselves most suitably to certain operations. Thus, highly volatile coals of a non-caking character are particularly adaptable to direct firing in short period intermittent furnaces. There are certain seams of coal in the Notts and Derby Coalfields which provide excellent producer coals, by reason of the fact that whilst they are sufficiently non-caking to eliminate channelling, they yield a coke of sufficient strength and porosity to ensure an even distribution of the blast in the fuel bed. The use of powdered fuel for the high intensity work of the cement kiln found its application long ago in this country, whereas, its development for the lower temperature requirements of the forge and heat treatment furnace has hitherto been slow. The use of oil and town's gas for the smaller type of furnace has become established, whilst producer gas will continue to hold its own for those larger furnaces of the continuous type which justify the use of the recuperator or regenerator.

RECUPERATION AND REGENERATION.

The main problem in any thermal machine is to develop the heat at the point at which it is required. However, in high temperature operation there must necessarily be a very high loss of sensible heat in the products of combustion coming from the furnace chamber calling for some preheating or regenerative device. The proportion of heat saved by the use of this principle can be deduced approximately by measuring the exit and entrance temperatures of the waste gases and air passing through the recuperative appliance. The additional effect of preheating of the combustion air in attaining higher calorific intensities and

Fig. 1.

Cast Carbonising Boxes with Lids of "ERA" ATV Non-Scaling Steel.

These Boxes withstand without scaling repeated heatings to, and continuous long exposure at, temperatures of 1,000°C.

in saving heat by improved combustion conditions is less tangible but real.

The regenerator acting as a flywheel tending to smooth out those fluctuations of heating which are to be avoided in furnace heating, and serving as a reservoir of heat, can only achieve its maximum efficiency in continuous working. The question of the design and dimensions of these appliances has been the subject of much inquiry. More recently mathematical solutions have been attempted, though it is realized that such methods can only serve to indicate lines of progress in so intricate a subject. Again, thermal considerations are limited by other properties of the refractories to be used, such as refractoriness, mechanical strength and resistance to spalling, chemical corrosion and abrasion. It has also been realized that there are limiting dimensions and arrangements of chequer work beyond which it is not economically advantageous to go. Thus analytical study of the thermal properties of various classes of brick have shown that the "brick efficiency" depends upon the dimensions and times of reversal. For example, 95% saturation of a silica brick is attained in 15 minute reversals, and 20 minutes for fire brick under normal conditions. These figures apply to $2\frac{1}{2}''$ bricks, whereas for $3''$ bricks the times become 20 and 30 minutes respectively. Provided it is practicable to measure the gas temperatures within required limits of accuracy, the proportion of heat recovered is given by the ratio of the temperature drop through the regenerator to the initial temperature of the ingoing heating gases, and the heat returned to the furnace by the rise in temperature of the heated air and a knowledge of the flow of gas and air. However, again the best thermal efficiency of the regenerative system may not be consistent with the best general efficiency of the furnace and its accessories as a whole. For example, a higher temperature of regeneration may only be attained at the expense of a higher outlet temperature of the waste gases. The point is well illustrated by the provision of waste heat boilers in the latest type of Open Hearth construction, as put forward by Clements in this country, and Kinney and McDermott in America.

The regenerator as usually constructed is a compromise between the demands of thermal and mechanical considerations, and it is for this reason that the orthodox methods of design have been more empirical than they might have been

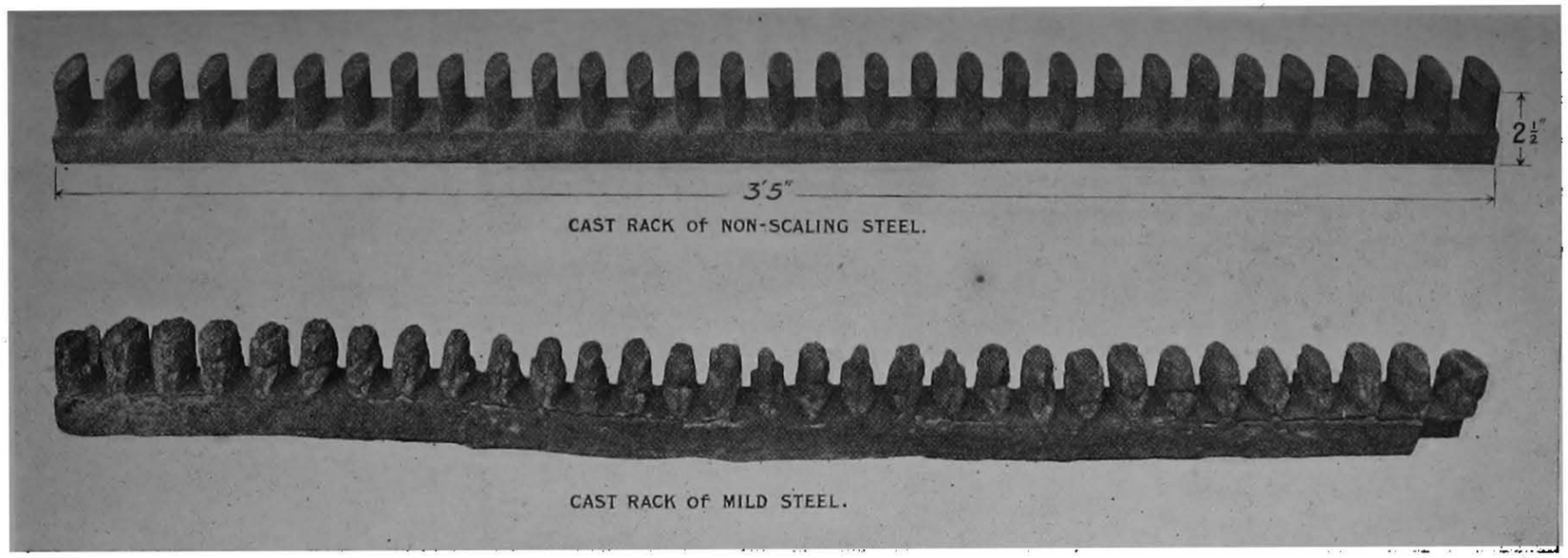


Fig. 2.

Comparison of Cast Furnace Racks of $\frac{\text{"ERA"}}{\text{ATV}}$ Non-Scaling and Ordinary Steels.

These Racks have been in use in a Spring Hardening Furnace for a period of 12 weeks, working at a temperature of about 900°C.

The Cast Steel Rack at the end of this period was so much oxidised as to be of no further use.

The Rack of Non-Scaling Steel was hardly affected. It has since been in use for a further period of 16 weeks, that is 28 weeks in all, and, according to present appearances, will last indefinitely.

Finally to cite but one line of development of considerable importance:—whilst the influence of the velocity of the gases has been exhaustively studied in regard to heat transmission in boiler tubes, little is known of any definite quantitative character with regard to its significance in regenerator design.

Referring in particular to the recuperator this is an appliance which should be capable of general application in furnace practice, but at present it is not because of the limitations in the thermal properties of the materials which may be used. Amongst the disadvantages which militate against their more extended use, are the relatively large bulk of material necessary for a given heat recovery, and trouble arising from leakages, and short circuiting of the gases. The metal recuperator has its limitations for high temperature work, but with the development of non-scaling materials having suitable thermal characteristics at economic prices they should come into more general use.

HEAT TRANSMISSION PROBLEMS IN FURNACES.

The questions raised in regard to the above heat saving appliances are of a general character, entailing quantitative expression of the laws of heat interchange between fluids and refractory or metallic materials, the definite fixing of ideal areas of openings, heating surfaces, velocities of gases, and linear dimensions for a required recovery of heat. A satisfactory solution of such a problem would be of wide applicability to many types of furnaces. In the furnace chamber itself, however, the problem of heat transmission becomes specific to the particular operation concerned of which the variety may be legion.

A critical exercise of the human judgment must here temper any stringent rules deduced from an attempted exact analysis, for the utility of mathematical methods depends upon the value of the data supplied. In flame furnaces the most uncertain factor is that dependent upon the combustion conditions. Thus a luminous flame is reputed to give a much better heat transmission owing to the radiant energy of the incandescent particles—a controversial question, and a view at variance with the results of the best scientific work on the subject, as shown in the British Association Reports 1910. Again little is known of the important question of flame volume in its relation to the rate of heat development, or of the factors which govern the

heat transmission from flame by radiation or convection; particularly respecting the latter, whether the usual direct law of the temperature difference between the heating and heated media holds. As regards the heating effect of hot gases, convection is the dominant means of heat transmission below 800°C; above this limit radiation rapidly exceeds the effects of convection.

SOME ITEMS OF THE HEAT BALANCE.

Whilst in practical operation the question of the generation of heat is inseparable from that of its transmission to the charge, in seeking for the directions of improvement it is necessary to consider them separately as far as practicable. In some cases as in a producer gas-fired furnace this is readily done, for the question of producer efficiency is as readily studied as any problem in Fuel Technology. There is one factor, however, which is difficult to assess, namely, the tars. This is not indicated by any ready means such as a gas analysis, or the usual temperature control. Again an accurate knowledge of the amount of undecomposed steam, if not of serious consequence in the heat balance, is desirable from other aspects. Its direct measurement in a ready and satisfactory manner is still one of the fields for profitable research. It may be deduced from a knowledge of the composition of the fuel, the temperature of the blast, and the composition of the gas, but it is doubtful whether this is satisfactory, as moisture taken up from the water seal introduces an uncertain factor. For control purposes in gas producer operation, the best guides in the author's experience are, the temperature of the gas and the relation of the calorific value of the gas, as deduced from its composition, to the total contained carbon.

As regards the utilisation of heat in the furnace, it has already been indicated that a knowledge of the heat contents of the products of combustion, and of the charge, and the means of estimating the efficiency of regenerative appliances, is of first importance. There is, however, the remaining loss in the furnace structure by conduction, and external losses, which are too frequently overlooked. This is bound up with the question of the lagging of the furnace. The heat distribution in the furnace structure itself, is a fruitful field of inquiry. For their own purposes the author's laboratories have found it useful to devise a rapid method of measuring the heat diffusivity and

conductivity of refractory materials, which combined with the method already indicated* of observing radiation losses, enables the lagging of the furnace to be improved up to the economical limit for any specified requirement.

A full study of any given problem with regard to intermittent furnaces involves the application of the methods of the Fourier analysis, combined with graphical methods of applying the results to specific problems. Geometrical factors, however, bring in complications, both as regards the charge and the furnace structure itself. Methods of this kind, combined with quantitative data as to flame and hot gas flow, and increasing use of recuperative devices will, it seems certain produce surprising developments in furnace efficiency.

QUESTION OF LOAD.

It must, however, be realised that the outstanding variable in practice is the question of load, which is largely a matter of the orders in hand. One would think that it should hardly be necessary to stress this point, but if more importance were attached to this question in shop design and layout then the above mentioned irregularities would undoubtedly be mitigated and large quantities of fuel would be saved.

(*c*) MELTING FURNACES.

In the higher temperature processes of melting furnaces temperature measurement is as important in its influence on both metallurgical and thermal considerations as in the lower temperature operations of the forge or heat treatment furnace. The optical pyrometer, the technical application of which has made much progress in this field, is the chief scientific instrument. In actual practice, personal observation of the appearance of the metal, pouring and rod tests, largely hold the field as the means of heat control. In so far as the temperature of a molten bath is concerned the last class of indications, i.e., the action of the bath on rods inserted and manipulated in a variety of ways, is generally favoured as the most reliable, and when the factors eventually come to be studied and the indications correlated to the thermometric scale perhaps a scientific basis may be found for their use. At present the optical pyrometer must be the means for correlating that scale with these methods. Its value as an index of true temperature conditions depends upon the change of emissivity

* Hadfield and Sarjant, loc. cit.

of the surface of the hot body. The question also as to whether " black body " conditions are being observed, for example, as to whether the door opening is modifying them, has to be considered. The solid angle subtended by the door opening at the point observed is a variable with different furnaces and conditions. Whilst the earlier values of Burgess for steel and slag emissivities in the absence of more complete data as to the effect of many variables have served a useful purpose, it is now being found that, in particular with regard to fluid slags and special steels the emissivity constants require revision.

With regard to the operation of the open hearth furnace as a thermal machine, comparatively few accurate heat balances have been published. Notably quite recently Mr. F. Clements in this country, has dealt with this subject; also Messrs. C. L. Kinney, and G. R. McDermott, in America, who were awarded by the American Institute of Mining and Metallurgical Engineers the prize offered by the author for the best paper on the conservation of fuel. The subject is unfortunately too wide to be dealt with here by more than passing mention.

The fuel consumption of the open hearth furnace depends not only on its efficiency as a thermal machine, but also upon metallurgical considerations, which may have considerable effect. The best index of the heating efficiency of the melting furnace is naturally the rate of melting, expressed in tons per hour. Many comparisons are met with, in which the fuel efficiency of the furnace is given as an overall fuel consumption per ton of output. In such cases it is not always realised that the major circumstances determining good fuel ratios have been purely metallurgical, namely, such factors as the percentage of scrap in the charge, its composition, the size of the material charged, the manner of charging, and then the length and character of the refining period, and fettling time.

From observations on the melting efficiency of Open Hearth Furnaces it may be said that such efficiency, based on the heat input to the furnace, varies from 20% to over 30% according to the size and character of the furnace, and the composition and character of the charge. The utilisation of the heat losses in the waste gases is a difficult problem in those cases where steam from waste heat boilers would be a useless by-product. These losses exceed 30% of the heating value of the fuel, and there is a practical limit to their use in the regenerative system,

though a certain proportion must be regarded as useful in a sense as it creates the chimney draught. The major portion of the radiation and conduction losses is from the working chamber itself and their reduction is a question of improved refractory materials and higher rates of heat transmission in the laboratory of the furnace. Careful control and improvement of producer conditions not only influences the producer losses within a range of 10% of the heat of the fuel, but also contributes a comparatively greater share towards the general efficiency of the plant.

The more recent developments in open hearth design have tended towards what amounts to harder driving, brought about by improved flame conditions as instanced by the McKune port which attempts to get a blow pipe action on the surface of the bath.

SECTION III.

TEMPERATURE COLOUR.

In presenting this paper, the author thought that it might not be out of place to refer to the question of temperature colours, that is, the self-luminous colours of heated bodies which are familair to all of us, and commonly known under various descriptions such as red heat, yellow heat, white heat, and so on, specially with regard to their utilisation in estimating temperatures.

TEMPERATURE COLOURS.

Before the advent of pyrometers the temperature of furnaces and heated objects was commonly estimated from their colour. Indeed, the practice is quite common to-day either where the advantages of pyrometers have not as yet been appreciated, or where exact control of temperature is not vitally essential. Even in the case of a works equipped with pyrometers there are often circumstances which do not justify the trouble of applying a pyrometer, but where it is useful to have some sort of estimate by eye of the temperature concerned.

The degree of accuracy with which in some cases temperatures can be estimated by the unaided eye is indeed surprising. Where, however, anything like accurate and regular control of temperature is essential such means are dangerous. The eye, although wonderfully sensitive, is easily deceived and influenced by extraneous factors; in particular, by illumination of the heated object by flame or sunlight, or the amount and

hue of the general illumination of the surroundings. It is necessary for each individual to carry his own scheme of temperature colours in his mind's eye so that the method is not available for those without experience; one man cannot, in fact, impart his knowledge to another.

There have been many attempts in the past to rectify this and to provide a tangible reproduction of the temperature colours by which it would be possible for anyone to estimate by comparison the temperature of a furnace or heated object. Something of the sort has been specially desirable for steel manufacturers as a guide to their customers in the correct heat treatment of their steels. While the more up-to-date users of steel are equipped with pyrometers, and steel manufacturers always strongly recommend their customers to use such means, it is a fact which cannot be ignored that many continue to attempt the control of their temperatures by eye. Accepting the position, it is therefore advisable to guide such user by the best means possible.

The reproduction of temperature colour charts in quantities which naturally must be done by colour printing, is especially difficult; it is not surprising, therefore, that many of the temperature colour charts which have been published from time to time give very poor reproductions of the true colours. Some which the author has seen are in fact so crude as to be quite misleading.

An additional difficulty is that colour alone cannot give an adequate idea of temperature. In estimating temperature by eye not only the tint but the intensity of the light are subconsciously taken into account. At the lower temperatures in the region of " red heat " brilliancy is perhaps not so important and the gradation of colour is the prominent factor. At the higher temperatures, however, in the region of those concerned, e.g., in steel melting furnaces, that is, round about 1,500 or 1,600°C., the colour is of so attentuated a description that its variations are almost imperceptible. In addition the brilliancy and glare on the eye is intense. At 1,500°C. the brilliancy is about seventy times that at 600°C. From 1,500 to 1,550°C. there is an increase in brilliancy of from thirty to forty times that caused by a similar increase of temperature at 600°C. Hence there seems no doubt that at the higher temperatures the eye is influenced in its judgment rather by brilliancy than by colour.

While the colours may with care be reproduced on paper, such variations of brilliancy cannot; consequently any colour chart cannot be used in quite the same way as a man would use his eye without any artificial aid. In using the chart he must perforce confine his attention to colour only and eliminate if he can any effects of brilliancy of the heated object by simply trying to match the colours without reference to their respective brilliancies. This is, of course, an important disability as regards the use of such a chart for the higher ranges of temperature, although not so much affecting its use for the lower temperatures.

The author has recently given some attention to this matter and prepared the temperature colour chart of which a large scale reproduction is now exhibited. In the preparation of this chart the author has received valuable assistance from Mr. W. F. Northend of Sheffield, who has had special and considerable experience in reproducing coloured prints of various kinds and in colour printing. It is not an easy matter to produce a true and accurate presentation of the various colours indicated by varying temperatures from 500° or 600°C. to approaching 2,000°C. Mr. Northend has been able to reproduce these most successfully.

Direct observation was made of the colours of heated furnaces at the Hecla and East Hecla Works of the author's firm, Messrs. Hadfields, Ltd., the temperatures of which were known accurately by pyrometer. Repeated adjustments of the colours on the chart were made until the colour match was as satisfactory as could be obtained. Some care was naturally necessary to ensure that as far as possible brilliancy and its effect on the eye should not be allowed to bias judgment of the colour. The work was carried out always in diffused daylight, and the chart naturally should be used under similar conditions. As exhibited at this meeting the large scale reproduction of the original chart is illuminated by artificial daylight lamps so as to achieve these conditions as nearly as possible in the circumstances.

Mr. Northend's calibration of the chart was checked independently by a member of the Hadfield research staff with fairly concordant results, the average difference over the whole of the scale amounting to not more than 15°C.

From this original chart printed copies were prepared under

the direction of Mr. Northend. One or two repetitions were necessary before a satisfactory reproduction of the colours was finally obtained, but eventually this printed chart, which is shown in Fig. 3, was also calibrated with about the same degree of agreement between the two observers. The large chart now exhibited was prepared by hand colouring.

To get the best results these colour charts should be used with a screen of black paper in front, in which a horizontal slot has been cut; by this means the particular portion of the chart concerned can be placed under observation. Otherwise the eye is distracted by the remainder and does not form a true idea of the colour.

At first sight to some even among those accustomed to viewing high temperatures, these colours may appear to be not quite according to their ideas. The author would ask them however to suspend criticism until they have had an opportunity of putting the chart to the test as has been done at the Hadfield works by those workmen, managers, and also members of the Research Department, who have had experience in the operation of furnaces and other high temperature work.

In these tests furnaces were adjusted to various temperatures covering a range of from 700° to 1,400°C., and the individual concerned was asked to find a colour on the chart which he considered to be the nearest match, using the black paper mask with slot for this purpose. If in his opinion an accurate match was not possible he was asked to make the nearest. The individual concerned had no information as to the actual temperature of the furnace, and the temperature scale was also previously removed from the colour chart so as to leave him entirely unbiassed. On the whole, the results were good, especially considering the number and variety of the observers. Practically all the observers were able to find a satisfactory colour match for each temperature at some point on the chart, so that it may, the author considers, be taken as a pretty good representation of the colours of heated objects. It was, in fact, interesting to note that although on first inspection some were inclined to be critical, after making an actual comparison of the colours with the furnace they were bound to admit that they were not far from the mark. Most of the observers had not previously considered the question purely from the standpoint of colour.

Some divergency was naturally found between the different observers as to the actual position of the colours on the chart corresponding with the colour of a particular furnace, thus exhibiting the anticipated weaknesses in its use by practical men. In most cases this was the first attempt at the use of such a chart, and naturally it required considerable mental effort to leave out of account the difference in brilliancy between the furnace and the chart and to match solely by colour. Experience in its use would no doubt improve matters in this respect.

A more important factor, however, is the question of colour blindness, to which everyone is subject to a greater or lesser degree. While in the case of an experienced workman using his eye in the ordinary way to judge temperatures, that is, by carrying a mental picture of the temperature colours, this failing is probably of little importance, since it is operative under comparative conditions throughout. Truly similar colours appearing, however, on paper and in the furnace may look to him very different. This is a difficulty which appears to be insurmountable in the use of such a chart.

This was actually met with in the calibration of the author's chart. Another experienced member of the research staff, who was asked to assist, produced a calibration very distinctly different from that of Mr. Northend, allocating temperatures to the various colours ranging from 30°C. higher at the lower end of the scale to 80°C. higher at the upper end. At one particular temperature, namely, about 1,100°C. there was a particularly marked difference of about 150°C. This assistant is fully competent in judging temperatures by eye in the ordinary way. He, however, is quite ready to admit that his eyesight is not of the best, and while the observers were not asked to submit to examination by an oculist, the author has every confidence in the indications given by the trained eye of Mr. Northend.

While, therefore, the author does not advocate the use of such a chart except in the total absence or impracticability of other means of determining temperature, even that of the eye of an experienced workman, he believes that since such charts find a use, the present one will be found a better guide than some which have hitherto been published, which indeed, if put to the test, as this one has been, would have hopelessly failed.

With these reservations as regards its use, no doubt power engineers and others concerned with the working of high temperature plant may find it useful to have such a chart, hence the author's mention and description of it here.

The chart has been limited at the upper end to a temperature of 1,600°C. mainly for the reason stated that discrimination of temperature by colour at this high temperature becomes very insensitive, the effects of brilliancy predominating. This temperature will be found high enough for most practical purposes.

The actual colour at this high temperature is a matter of interest. Quite commonly, but probably without sufficient care, temperatures even below 1,600°C. are often referred to as a white heat, which, of course, does not really exist. No doubt brilliancy and glare on the eye being allowed to affect its true judgment is the cause of this. The reproduction by artificial means even of daylight, which is generally regarded as white, as will be seen from the lamps used in illuminating the chart, involves the use of a particular shade of blue. The actual description of the true colours is a matter of some difficulty and the author would be glad to have suggestions. In terms of colours of familiar objects the nearest descriptions the author has been able to find are those shown, although obviously they admit of some improvement.

It is important to add that the chart should not be used to estimate the temperature of flames nor of heated objects illuminated in any way by flames. The colour of flames is a matter quite distinct from that of solid bodies, and in fact flames, even those of approximately the same temperature, may differ widely in colour, depending on the materials under combustion.

Even in the case of solid bodies, especially in the open, their colours are not quite identical. Under enclosed conditions, as in a furnace, however, the differences are negligible, or at any rate within the limits of accuracy of a colour chart. When confined to iron and steel the chart may be used indiscriminately on material in the furnace, or in the open, as in the case of a rolling mill. For use with some other metals in the open, however, it would require modification.

Finally, in this connection, the author may perhaps be allowed to digress for a moment from the scientific to the

artistic aspect of temperature colours. It is hardly possible to conceive a more beautiful attempt to depict the different colours and the shades of high temperatures than that shown in the wonderful picture, "Mount Vesuvius in Eruption in 1817," painted by that renowned British artist, J. M. W. Turner, R.A. As this water colour happens to belong to the author, having been purchased at Christie's about two years ago, and originally forming part of the Farnley Hall Collection, he hopes to have the pleasure of exhibiting the picture itself at the Congress, or, failing this being possible, then as a lantern slide, should the one now being prepared prove satisfactory. No mere copy, no matter how carefully prepared, can at all equal the beautiful tones of the colours in the picture itself, which vary from dull red to the most delicate tints, indicating temperatures from about 600°C. to 1400°C., these being depicted by Turner in a marvellously artistic manner.

It may be of interest to mention that this picture was largely the means of bringing about the preparation of the coloured diagram now exhibited and represented by Fig. 3. If this great artist was able to depict temperature colours so correctly, it was thought that surely we should be able to follow his example. As explained in the paper, this has proved to be not at all an easy task, but it is hoped the results which have been obtained and depicted in Fig. 3 may be of service in guiding the large number of individuals who are concerned and interested in dealing with high temperatures, whether in furnaces used for melting, heating, annealing, heat treatment, or in the boiler house.

The author feels sure that Turner would have been delighted to find that artistic work of his carried out in 1817, that is rather more than one hundred years ago, has now been made use of for practical purposes by the Metallurgist and Heat Engineer of to-day.

SECTION IV.

CONCLUSION.

The author trusts that this paper, which deals with several new features in connection with fuel economy and the measurement of high temperatures, will be found of service in our Empire generally, and to our various visitors from America and also other countries.

The old saying that " whoever could make two ears of corn, or two blades of grass to grow upon a spot of ground where only one grew before is a public benefactor," surely applies with quite as great force with regard to methods of effecting fuel economy.

All nations are chiefly dependent upon fuel combustion to carry on their modern civilisation. The war brought this out in a remarkable degree, and now peace happily prevails there is even more urgent necessity for studying methods for effecting economy of fuel, in all the thousand-and-one industries throughout the world.

In conclusion the author desires to say how much he has been indebted for the help rendered in the preparation of this paper by Mr. W. J. Dawson, Mr. R. J. Sarjant, M.Sc., and Mr. S. A. Main, B.Sc., all of whom, along with the author himself, have for several years past taken an active interest in the development of this important subject, also in carrying out investigations, both practically and by scientific research, at the works of the author's firm. The author again offers grateful thanks to his friend, Professor W. A. Bone, F.R.S., for much useful help and guidance from time to time with regard to Fuel Researches and their practical application to Works practice.

RÉSUMÉ.

1ère Section. (INTRODUCTION.) Importance de l'économie de combustible pendant la dernière guerre et la période d'après guerre; durant cette dernière surtout en vue de la réduction des prix de revient.

Brève référence sur les travaux effectués antérieurement, y compris les recherches faites par la Fédération des Industries Britanniques et les travaux effectués aux Usines de MM. Hadfield, Ltd.

Connaissance de la distribution de la température dans une usine consommant du combustible, l'un des facteurs les plus importants dans l'étude de l'économie de combustible.

Insuffisance comparative de la connaissance des effets dus à la haute température et importance des recherches dans cette direction.

Méthodes modernes de pyrométrie et quelques difficultés dans leur application.

2ème Section. Examen des champs où la pyrométrie a permis d'obtenir des bilans thermiques exacts.

a. CHAUDIERES A VAPEUR. Un champ pour l'économie de combustible auquel on a consacré beaucoup d'attention durant les 50 dernières années, et qui se prête à des mesures scientifiques exactes sur les divers items du bilan thermique.

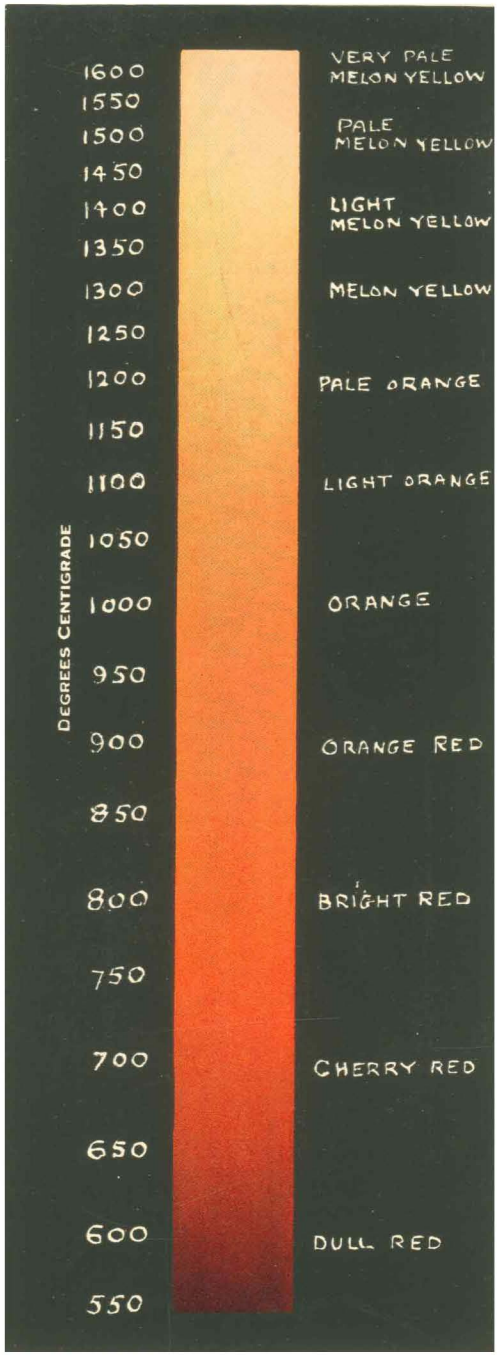
Les possibilités scientifiques du développement de la chaudière sont discutées en se basant sur les travaux d'éminents pionniers sur la question. Des développements industriels de première importance ont suivi la mise au point d'appareils subordonnés à l'agent principal. Un bref aperçu est donné sur les développements importants réalisés.

Les installations et la pratique des temps modernes demandent des raffinements dans les méthodes de mesure. Les méthodes les plus saillantes pour déterminer le rendement sont indiquées rapidement, et la détermination de la chaleur perdue dans les gaz, revélée par les observations pyrométriques et analytiques de la composition des gaz, est la clef vers l'obtention d'une combustion complète et le passage convenable des gaz à travers le système de la chaudière. Les pertes dues aux combustibles non brulés, au rayonnement et à la conduction des revêtements sont passées en revue.

Les limites d'exactitude sont plus étroites dans la mesure des températures que dans la mesure de l'énergie du combustible et de l'eau évaporée. Les sources d'erreur sont examinées.

La haute température dans la conduite des chaudières. Les tendances modernes conduisant vers de plus grandes unités et de plus grands débits, réclament des intensités de combustion plus grandes. Relation entre la température et l'intensité calorifique. Variation de l'intensité calorifique suivant le caractère du combustible. Etat des recherches modernes concernant la constitution et les propriétés des combustibles solides et gazeux et leur influence sur cette question.

Directions dans lesquelles on peut espérer des perfectionnements en ce qui concerne de meilleures intensités. Limitations actuelles des matériaux utilisés pour les garnitures réfractaires et les grilles. Acier empêchant l'entartrage.



TEMPERATURE COLOUR CHART.

These Colours correctly correspond with the temperature indicated only when viewed by daylight.

Fig. 3.

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b. FOURS DE FORGE ET FOURS POUR LE TRAITEMENT THERMIQUE DE L'ACIER.

Relation entre la distribution des températures et l'économie de combustible. Erreurs dans la détermination de la distribution des températures dans les fours à flamme.

Températures des flammes et rendement des fours. Influence du choix du combustible. Effet de la récupération et de la régénération. Etat actuel de la pratique en régénération et récupération.

Problèmes de la transmission calorifique dans les fours. Directions dans lesquelles on peut prévoir des perfectionnements. Influence relative du rayonnement et de la convection. Etude d'un bilan thermique, influence de la charge.

c. FOURS SIEMENS MARTIN. Examen d'un bilan thermique. Etat actuel de la mesure des hautes températures dans la fabrication de l'acier.

3ème Section. Couleur des températures. Evaluation des températures d'après l'œil. La coloration et le brillant tous deux influent. Le brillant ne peut être reproduit sur la carte ordinaire des couleurs de températures, d'où incapacité d'une telle carte, particulièrement aux plus hautes températures.

Carte de l'auteur donnant les couleurs des températures; méthode pour l'établir et manière de l'utiliser. Essais de cette carte par des observations pratiques. Quelques réserves sur son utilisation. Daltonisme. Description des couleurs des températures.

Aspect artistique des couleurs des températures.

COKE AS FUEL FOR STEAM RAISING

E. W. L. NICOL, A.M.I.E.E., M.I.Mar.E., Assoc.Inst.C.E.
Engineer and Fuel Expert to the London Coke Comm tee.

In a contribution to the Gas and Fuel Section of the First World Power Conference it is appropriate to direct attention to the dependent position of the British Empire in regard to petroleum and petroleum products, with a view to consider ways and means whereby this position may be alleviated.

The increasing use of liquid fuels for land, sea and aerial transport, for the Royal Navy, and for industrial and domestic purposes, has rendered adequate and continuous supplies vital to the maintenance of our economic life, and therefore to our prosperity as a nation.

Our immunity from serious bombardment and invasion, our lines of communication for troop transport, food and munitions supplies, were maintained intact during the war by means of sea and air craft fired with liquid fuel. This fact, and the bitter experiences of our late adversaries through lack of liquid hydro-carbons and lubricants, should serve to remind us of our own anxiety, and the grave necessity of economising and supplementing precarious foreign supplies by promoting home production at coke ovens and gasworks. It is indeed almost forgotten that gas, carried in flexible containers, was used during the war in order to economise petrol and to maintain road transport vehicles in commission.

Notwithstanding these facts and experiences, the daily increasing extent to which we in this country are in normal circumstances dependent upon foreign countries for supplies of liquid fuels and lubricants, and the inevitable consequences of failure to maintain supplies, do not appear to be fully appreciated. It is, indeed, doubtful whether the general public realise in the least how serious the position is, and is likely to become.

How many realise, for instance, that quite apart from liquid fuels for internal combustion engines, no modern gas, steam or petrol engine, or other high-speed machine, can be run for a single hour without the special lubricants at present derived solely from petroleum?

So utterly complete is our dependence upon petroleum and petroleum products of foreign origin, that even a temporary interruption or withholding of supplies would in peace have the most serious

consequences, and would entail dislocation of all our industrial and commercial activities. During a period of war, the immediate consequence of inadequate supplies would be the first step towards national disaster.

Oil and oil-bearing lands are already much-used pawns in foreign politics, and the question as to the wisdom of exporting oil so freely from oil-producing countries is bound to arise on the ground that oil reserves are a wasting and vital asset that cannot be replaced; and wisdom no doubt will prove to be on the side of keeping a jealous watch upon all that remains.

Only a relatively small quantity of petroleum is produced within the British Empire. The knowledge that British capital is largely engaged in its production in foreign countries, where the proportion available for export is comparatively large, is a somewhat dubious consolation, as it must be borne in mind that transportation from those countries is always subject to hostile aerial and submarine action, while the oil wells and pipe-lines are not immune from the possibility of destruction.

Since 1918, the number of cargo and other vessels using petroleum fuel oil in one form or another has increased enormously; but the most convincing evidence of potential increase in demand for petroleum products is, perhaps, the daily increasing number of motor vehicles and tractors in this and in other countries.

According to reliable authorities the number of motor vehicles in this country has increased from 620,000 in 1919 to 978,000 in 1923. In the United States and Mexico, upon whose *exportable* surplus of petroleum we are at present dependent to the extent of 63 per cent. of our requirements, the percentage increase has been much greater, the present number of motor vehicles in the U.S. being 14,652,000 as compared with 7,596,000 in 1919.

As a rough estimate, it may be assumed that the annual consumption of motor spirit for each vehicle and tractor is, on the average, about 350 gallons, a figure which will serve to indicate the enormous annual increment in demand due to the increasing output of motor vehicles and tractors, estimated at over two million per annum in the U.S. alone.

The present approximate world production of coal and petroleum is 1,500,000,000 tons, and 118,000,000 tons respectively. The ratio of relative importance is, however, much greater than these figures indicate. For many power purposes, petroleum is a convenient substitute for coal; but coal, or coal products, can never be a complete substitute for petroleum and its derivatives.

The importance of petroleum extends beyond its use as fuel, as it forms the basis of most lubricating oils; and research has so far failed to recover from coal distillation products the heavy hydrocarbon lubricants upon which the operation of modern superheated steam engines and internal combustion engines depends.

As already stated, an oil-field in production is a wasting asset. Compared with that of a coal-field, the rate of depletion is more rapid and its economic life is relatively more limited. After a comparatively brief period of exploitation some of the first oilfields to be developed in Russia and in the U.S.A. are showing signs of depletion. New oil-fields, capable of profitable exploitation will, no doubt, be discovered; but there is at present not the slightest prospect of such development keeping pace at a rate equal to that at which the demand is increasing. Foreign countries, moreover, are more likely than Great Britain to discover and develop new oilfields; and in the future the race will be to those who secure in their favour a balance of comparatively cheap liquid fuels, from whatever source it is derived.

During 1918, it was stated that in America petrol consumption was overtaking production, and that the end of the economic life of the U.S. oilfields was in sight. Since then new oilfields have been discovered in California, Texas and Oklahoma, with the result that production is again temporarily in excess of demand; but notwithstanding the present abundance and cheapness of petrol in America, it is significant that in the U.S. there has been an amazing growth in the production of benzol, the output having increased from 1,500,000 gallons in 1910, to 70,000,000 gallons in 1920. The present output finds its main outlet for motor spirit blends, but by no means does it represent the full quantity obtainable from the coal carbonised and gas produced.

In Germany, too, benzol is already produced in very large quantities and it has been asserted that before long that country will use home-produced motor spirit to the total exclusion of imported petrol.

In Great Britain, the production of benzol from native coal reached its maximum in 1918, the total output from all sources, but mainly from by-product recovery coke-ovens and gasworks, being 26,400,000 gallons. In 1922, the output, owing to various reasons, but mainly owing to the competition of relatively cheap petrol, had fallen to 11,155,000 gallons. If all the available spirit were recovered from the coke-oven and town gas at present made in Great Britain, the total yield has been estimated at 46,000,000 gallons, whereas the U.K.

consumption of motor spirit in 1922 was of the order of 350,000,000 gallons. The total U.K. consumption of petroleum products of all grades for the same year, according to official statistics, reached 4,631,455 *tons.*

The present home production of motor spirit from shale is approximately 6,500,000 gallons per annum.

The amount of petrol that the world can at present produce is in fact rapidly being overtaken by the increased demand.

Although many material factors have been omitted in thus briefly reviewing the situation and arriving at this conclusion, the enumeration of the foregoing facts, coupled with the knowledge that we in this country possess enormous resources of solid hydro-carbon of the best type in the form of bituminous coal, should be sufficient to indicate *the imperative need for at once embarking upon a national policy of making the most of our coal resources, for our own benefit and credit, and in the interest of those who in succeeding generations are to take up the burdens of Empire.* In formulating such a policy of so developing and conserving our coal resources as to render the country, so far as possible, self-supporting in the matter of liquid fuels, one would naturally aim first at the elimination of waste at the pits, as recommended by the Coal Conservation Committee in 1918, by inducing colliery owners to recover more of the low grade small coal at present left underground in great quantities.* *A greater quantity of large coal which, by reason of its higher quality, is better able to bear heavy freights and meet competition from foreign sources in overseas markets, would thus be set free for export.*

Treated at the pits for the elimination of excess inert matter, much low grade coal is capable of profitable utilisation by means of carbonisation. By treating all classes of bituminous coal as raw material for the manufacture of fuels, fertilisers, and other products used in our industries, its commercial value would not only be increased, but more labour would be employed per ton of coal mined.

A fuller utilisation of our coal resources by means of carbonisation and by product recovery may, in fact, be regarded as one of the first essentials in solving the problem of unemployment through the more efficient use of the land and in the development of industry.

The importance of the relationship of fuel, food and fertilisers, as an economic factor in the maintenance of our huge agricultural and industrial population, as well as in the defence of the Empire, does not appear to be fully realised.

* Estimated by competent authorities at 25 to 30 per cent. of total coal worked. In addition, a considerable proportion of the coal seam is unavoidably left standing.

That our present methods of using coal as fuel are for the greater part inefficient and wasteful is frankly admitted. Of the 189,000,000 tons consumed annually in this country, 139,000,000 tons are burned in the raw state; and, moreover, the relatively small proportion of our annual coal consumption which is treated at coke ovens and gasworks is almost entirely of the strongly-coking description, of which available resources are comparatively small.

Attention should therefore be directed to devising processes by means of which bituminous coals of *all* descriptions may profitably be utilised with a view to produce: (1) fuel oils for internal combustion engines and for steam raising; (2) motor spirit for road and aerial transport; (3) gaseous and solid fuels for industrial and domestic use. The successful and adequate development of such processes would go far not only to render the country more independent of foreign supplies of liquid fuels, but would tend to mitigate the coal smoke evil, and also contribute to the more economical working of the coal industry itself.

Recent research has been active in devising such processes, and also in the elucidation of the problem of finding a substitute for petrol. But of all the possible solutions which have been examined, the most promising and effective in the latter connection, is, by common consent, the production of benzol in the gasworks and by-product recovery coke-oven processes of coal distillation.

At the present time, less than 15 *per cent. of the coal used in Great Britain is treated at gasworks and by-product recovery coke-ovens;* and the proposal that no coal capable of profitable carbonisation should be used in its crude state is one that should receive immediate attention.

Against such a proposal it has been advanced by responsible authorities that great difficulty would be experienced in disposing of the principal concomitant secondary product, coke; and acceptance of this view has in the past had a profound influence upon the policy of important gas supply authorities in adopting plant and processes of gas manufacture which tend to diminish the output of coke, or to absorb coke, as in the manufacture of water gas.

Much effort has also been expended in perfecting low-temperature processes of carbonisation with a view to produce, for use in open fire grates, a soft coke or smokeless solid fuel possessing some of the free-burning qualities of domestic coal.

The unsatisfactory position of the coke market, which reached a climax in 1913, when enormous stocks of surplus coke were the rule at all large gasworks, no doubt gave some grounds for the

consideration and adoption of such methods; but the recent introduction of coke as fuel for steam raising at electric and other power stations, and the development and introduction of coke-burning domestic heating appliances, have together created a demand for coke which already promises to overtake the available supply at no distant date. For these purposes, not soft coke, but gas coke of the hardest description is required for efficient operation.

There are already some forty British firms specialising in the manufacture of coke-burning domestic heating appliances; and the potential outlet for coke in this direction, and for steam raising, may be gauged by the fact that the annual coal consumption for domestic purposes in this country is estimated at 35,000,000 tons, and that for steam raising, 60,000,000 tons.

Another factor which has in the past influenced the conduct of the gas supply industry is the necessity for producing a non-friable coke that would bear handling without undue breakage. This consideration will continue to have an important bearing in the selection of strongly-coking coal that will, by itself, or blended with coals of other descriptions, produce a saleable coke; but it must be borne in mind that for use on mechanical stokers such coke must be cut or graded down to nut size.

In order, therefore, to cater for the requirements of power stations equipped with coke-burning mechanical stokers, relatively cheap non-coking coal, which has hitherto been considered unsuitable, might profitably be used at gasworks, or for certain sections of gasworks, with a view to produce a friable coke or breeze that will not require cutting or grading.

Such coal could not, of course, be used alone in horizontal retorts, but the vertical retort, or the inclined retort, should facilitate its use and thus tend to economise coking coal, which, of all our mineral resources is perhaps the most precious.

Sufficient has been said to show that the use of coke as fuel is closely associated with the whole question of national economy. Its advantages as fuel for steam raising are now widely recognised. In ordinary boiler practice, its chief advantage, apart from its smokeless characteristic, is that it burns completely, without pulverising or other treatment, with a minimum excess of air, whereas, in ordinary practice, bituminous coal is unavoidably allowed a quantity greatly in excess of that theoretically necessary. Coke gives therefore a correspondingly high temperature head and radiant effect.

Economic results obtained in ordinary hand-fired boiler practice at London public institutions, factories, and at power stations, are such that coke of average quality more than holds its own in the estimation of discriminating steam users. Indeed, in many districts, the available supply is now unequal to the demand.

This result has been achieved after only a comparatively short period of intensive propaganda in popularising coke as an industrial and domestic fuel. The impetus thus given to the movement should be sufficient eventually to absorb very large quantities of coke, and, moreover, to indicate the probable trend of future development in gasworks practice.

For use at power stations equipped with coke-burning mechanical stokers, coke breeze, or coke of a friable nature is preferable, as already shown. Such coke-burning mechanical stokers have recently been developed and perfected; and the ordinary natural-draught chain grate mechanical stoker has been adapted successfully to burn low-grade coal and coke by means of the patent Sandwich system.

Adapted to operate on this system, the stoker feed-hopper is divided into two separate compartments, from which coal and coke, in about equal proportions, are fed in super-imposed layers, the coal being uppermost. The coal (which should preferably be low grade small coal or slack) thus serves to ignite the coke as it enters the boiler furnace. The coal and coke are stored in separate overhead bunkers.*

The potential outlet for coke in this direction is further instanced by the fact that by means of the Sandwich system one London power station alone, has, since 1918, consumed coke at the rate of 40,000 tons per annum, a quantity equal to about half its total fuel requirements. Needless to say, this method of steam raising is preferred on its merits as being more economical than is the usual practice of burning relatively expensive coal alone.

Results of independent comparative tests with coke, and with coal and coke, fired by hand and on the Sandwich system, obtained from an important London power station, are appended.

CONCLUSION.

Nothing is more certain than that the world demand for petroleum and petroleum products must ere long exceed the available world supply: and while we may enjoy to the fullest extent the felicity

* A notable installation of this description has been embodied in the design of the new Municipal Power Station at Barton, Manchester, which, at the present time, is stated to be the most efficient power station in Great Britain.

and prosperity which petroleum has brought us, let us bear in mind that *coal and coal products are, and must remain to an ever-increasing extent, the mainstay of our power as an Empire.*

It is equally certain that an adequate and independent supply of liquid fuels must remain a factor of vital importance in peace, as in war. *If Great Britain and the Dominions are to escape a costly and increasingly precarious dependence upon foreign countries, our coal deposits must be made to yield the liquid fuels we require.*

All authorities on the subject are agreed that our coal can, and should, be made to yield such fuels in adequate quantities; they differ only as to the methods by which the agreed common object should be accomplished. It is quite clear, however, that whatever method or methods may be adopted, coal distillation must eventually be carried on, on a scale hitherto undreamed of in this country, if liquid fuels adequate to the country's requirements are to be internally produced.

The one process which is capable of immediate and unlimited development, and which has for over a century withstood the test of commercial exploitation and still makes steady progress, is that carried on at gasworks; and sufficient has been said to show that that which hitherto has been an obstacle to large-scale operations, *viz.* the disposal of the resultant coke, has to a large extent been overcome in open competition with raw coal.

TABLE I.

Specimen Daily Records of Hand-fired Lancashire Boilers.

COKE FUEL.

Date.	Economiser. Inlet.	Economiser. Outlet.	Pounds of water evaporated per Pound of Coke as fired.	
	Deg. Fahr.	Deg. Fahr.	Actual.	From and at 212° Fahr.
June 27th	120	240	9·06	10·18
28th	115	225	8·31	9·35
29th	120	215	8·67	9·74
30th	120	210	8·45	9·49
July 1st	120	215	8·84	9·93
3rd	120	210	9·0	10·11
4th	120	230	9·38	10·45
5th	120	225	8·93	10·02
6th	120	225	9·03	10·14
7th	120	225	8·60	9·66
8th	120	240	9·16	10·29
9th	115	225	9·02	10·13
10th	115	225	9·52	9·57
11th	110	230	8·87	10·05
			Average:	9·9 lb.

TABLE II.

Coke and Coal Slack fired by means of the patent Sandwich System.

	Test No. 1 Coal and Coke.	Test No. 2 Coal only.
Calorific power as fired	11,138 B.Th.U.	12,150 B.T.U.
Fuel consumed per grate ft. hour ...	30·66 lb.	31·66 lb.
Ash and Clinker, actual	16·22%	12·7%
Average Steam pressure	178 lb.	179 lb.
Superheat Temperature	486°F.	490°F.
Water evaporated per hour	10,505 lb.	8,747 lb.
,, ,, ,, sq. ft. of heating surface ...	5·22 lb.	4·35 lb.
Water evaporated per lb. of fuel as fired, from feed temperature	7·18 lb	5·76 lb.
Water evaporated from and at 212°F. ...	9·22 lb.	7·44 lb.
Efficiency boiler and superheater ...	69·9%	53·12%
,, ,, with economiser ...	79·96%	60·98%
Draught over fire...	0·25 in.	0·25 in.

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RÉSUMÉ.

Dans une contribution à la Section du Gaz et des Combustibles de la Premièra Conférence Mondiale de l'Energie, l'auteur attire l'attention sur la dépendance dans laquelle se trouve l'Empire Britannique, vis à vis des pays étrangers, pour la fourniture du pétrole et de ses sous-produits, en vue d'examiner les voies et moyens par lesquels cette situation pourrait être atténuée.

Il indique l'augmentation continue des besoins en huile lourde et en essence, pour les transports terrestres, la marine et la navigation aérienne et insiste sur l'importance vitale de la continuité des approvisionnements pour ces services, ainsi que pour la marine de guerre.

L'auteur maintient que rien n'est plus certain, que les besoins en pétrole et en produits du pétrole, avant longtemps excéderont la production mondiale, et qu'il est également certain qu'une source suffisante et indépendante de combustibles liquides, doit rester un facteur d'importance vitale pour l'Empire, aussi bien en temps de paix qu'en temps de guerre.

Le charbon est le combustible basique de l'Empire, et les produits du charbon sont et doivent rester, à un degré de plus en plus important, le soutien principal de la puissance de l'Empire. L'auteur fait remarquer que tous les spécialistes sont d'accord sur le fait, que le charbon Britannique peut et devrait produire les combustibles liquides nécessaires ; et si la Grande Bretagne et les Dominions doivent échapper aux conséquences d'une dépendance des pays étrangers de plus en plus précaire et coûteuse, il est impératif qu'une politique de combustible national, prévue dans ce but, soit formulée et suivie.

La conclusion à laquelle est arrivée l'auteur est que tout procédé d'utilisation du charbon, établi en vue d'atténuer la situation, doit commencer par la distillation du charbon dans les usines à gaz sur une plus grande échelle que ce qui a été tenté jusqu'ici en Grande Bretagne ; et le coke étant le principal sous-produit de cette distillation, il procède en montrant que, pour la production de vapeur dans les stations centrales ou pour les usages domestiques, le coke de gaz peut être utilisé avantageusement sans aucune ou sans modification sérieuse aux stations centrales à vapeur ou aux appareils domestiques existants.

L'auteur décrit son système " Sandwich " consistant à utiliser pour la production de la vapeur le coke et le poussier de charbon de qualité inférieure en couches superposées à l'aide de foyers à grilles mécaniques ; des résultats comparatifs sont donnés, soit obtenus avec ce système, soit avec des chaudières à vapeur chargées manuellement et alimentées exclusivement avec du coke.

I.

L'auteur préconise pour la production industrielle de la vapeur, la fabrication du coke ou du poussier de coke avec du charbon maigre bon marché, en vue d'économiser la houille à coke et d'éviter la nécessité de casser et de classer le coke obtenu avec la bonne houille à coke, afin qu'il soit utilisable dans les foyers à grilles mécaniques.

PULVERISED FUEL FOR BOILERS

W. M. SELVEY, Wh. Sc., M.I.Mech.E.

SYNOPSIS:

General Observations.
The Fuel.
Preparation of Fuel in Pulverised Form.
The Fuel Burner.
The Combustion of the Fuel.
The Absorption of the Heat.
Application to British Conditions.
Conclusions and Recommendations.

GENERAL OBSERVATIONS.

No apology is necessary for venturing to put forward a paper on Pulverised Fuel to-day. Although its application is comparatively new as applied to boilers even in the U.S.A., and is hardly in existence in this country, there is no subject which is eliciting more lively interest among power station engineers.

The scheme of burning fuel in a pulverised form has been applied for a fair number of years in the cement industry, but under circumstances rather special to that industry. Other circumstances, both as regards preparation and use, obtain in boiler firing, but the success which has already been attained owes a debt to experience in the older application, if only for showing what to avoid.

Owing very largely to the spirited action of Mr. John Anderson in adopting Pulverised Fuel at Milwaulkee, the process can be said to have finally arrived, as the example set has been speedily followed at quite a considerable number of super stations. Engineers are already getting familiar with illustrations of Lakeside, Cahokia, St. Joseph Lead Co., River Rouge and other similar installations. Great interest also attaches to the adoption of the system at Vitry, Paris, one of the stations of the Union d'Electricité, and its possible adoption for extensions at Gennevilliers.

The particular feature about all these installations which commands notice is that of size. Side by side with this development, there has been another line of thought which has developed what is known

as the " Unit System." This alternative may be described as the simple system for small units. It has been most extensively developed on the Continent, and has, and is producing a host of variations there and in Britain.

Engineers in the States are also turning their attention to this problem, which to them is not primarily one of the right scheme, so much as an adaptation to the heterogeneous set of conditions now existing the world over. The super station represented virgin ground and a clear field, but the adaptation to the existing conditions will produce a literature and tradition which could well have been avoided under the more co-operative scheme.

It will be gathered that at this state of the art, opinions which will be tentatively set forward in this paper can only be a basis for discussion, and apparatus and schemes mentioned can only be of topical interest. In a few years' time, in fact, in a few months' time, opinions will have developed and changed, and new schemes will have appeared, supported by equally enthusiastic protagonists.

Controversy will rage as to storage versus non-storage systems, and dried versus non-dried fuel, co-operative systems versus unit systems, highly pulverised versus uniformly pulverised fuel, attrition systems versus grinding and crushing systems, and so on. All of this will be to the good, if every engineer who uses fuel will adopt some system as his preference and go out whole-heartedly to make success of it.

THE FUEL.

Man when he approaches a new object, displays an anxiety and a satisfaction in inventing a " Label " for it. Thereafter he speaks and writes volumes to show how different the object is from what the " Label " first implied. In the end the condensed knowledge acquired turns largely on the differences. Iron, for instance, add a little carbon, and what an enhancement; a little sulphur and phorphorus, and what a handicap.

It is not so different with coal. The matter which has to be considered is not anything connected with the staple " Carbon," similar to the old charcoal whose use was so easy and world-wide under primitive conditions, but those other matters known colloquially as " Volatile " and " Ash." On this basis we can at once come to grips with our subject.

Volatile Contents.

From the point of view of pulverised fuel the "Volatile" means that

portion of the fuel which readily distils off on moderate heating and which as readily ignites. No doubt, for purposes of comparison, it is sufficiently represented by the chemist's "Proximate" analysis, although it is not quite the same thing. Perhaps a chemistry will be developed of testing fuels for igniting properties along the lines of the Pensky-Martin flash test for oil. This is the first suggestion thrown out.

The proportion of volatile varies largely and it will be necessary perhaps, to classify fuels under some such headings as :—

(a)	Anthracite ..	Volatile 5 per cent. mostly hydrogen—oxygen almost absent. Peculiar physical properties.	Range 3 to 7·5 %
(b)	Semi Anthracitic	Lean or hard steam coals. Volatile varying 7·5 to 12·5 %.	
(c)	Semi Bituminous	Good steam coals. Volatile ranging from 12·5 to 25 %.	
(d)	Bituminous ..	Coals difficult to burn without smoke—high oxygen contents "fat" coals. Volatile 25 % to 35 %.	
(e)	Highly Bituminous	To include gas coals, coking coals—coals difficult to store—liable to spontaneous combustion—not usually used for steam raising—Volatile 30 % to 45 %.	
(f)	Lignite	Brown coal and the like. (Continental sources principally, but also world-wide—Morwell, for instance).	

In the above classification—"Steam" to some extent has been followed, and the second suggestion made is that some such classification shall be adopted by agreement and discussion in addition to the "ignition" specification. It will probably be found that different specifications as to fineness of grinding, type of pulveriser, type of air feed, and type of combustion chamber will ultimately be necessary or convenient for these different varieties.

Fineness of Grinding.

The question must be asked—what is Pulverised Fuel?

A standard of fineness that has been widely adopted in the U.S.A. is such that 85 per cent. of the product will pass through a 200-mesh screen and 95 per cent. through a 100-mesh screen (Harvey). What this means is not quite definite for universal use, neither does it seem to be equally satisfactory for all classes of fuel. It also

leaves out of account the moisture content which has a considerable bearing on co-operative installations.

For these latter it would seem essential to include some scheme of drying in the fuel preparation system, as even the temporary storage of undried powdered fuel gives rise to minor problems, while its storage for any length of time gives rise to more serious problems. On the other hand, what may be considered practically dry fuel appears to offer no difficulties in power station work if properly contained after pulverisation.

Another aspect of the matter is one which, while realising the value of a portion of the fuel being very fine for purposes of ignition, deprecates the mass as a whole being of the highest degree of fineness, and stresses rather the absence of any large particles.

The question is somewhat wrapped up in the combustion chamber system used and what will be termed later "isothermal" combustion.

The author has discussed the question at length with Mr. A. C. Raymond, and his opinion based on experience to date is briefly as follows :—

"For the actual burning of the coal it is necessary that it shall contain no particles which are too large to pass a 50-mesh screen . . . this applies to ordinary bituminous coals, *i.e.*, quick-burning coals. For anthracite coals and other slow-burning coals it is necessary to change this specification . . . to 80-mesh screen. Other coals will lend themselves to a specification somewhere between.

"In my opinion it is not necessary to specify what is the percentage of dust which will pass over 100 and 200-mesh screens, as all the pulverising equipments now on the market will when working to the above specification, produce a product containing a sufficient quantity of fine dust to meet all burning requirements. . . . . However, as the art progresses we have found that often too quick a combustion is as detrimental to good results as slow or incomplete combustion.

"It is now recognised that the best results have been obtained when the coal is ground . . . (*i.e.*, as above), and with as low as 60 per cent. of 200-mesh material for bituminous coals, and 75 per cent. for 200-mesh for anthracite coals.

"Up to the present time . . . no pulverising equipment . . . . is capable of grinding so that all will pass a 50-mesh screen . . . and not more than 60 per cent. passing a

200-mesh screen. And finally . . the degree of pulverisation must be constant . . . "

The author is indebted to Mr. Raymond for this valuable expression of opinion, and recognises the sincerity of the pronouncement. He thinks that its rationale is derivable from the particular system of screw-feed and " U-type " flame which has been so successfully adopted in the U.S.A., to which reference will be made later.

The third suggestion now made is—certainly for Great Britain, that some connection be established between such a specification and the class of coal to be dealt with. In this way the maximum efficiency and the lowest H.P. will be attained by experience.

Specification for class (X) coal :—The pulverisation shall be such that all the coal passes a " M " mesh screen, and not more than Y per cent. shall pass a " N " mesh screen.

It is well known that some forms of pulverising machinery claim to deal with practically all the fuel through a 200-mesh screen, and this when grinding undried coal.

A fourth suggestion is that it will be necessary to standardise the wires of which the test screens are woven. A table furnished by Mr. Raymond is attached.

Drying the Fuel.

The need for drying or not drying depends on the question of storage and of power used in grinding. Commercial coals may contain up to 15 per cent. moisture, but 8 per cent. is a good figure for washed beans or pearls if not abnormally wet. Dry slacks contain 3 to 5 per cent. moisture, but artificially wetted slacks may contain indefinitely large amounts. These latter coals are a nuisance in the bin, and in any case call for drying. The nuts and dry slack can, however, be well pulverised without drying, but must be directly used, and be borne to the furnace without intermediate feeding arrangements.

The standard specification for the present appears to be to dry down to 1·0 per cent. of free moisture. The author's experience on ordinary calorimeter work leads him to look on this specification as a doubtful one to work to, and the fifth suggestion is that our chemical friends should draw up a specification to suit their methods of determining dryness, stating whether the sample should be taken on the coal leaving the dryer or entering the pulverised coal bin and what method is to be used in determining this ultimate dryness fraction.

RAYMOND.

NORMAL DIMENSIONS AND SCREEN APERTURES.

FRENCH AND AMERICAN MEASUREMENTS.

No. of the screen.	Openings to the square centimetre.	No. of the wire.	Diameter of the wire. mm.	Opening between wires. mm.
60 French*	484	38	0·11	0·34
60 fr.*	484	32	0·16	0·29
60 fr.	484	28	0·20	0·25
60 fr.*	484	26	0·22	0·23
60 American	560			0·22
65 fr.	567	30	0·18	0·23
70 fr.	658	30	0·18	0·20
70 am.	760			0·185
80 fr.*	860	42	0·20	0·247
80 fr.*	860	36	0·12	0·217
80 fr.	860	32	0·16	0·177
80 am.	992			0·173
90 fr.	1,087	34	0·14	0·16
90 am.	1,255			0·15
100 fr.	1,344	36	0·12	0·15
100 am.	1,552			0·14
110 fr.	1,625	38	0·11	0·135
110 am.	1,880			0·130
120 fr.	1,936	40	0·10	0·125
120 am.	2,218			0·117
130 fr.	2,272	40	0·10	0·107
130 am.	2,618			0·109
140 fr.	2,635	42	0·90	0·103
140 am.	3,020			0·107
150 fr.	3,025	44	0·08	0·10
150 am.	3,500			0·104
160 fr.	3,442	44	0·08	0·089
160 am.	3,980			0·096
170 fr.	3,964	46	0·07	0·089
170 am.	4,495			0·089
180 fr.	4,356	46	0·07	0·08
180 am.	5,050			0·084
190 fr.	4,854	48	0·06	0·082
190 am.	5,600			0·079
200 fr.*	5,378	50	0·05	0·085
200 fr.	5,378	48	0·06	0·075
200 fr.*	5,378	46	0·07	0·065
200 am.	6,200			0·074
220 fr.	6,639	50	0·05	0·073
220 fr.*	6,639	48	0·06	0·063
250 fr.	9,259	50	0·05	0·058
250 fr.*	9,259	48	0·06	0·048
250 am.	9,700			0·061
300 fr.	12,345	52	0·04	0·05
300 am.	13,950			0·046
350 am.	19,100			0·042

* The screens marked with an asterisk are not normal screens.

The table herewith gives relative specification for fabric and screens manufactured in France and the United States. The number of the screen corresponds to the number of the squares per linear American inch of 25·4 millimetres when the screen is American and the linear French inch 27·7 millimetres when the screen is French. The dimension of the squares varies slightly according to the material used, but unfortunately there is neither specification nor official measurement registering these dimensions. It would therefore be preferable, in order to be exact, to speak of a product passing through a screen having squares with a side of 75 thousandths of a millimetre rather than to speak of a product passing through a screen having 200 squares to the linear inch.

The dimensions given in this table are those most commonly used and manufactured. Fortunately the variations are small, even negligible.

By what has been said it will be seen that no product can be correctly designated under 100-200 squares, etc., without incorporating in this designation the per cent. of the product passing through the actual area of the squares.

Ash Contents.

The common specification for coal gives only the percentage ash. While this is of great value for commercial purposes, for the purpose of pulverised fuel it is also of moment to know the composition and melting point of the ash.

Judging from the relative experience in stoker work in U.S.A. and Great Britain, the author would expect much more trouble in this country arising out of easily fusible ash. Not only is there the question of Calcium and Iron Silicates fluxing the furnace lining at high temperatures, there is also a fluxing which takes place at comparatively low temperatures, due to the presence of sodium and potassium (as Chlorides).

Little information is available in this direction with British coals, but 1,160 results have been given in an American publication for U.S.A. coals.

The sixth suggestion is that engineers who are now contemplating pulverised fuel problems should arrange for such data to be previously obtained for the coal they commonly use, and our chemical friends should also agree on a standard method of determining melting point. The action of the ash on local firebrick might concurrently be considered.

PREPARATION OF THE FUEL.

It is necessary now to turn from a consideration of the principles to the practical side of the question, although it is hoped that what has already been said has some practical bearing. At the present time it is inevitable that mention should be made and descriptions given of proprietary apparatus and systems. Moreover, there are now so many of these that many must perforce be omitted. It is hoped that contributors to the discussion will supplement the little that has been said herein.

Driers.

Attention is first directed to driers. The earlier systems such as Simon-Carves, Bonnot, Buck-Eye, Cumner, Fuller, Grindle, Sturtevant and others, dry the coal with heat supplied by burning other fuel.

Some of these systems allowed the gases to come into direct contact with the fuel, others were indirect. They were mostly based on cement practice, and all had the disadvantage of occasional overheating of the fuel, coupled with a large space taken up. The first super power station was on the Fuller system and had a separate pulverising house and rotary driers.

According to Mr. Anderson's paper the coal used in drying was about 1·3 per cent. of the total dried. Progress is, however, so rapid that the type of coal-fired driers is already referred to as " old-fashioned." This is perhaps due to the obvious advantage of drying by waste heat from the flue gases, a system introduced by the Underfeed Stoker Co. The coal descending the chute from the main bunker has a proportion of the flue gases passed transversely across it several times. These gases, being of a moderate temperature, the risk of overheating the coal is minimised. The system, however, involves a powerful fan and cyclone separator system. In various unit systems pulverising wet coal, arrangements are now made to feed the pulveriser casing with hot air from air heaters.

Pulverisers.

The number of pulverisers in use is very numerous, but it is possible to consider them systematically. Their aims are (a) slow crushing, (b) medium speed grinding, (c) high speed attrition.

For boiler work we may dismiss, without discourtesy, the large slow speed ball and tube mills which depended on screening for separating the fines. A few of the later ball mills, which are quite successful in operation, have air separation, which is the essential feature of

successful mills of types (b) and (c). In these later types the essential principle is to remove the fines by a current of air as soon as they are formed, and then by a lowering of velocity separate out particles coarser than desired and feed them back to the process again.

The Raymond is perhaps one of the best known mills in U.S.A. It has rather significantly been adopted for the recent Lopulco systems. The mechanism is that of circular rollers grinding on a ring. The coal is fed to the grinding space by ploughs and removed by the air blast. An external fan delivers the fines to a cyclone separator. Any fines not retained are returned to the mill in a closed circuit. There are several other successful mills on somewhat similar lines.

Of the attrition type there are a number of well-known examples. Great credit is due to the early example invented by Bettington and used in connection with his boiler. Other makes now coming to the front are the Atritor (Herbert), Unit type (Simon-Carves), Turbo (Stein & Atkinson), Gyro (Duffield), K.E.K. (Chemical Engineering Co.), and others in this country. Messrs. Raymond have also recently developed a pulveriser of this type.

Generally speaking, all these work at high speeds and depend in principle on battering the coal to and fro between moving and fixed hardened surfaces, which however, do not as a rule come into grinding contact with the coal. It will be seen that this idea suggests endless varieties of design. As before suggested, it appears possible that these various methods will have varying degrees of success with the wide range of coals available and the author makes here a further suggestion as to specification for pulverisation.

Before reasonable comparison can be made between various machines it is necessary to be clear on the duty required. The heads are :—

(1) Class of coal to be ground.
(2) Moisture in unground coal.
(3) Degree of fineness (see page 1218).
(4) Quantity of air delivered with coal for effective use in combustion chamber.
(5) H.P. taken per ton of coal per hour under various specifications for coal and for various outputs.
(6) Replacable parts and average life of these guaranteed for various specifications of coal.

Since some systems of type (b) use air separation, but do not deliver

any with the products, while other of type (c) deliver a large proportion and in some cases the whole of the air necessary for combustion, it is necessary to take into account all the various usages of power in type (b), not only the actual mill, but the separation fan, any elevation of the fuel to overhead bunkers, power for feeding (small) and power for injection air. Any statement that such and such a system require " X " H.P. per ton of coal requires to be examined carefully to see that all uses are included.

The author is not satisfied that it is quite fair to quote without more detailed specification the following figures which are from catalogues, and hopes that this aspect of the matter will be thoroughly discussed.

KVA.'s PER TON OF COAL AS RECEIVED.

System.	Lopulco	Turbo.	Atrito.	Gyro.	Unit.
Pulverising Mills	12·5	—	—	11	—
Conveyors	1·0	—	—	—	—
Driers	2·7	—	—	—	—
Fans	3·0	—	—	—	—
Pulverised Coal Feeder ...	0·8	—	—	—	—
	19·5	22	25	11	25

THE FUEL BURNER.

Fuel burners are at present very simple, having developed from a plain pipe which was used for blowing the mixture into a furnace with or without secondary air. As combustion chamber theory develops it will have a marked reaction on the burner. Leaving aside complicated systems of mixing such as the Arrowood, the question really turns on whether primary air is to be used merely as a means for injection, or whether it is part of the scheme of combustion. Generally speaking such types as follow from a storage system provide for a small quantity of injection air carrying the actual fuel, to be surrounded almost immediately by a proportion of secondary air say 20 to 30 per cent., and arrange for the balance of the secondary air to be supplied through furnace walls by the pull of the stack.

So far not much contact has been established in principle between these burners and those of gas and oil combustion systems, but there are signs already of splitting up the burners into small units, of flattening out the primary jet to get more intimate contact with secondary air and so on.

No vortex action seems yet to have been applied for the purpose of shortening the flame. It is considered that this part of the art is closely bound up with the system of combustion, and is susceptible of considerable variation in the immediate future.

The unit systems aim at supplying practically the whole of the necessary air at the burner, which with few large burners results in high gas velocities.

Mention should be made of the various feeding systems, the favourite of which appears to be the variable speed screw conveyor, although a revolving plate with pockets (Simon-Carves) known as a table feeder is also successfully used.

THE COMBUSTION OF THE FUEL.

This is perhaps the most interesting and controversial part of the whole subject. At first high injection velocities were used for the full mixture and combustion chambers were small. At present matters have gone to the other extreme. Injection velocities are as low as possible and the combustion chamber occupies as much as 150 per cent. of the space taken by the Boiler proper. In addition, the flame is made to travel in a " U " shape, so that it is in length nearly twice the depth of the chamber. It is under these conditions that success has been achieved.

It seems certain that under the efficient conditions of combustion which are essential to make pulverising worth while the temperatures are so high that the direct impingement of flame on brickwork is inadmissible unless the latter is cooled. This is not only due to heat effects but still more to the chemical action of the slag on ordinary firebricks. Alternative linings of refractories are only obtainable at almost prohibitive expense. Hence it is not surprising that the present-day successful system depends on partial cooling of the brickwork. This is done by making it of cellular construction and passing the bulk of the secondary air through the channels into the furnace and also by further means which will be considered later.

At Vitry, the latest example readily accessible to English engineers, the ash hopper is also of cellular construction. The author is impressed by what he saw of this brickwork construction, especially by the arrangements for expansion. Briefly, the construction depends on the steel outer wall and the brickwork is anchored up to it.

This partial cooling is, however, not considered sufficient and elaborate arrangements are now made for further partial cooling, not

only of the brickwork, but also of the combustion chamber contents by use of boiler heating surface. Popularly known as the water screen and primarily directed to the rapid sublimation of liquid and gaseous ash it has really other functions.

The success of powdered fuel must in the long run turn on efficiency, since mechanical arrangements, however faulty at first, tend to correct themselves if no fundamental principle is outraged. Efficiency turns on complete combustion with the minimum of excess air. This gives rise in theory to excessive temperature even without heated air, and with it the maximum temperature allowed by the laws of equilibrium of $CO_2+C \rightleftharpoons 2CO$. Now this maximum temperature is in some senses unrelated to any simple calculation of heat contents, and we are translated to the physical realm of other degrees of freedom for the combining molecules. In fact, not only do we come on the increasing internal energy problem, but also the " Isothermal " or " after burning " state or condition now becoming familiar in the Diesel engine.

As far as boiler heat absorption is concerned these considerations might have been only of academic interest were it not for the presence of the ash in the fuel. It is, however, the presence of this ash, whether condensed in the furnace, condensed on the heating surface, or carried into the atmosphere, which gives rise to acute questions in the mind of the average engineer.

Without some further checking of the brickwork temperature than is provided by the air jacketing, the ash is still deposited in liquid form, giving rise to congealed masses which solidify at lower loads and give troublesome working. The very clever solution has been found of checking the temperature of the flame after combustion has been well established, by using boiler heat absorbing surface. This is arranged first at the bottom of the " U " flame and then on the right hand limb. This results in rapidly chilling the outer envelope of the flame and as if the flame were entirely chilled, smoke would be produced, so with this partial chilling smoke of ash particles is formed, a proportion of which stays in the furnace as fine dust, or by analogy soot.

The flame being of the long type as used in a reverberatory furnace keeps up its incandescent temperature nearly to the end of its travel. If insufficiently chilled by then, birdnesting occurs on the front tubes, instead of a similar settlement of fine dust such as is found later on in pockets, and a fair proportion of which floats up the stack.

There are still rapid developments along the lines of this scheme which tend to correct the very small solid angle subtended by the

main boiler surface at the thermic centre of these large combustion chambers. Great care is, however, necessary not to overdo the scheme or the flame will be too much chilled at light loads.

An illustration is shown whereby a complete tube wall is constructed with gilled tubes, as a part of the furnace wall. This wall may cause deposition of dust, but if slag adheres to it this will build up to a certain thickness and melt or break off. Such action is familiar on the water jackets of copper blast furnaces.

So firmly has this general scheme of firing become fixed in the minds of American Engineers that they have reduced furnace design in theory to the burning of so much coal per cu. ft. of combustion space. This empirical relationship is already being quoted as a line of progress by saying that although the most efficient rates have been 1 to 1·5 lbs. of coal per cub. ft. per minute, efficiencies change very little in a properly designed furnace up to 2 lbs. (Savage). The author has already heard that American engineers hope to increase this to 3 lbs. In order to meet the case of low-grade fuels some authorities prefer to speak only of B.Th.U's. per cu. ft. of furnace volume. Their experience is that 4 lbs. of 6,000 B.Th.U's. coal can be burnt as easily at 2 lbs. of 12,000 B.Th.U's coal in the same space. This empirical relationship is based on no particular physical law, and the expense of the large combustion chamber has already produced a material reaction.

As before mentioned this reaction will be felt in burner design. The simple burner gives the long flame, the long flame requires the large combustion chamber. Hence it is quite natural that attention is now being paid to different systems, of which one not yet in operation will be briefly mentioned.

Most engineers are aware of the principles involved in the series—Bunsen Burner—Meker Burner—Surface Combustion. These are a progression of intensive mixtures and shorter flames.

The remarks by Mr. Raymond which I have quoted earlier will be seen to have their more pertinent application to the problem of the long "U" flame which were the conditions set for the pulveriser. It can be seen how the absence of large particles is advantageous, while the presence of much fines causes too early a rapid combustion before general combustion is forward or the flame advanced to the chilling surfaces, thus causing local brickwork and burner troubles close up to the burner.

Could we, however, conceive of an arrangement similar to a Meker burner, as in the system of Dr. Lulofs which he is installing at Amsterdam, a much shorter flame will result and the problem

becomes entirely different. Local rapid combustion is then desirable and the solid angle subtended by the chilling surfaces can be much increased. Dr. Lulofs provides a large number of small burners over the bottom of his combustion chamber and the bars of the Meker burner are imitated by the water tube screen as in other systems. The side walls are all semi-cooled by lightly buried tubes which support the brick work, and as regards the ash, the tendency will be to form a hemispherical dome of flame, the stream lines of which will be somewhat similar to the lines of force from one pole of a vertical bar magnet.

For the time being the combustion chamber is still of the lofty pattern so that if the flame is short it will lose its incandescence some distance below the lowest boiler tubes, which will be heated mostly by radiation as from a fuel bed. It will be granted that this is an interesting alternative.

Yet another scheme is postulated which is of interest, and that is one which proceeding along the lines of producer practice proposes to employ stage combustion. This has been labelled Gyro gasification. The pulverised fuel is to be fired within a cylindrical brickwork structure similar in shape to a cyclone dust catcher having a water trough at the bottom for ashes. The revolving flame of partially combusted material gives the necessary length-time element in the process. It is hoped to separate out the ash at this intermediate stage, which, at a temperature of 1,000 to 1,200 C., is hardly up to fusing temperature. Thereafter the gas is burnt with secondary air in an ordinary manner. The system is under construction in a large power station in this country, but is not yet in operation, so that no practical comments can be made on it. It does, however, open a line of vision for dealing with the ash trouble. Again the impression is made on the mind of the author, that while successful schemes are undoubtedly in operation, the whole art is in a rapid state of flux.

THE ABSORPTION OF THE HEAT.

It is necessary to be very brief on this section of the subject. So far no special boiler designs have been called for in order to meet powdered fuel conditions.

Given a short flame it is obvious that the more surface that can be got in the "front window" to absorb heat the better. In fact, considering the water screens as part of the boiler surface, we are approaching a large locomotive fire box arrangement with just the minimum of brick work to keep up the local temperature during combustion.

The experience in America as to deposit on the tubes seems to suggest that in the powdered form it presents no difficulties, and all that is necessary is a proper system of Diamond Soot Blowers. The author is a little dubious about this with some English coals, as he has known the whole of the tubes of a Babcock boiler covered with a sublimation $\frac{1}{8}$ in. thick, which proved very non-conducting and could only be removed by a thorough sooting. This was in some experiments on a chain-grate stoker running with an average CO_2 of 15 per cent.

Such a point can only be dealt with by experience. It is, however, of some importance when the efficiency to be maintained is considered. There seems no doubt that 15 per cent. to 16 per cent. CO_2 can be maintained in practice, and the fact that this greatly reduces the amount of gas to be dealt with confirms that the low exit temperatures which have already been obtained with stokers can be surpassed. Thus there is no need to cavil at the high heat transference efficiencies claimed, which approach 90 per cent. What is of much greater importance is how high can they be maintained both in course of time and at variable loads. This matters much to British engineers with their comparatively small units and poor load factors.

Here U.S.A. experience cannot help much, as there power stations are not built and run for only a quarter of the time. This point again must be put to the test of local experience. Much has been made in the immediate past of the capital cost and power taken by pulverised fuel systems. The author has never attached critical importance to this, as it should always be recognised that the cost of initial experimenting is high. The position in both directions is rapidly improving, and need not deter any engineer from making an attempt at the matter. The extra boiler rating that can be obtained from any reasonable system should be sufficiently attractive to justify a start.

Even with excess of timidity it would be worth while to fit up one boiler with an auxiliary supply over the stoker, as has been done at Amsterdam, and which the author has seen put into operation with no more trouble than if an oil jet had been turned on.

There remains the question of the ash leaving the stack. Perhaps much of the apprehension felt is due to grit troubles which have frequently occurred with forced draft stokers and high chimney velocities.

Reference to any text book on meteorology will show how the wind velocity varies with the height above the earth's surface, and will

suggest why with the high American stacks we hear of no trouble there from this course. The reader will probably also come across the statement that the fine dust from the Krakatoa eruption was carried half-way round the globe. The author thinks that under proper conditions there is not much substance in the apprehensions on this score.

APPLICATION TO BRITISH CONDITIONS.

Conditions in this country are so affected and tangled up with political matters, that the author must restrain himself from perfect frankness. Most British engineers are intensely hampered, both by the state of electrical development, and also by the mixed system of local and central government.

This checks experimenting, and the " perfect engineer " in practice is the one against whom there are " no complaints."

Hence are accepted with comparative equanimity mass complaints against the whole profession. It is submitted, however, that in this connection, experimenting is unavoidable. The classes of fuel available at any one spot are so numerous and variable in their characteristics that one plant may be a great success at one station and only a partial success at others.

The amount of unsaleable fuel is not large in any locality, as most British coals are good. Such does exist, however, and this points to experiments at the pithead, which some collieries are already commencing. Given good success with " run of mine " or " through and through " coal at the pit head or even " all below cobbles," a check would be given to the movement from the " centre of gravity of the load " to the " water facilities centre " now taking place, in favour of a movement to the " centre of gravity of fuel production."

The principal requirement, " elbow room," is equally available, and it is being found now that the margin between good cooling tower stations and riverside stations is diminishing owing to the concurrent increase in the economic size of turbines and improvement in the art of steam condensation. This is to be hoped, therefore, that one of the new stations to be built, say in Yorkshire, Derbyshire or South Wales, may be based on this consideration. It is submitted that it is imperative that the matter be tried out as early as possible.

RECOMMENDATIONS AND CONCLUSIONS.

It has been submitted, and is here repeated, that the art of pulverised fuel firing has so far successfully advanced that its application must be widely considered.

Owing to the range of apparatus available experiments can be made from the smallest scale up to the largest units yet manufactured. It is not considered that there will be no difficulties. On the contrary, it is suggested that they are there unknown, must be discovered, and met. It is, however, contended that they are not likely to be serious or permanent.

It is not necessary to depreciate existing stoker plant, which has served the cause well, and in many instances will continue in operation for local reasons for a long time.

The industrial world which at first suffered, as it thought, by the introduction of machinery, is now suffering from too little machinery. This is a half-way stage which satisfies no one. The combination side by side of a machine which does half the work and leaves the other half to be accomplished by hard labour, cannot be permanent. The engineer of the future must design, make, work and repair a machine to do his work, and concentrate on cheap manufacture, little upkeep and quick repair.

Reflection on the subject of the Switchboard controlling the boilers at River Rouge works will bring home the above suggestion more than any eloquence, and perhaps indicate the line of development in the future.

RÉSUMÉ.

OBSERVATIONS GENERALES.

Etat général de l'avancement de l'art du charbon pulvérisé—œuvre de pionnier de Mr. John Anderson de Milwaulkee—son utilisation dans les grandes stations centrales—développement simultané dans les petites stations—opinions contraires quant aux mérites des divers systèmes.

COMBUSTIBLE.

Variation dans la qualité du charbon—pourcentages de matières volatiles et de cendres—suggestion d'un essai d'inflammation pour les échantillons de charbon—proposition de classification du charbon au point de vue de la combustion à l'état pulvérisé—suggestion d'une spécification pour le broyage, discussion des différents points de vue—normalisation de la détermination de la finesse—méthode de séchage du combustible pour en déterminer la sécheresse—analyse des cendres—détermination du point de fusion.

PREPARATION DU COMBUSTIBLE.

Sécheurs—à action directe, indirecte ou par chaleur perdue—pulvérisateurs—caractéristiques des méthodes de concassage, de broyage et d'attrition—points pour une spécification concernant le travail d'un pulvérisateur—puissance prise par les divers systèmes.

SELVEY: PULVERISED FUEL

LE BRULEUR.

Considérations sur le mélange de l'air et la quantité—types de brûleurs.

COMBUSTION DU COMBUSTIBLE.

Grandes chambres de combustion—considérations de température—action des scories sur les maçonneries en briques—méthode de construction de la maçonnerie en briques—rideaux d'eau et prolongation de la surface de la chaudière dans le foyer—combustion isothermique et longues flammes—dépôt de cendres sous forme liquide et en poudre—utilisation de la surface de chauffe propre comme paroi du foyer—capacité de la chambre de combustion en indiquant les dimensions—combustion à flamme courte—sa relation avec la finesse de broyage—systèmes proposés pour son application—combustion par étage suivant les principes du gazogène—évacuation des cendres après le premier étage.

ABSORPTION DE CHALEUR.

Construction des chaudières—dépôt sur les tubes—Expérience spéciale avec des charbons anglais—rendements élevés revendiqués—question de maintien du rendement—coût de l'installation—installation auxiliaire pour pointes de charge—cendres s'échappant par la cheminée.

APPLICATION AUX CONDITIONS BRITANNIQUES.

Difficultés nationales d'essais sur une grande échelle—nécessité d'expérimenter à telle échelle qui soit disponible—Stations Centrales à la " tête du puits de mine."

RECOMMANDATIONS ET CONCLUSIONS.

Recommandation de commencer les travaux sur des applications locales—sans question à première vue de déprécier la pratique courante—nécessité de compléter le système réellement complètement fermé de manipulation mécanique de combustible—exemple de la chaudière contrôlée par un tableau de distribution.

LE FOYER SYSTEME COMBINE "PUITS-GRILLES A CHAINE" POUR LA COMBUSTION DE LA TOURBE

PROF. T. MAKARIEW

Un des principaux obstacles à l'utilisation de la tourbe pour les besoins des stations électriques a été jusqu'à present, la difficulté de faire brûler rationnellement ce combustible en quantité suffisante.

Pendant ces dernières années, par suite du changement de combustible (le charbon a été remplacé par la tourbe) à la station des tramways électriques de Léningrad (anc. Pétrograd), l'auteur a eu la possibilité d'étudier pratiquement cette question, et le foyer combiné " puits-grilles à chaîne " pour la combustion de la tourbe fut le résultat de ces travaux.

Jusqu'à ces derniers temps, la tourbe fut consommée dans des foyers à puits avec des grilles en forme de plan incliné ou des grilles à gradins, et souvent dans le dernier cas, les barreaux étaient remplacés par des voûtes en briques.

Théoriquement, le foyer à puits ne doit pas avoir les défauts des foyers à grilles ordinaires. Dans le foyer à puits, le combustible doit se déplacer graduellement le long des barreaux ou des voûtes inclinées, et il devrait par conséquent s'établir une marche de combustion régulière, dans l'ordre successif suivant : sèchage, gazéification, combustion avec formation de coke, combustion du coke, formation des mâchefers, éloignement des mâchefers.

En réalité, le tableau de fonctionnement du foyer à puits est absolument différent : par suite de plusieurs causes, le combustible n'est pas transmis régulièrement le long des grilles; la marche régulière de combustion, mentionnée plus haut, n'existe pas non plus. Le mouvement de la tourbe le long de la grille dépend de la forme et de la grandeur des morceaux, de leur poids spécifique, de leur humidité, de l'état de la surface de la grille, etc. Les morceaux plus petits et légers restent en haut, tandis que les plus grands et lourds tombent. A l'endroit où, en cas d'avancement régulier du combustible, devrait être la zone du coke incandescent

on trouve une accumulation de morceaux de tourbe qui ont roulé de la partie supérieure. Les mâchefers formés, au lieu de descendre vers l'extrémité du foyer, restent collés sur les barreaux de toute la surface de la grille. Pour les éloigner il faut brûler la grille et même les ôter à l'aide de leviers. Il en résulte que l'éloignement du mâchefer amène avec soi l'irrégularité du procédé de combustion, la pénétration d'air froid et par suite l'abaissement du rendement et de la puissance de la chaudière. Pour réduire cet effet, on imprime aux grilles un mouvement d'oscillation, mais ce moyen, comme une longue pratique l'a démontré, ne parvient pas à annuller les défauts suivants de ces foyers: (1) l'absence de succession régulière dans le procédé de combustion; (2) l'emploi de force manuelle pour le nettoyage des grilles et la descente des mâchefers; (3) la combustion mécanique incomplète, c'est-à-dire l'éloignement d'une grande quantité de combustible avec les mâchefers; (4) l'inconstance de la puissance de vaporisation de la chaudière, baissant fortement pendant le nettoyage de la grille; (5) la prompte détérioration de la grille; (6) l'impossibilité de règler la combustion et forcer la chaudière. Par suite de tous ces inconvénients il devient impossible de rendre mécanique la combustion de la tourbe avec les foyers à puits munis de grilles à plan incliné, alors que la combustion mécanique doit être une des conditions essentielles pour les foyers des station centrales électriques.

Les résultats de fonctionnement des foyers à puits avec grilles à plan incliné, en ce qui concerne la production de vapeur par mètre carré de surface de la chaudière, peuvent être caractérisés par les données suivantes:

Pour les foyers du système Stépanow, installés à la station " Electropérédatcha "—13-14 kg. par mètre carré de surface de chauffe.

Pour les foyers du système Kovalsky—17-18 kg.

Pour les foyers du systéme du Prof. K. W. Kirsch—18-25 kg.

Des résultats analogues ont été obtenus en Allemagne pour la station de Wismor, où l'on emploie des foyers à puits avec grilles à gradins. La combustion de différentes espèces de tourbe, séche et humide (plus de 35% d'humidité) n'y est pas produite rationnellement. En cas de tourbe sèche—il y a production excessive de fumée; avec de la tourbe humide—le foyer commence à étouffer. La production de vapeur pour cette station, avec de la tourbe normale, est d'environ 16 kg. par mètre carré de surface de chauffe

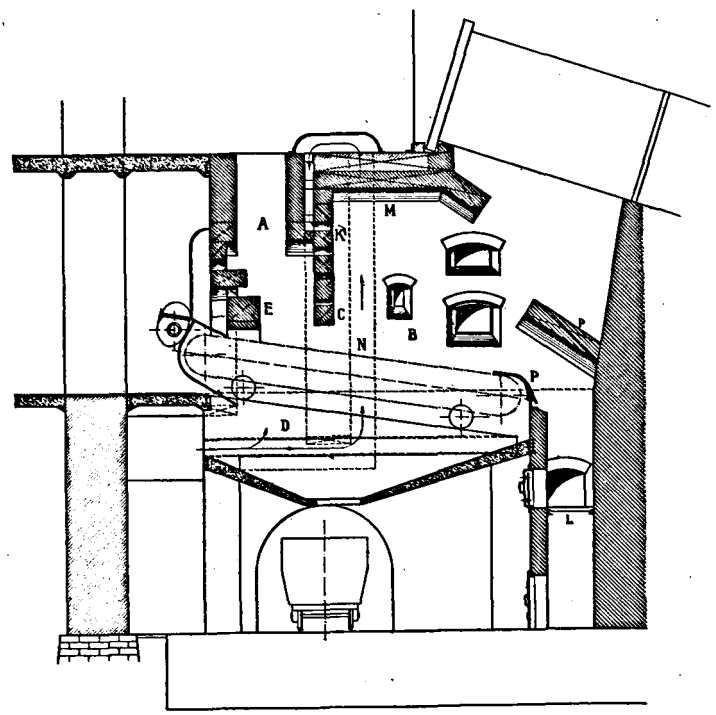
de la chaudière. La puissance calorifique de cette tourbe se rapproche beaucoup de celle des espèces russes, mais avec une teneur en cendres inférieure (1-2%). De plus cette tourbe ne forme absolument pas de mâchefers.

Afin de libérer ce type de foyer de tous les défauts mentionnés, il est indispensable de pouvoir transférer, à volonté, le combustible dans le foyer avec une vitesse convenable. C'est seulement par ce moyen que la combustion et son intensité peuvent être réglées par le surveillant.

La seule grille, pouvant satisfaire à cette condition, est la grille à chaîne, car, grâce à elle, le combustible peut être déplacé à l'intérieur du foyer sans nuire à ses qualités. Dans ce but l'auteur a pris la grille à chaîne comme base de son foyer (fig. 1).

Fig. 1.

Foyer combiné puit-grille à chaine



Le foyer est formé de deux parties : antérieure—le puits A, et inférieure—la chambre de combustion B. Les deux parties sont séparées par des petites voûtes C, sous lesquelles se trouve l'ouverture pour le passage de la tourbe. Les voûtes E sont disposées dans le mur antérieur ; la grille à chaîne N sert de fond au puits. Le séchage de la tourbe se produit dans le puits avec l'aide essentiel d'air introduit entre les voûtes E. C'est aussi dans le puits qu'a lieu la gazéification partielle du combustible. Les vapeurs et les gaz passent entre les voûtes C dans la chambre de combustion. Du fond du puits la tourbe séchée et même partiellement enflammée, grâce au mouvement continu de la grille, passe dans la seconde partie du foyer—la chambre de combustion. Cette dernière est formée par des murs verticaux, les voûtes M et la grille à chaîne. Les murs et les voûtes, lors de leur échauffement, donnent dans l'espace du foyer une haute température qui contribue : (1) au séchage de la tourbe à l'aide des voûtes C et des espaces ménagés entre elles ; (2) à la prompte gazéification de la tourbe près des voûtes C ; (3) à la stabilisation et au réglage du procédé de combustion. En outre, le mélange des gaz avec l'air pénétrant par le puits se produit aussi dans cet espace, ce qui aide à la combustion complète. En cas de besoin, par le canal K, on peut faire pénétrer dans la chambre de combustion une quantité d'air supplémentaire. Il reste encore la possibilité de surchauffer dans les canaux réservés dans les parois de la chaudière l'air servant à la combustion (non indiqué sur le dessin).

Dans la chambre de combustion ont lieu successivement toutes les phases du procédé de combustion : gazéification, formation du coke, combustion du coke, formation des mâchefers, l'éloignement de ces derniers. Pour l'éloignement des mâchefers on a prévu des dispositifs spéciaux P. En les traversant, les mâchefers tombent sur la grille supplémentaire L, où se produit généralment le dégagement des gaz et le refroidissement du mâchefer. Le coke non complètement consommé peut y tomber également lors d'un mauvais réglage de la vitesse du mouvement de la grille à chaîne. Dans ce cas il y finit de brûler. La grille supplémentaire est construite afin de pouvoir être renversée. Le procédé de combustion se produit depuis le commencement jusqu'à la fin sur la grille à chaîne.

Une quantité peu importante de mâchefer (1-1½%) tombe à travers la grille dans les cendriers. Les mâchefers contenus dans les

deux cendriers sont versés dans des wagonets et transportés hors de la cave.

Pour forcer le foyer on a recourt au soufflage. L'air est dirigé vers l'ouverture D, d'où une partie passe par les voûtes E du mur antérieur du puits. Cette partie d'air peut être réglée à l'aide de vannes (non indiquées sur le dessin). Une certaine quantité d'air superflu pénétrant dans l'espace du foyer à la fin de la grille à chaîne et entre les dispositifs pour l'enlèvement du mâchefer, aide à terminer la combustion des gaz formés dans la partie antérieure du foyer. La visière p est établie au-dessus des cendriers pour faciliter le mélange de l'air comburant avec les gaz.

La grille à chaîne est située dans un plan incliné pour former dans le foyer du côté de la chaudière un espace plus profond et pour la disposition régulière des voûtes E du côté antérieur du foyer. Suivant la qualité de la tourbe, les voûtes C sont plus ou moins rapprochées de la grille à chaîne. La position de ces voûtes fixe approximativement l'épaisseur de la couche de tourbe sur la grille. La disposition régulière du combustible sur toute la surface de la grille est acquise suivant la qualité et l'intensité de combustion, par l'altération de la vitesse du mouvement de la grille à chaîne. Pour une tourbe humide, le mouvement doit être plus lent que pour une tourbe sèche.

L'expérience a démontré que la position des voûtes ne doit être changée que dans des cas très rares, comme p. ex. lors du changement d'espèce de tourbe (de la tourbe extraite à la bêche à celle extraite à la machine). Toute autre différence dans la qualité de la tourbe, peut être réglée par l'altération de la vitesse du mouvement de la grille. Les voûtes peuvent être remplacées par des régistres réfractaires, mais l'expérience a prouvé qu'il n'y a aucune nécessité d'effectuer ce remplacement, et que les difficultés techniques résultant de leur emploi, sont très grandes.

L'introduction de l'air entre les voûtes E peut être réglée à l'aide d'une vanne spéciale, non représentée sur le dessin, suivant la qualité de la tourbe. Les voûtes C, réglant l'épaisseur de la couche de combustible, ne sont pas faites en bloc et les espaces entre elles servent, comme cela a déjà été dit, au séchage du combustible et au dégagement des gaz.

Le premier foyer de ce système fut construit à la 4ème station électrique municipale de Léningrad (Pétrograd) (Station des tramways électriques) pour une chaudière système " Garbe ", de sur-

face égale à 420 m.²; on a installé sous la chaudière deux foyers avec les puits et grilles à chaîne séparés.

La construction du premier foyer a été commencée le 10 Décembre, 1920; le 30 Mars 1921, ce foyer fut mis en marche. Les résultats de son fonctionnement furent satisfaisants dès les premiers jours. Après avoir fonctionné 16 jours, la chaudière fut arrêtée et l'on procéda à l'installation du second foyer. Le 18 Mai, 1921, ce travail était terminé et la chaudière fut mise en service régulier, depuis elle fonctionne sans interruption. A présent trois chaudières de cette station sont munies de foyers du système de l'auteur.

Les grilles à chaîne, système Babcock et Wilcox, ont une longueur de 4,300 mm. et une largeur aux barreaux de 1,5 m.

La surface utile des grilles forme 30-35 pour cent de la surface totale. La surface totale des deux grilles à chaîne est 12,9 m.², la surface utile, 9,75; la surface de combustion, 7,64 m.²; le rapport de la surface utile de la grille à la surface de chauffe de la chaudière est de 1 : 43, tandis que pour les chaudières à charbon munies de foyers mécaniques, ce rapport est à peu près de 1 : 30. Il en résulte comme nous le verrons plus tard, que la forte production de vapeur est obtenue non par les dimensions démesurées de la grille, mais exclusivement par suite de l'intensité de combustion de la tourbe.

La table ci-dessous donne les résultats des essais de fonctionnement de la chaudière pour une combustion de tourbe ayant 38% d'humidité, obtenus par le personnel technique de la station. Les pertes, non comptées dans l'essai, pour cette chaudière, étaient à peu près égales aux pertes lors de la combustion de charbon anglais sur des grilles à chaîne; de sorte que la valeur de ces pertes dépend du caractère de l'installation.

Les données obtenues, peuvent être comptées comme moyennes; pour d'autres essais, les résultats obtenus furent bien meilleurs, tant pour la production de vapeur que par l'excès d'air comburant. Pour une tourbe ayant 30% d'humidité la production de vapeur a atteint jusqu'à 50 kg. par mètre carré de surface de chauffe.

La plus grande difficulté fut d'obtenir une combustion complète. Les travaux furent menés dans deux directions différentes; l'amélioration du mélange des gaz et la conduite d'air supplémentaire. A présent, grâce à ces travaux, la combustion incomplète oscille entre des limites inférieures à 0,5% d'acide carbonique,

et dans beaucoup de cas, on réussit à obtenir une combustion complète avec un excès d'air inférieur à 1,5%.

Les chiffres suivants donnent l'analyse des gaz avant l'économiseur, servent à fixer cette question, les données étant moyennes pour une chaudière forcée journellement pendant cinq heures.

Date.	CO_2.	$CO_2 \div 0$
5/XII.	14·8	20·1
8/XII.	14·7	20·2
12/XII.	13·8	20·2
14/XII.	14·5	20·1
16/XII.	11·6	20·3
25/XII.	12·1	20·1
26/XII.	14·5	20·0
26/XII.	14·5	20·0

La teneur en CO était égale à zéro, et l'excès d'air comburant $\alpha = 1{,}35$.

Une production de vapeur égale à 41,3-50 kg. par m.² ne se rencontre pas dans la pratique moderne, une telle puissance de vaporisation n'a même pas pu être obtenue avec les meilleures qualités de combustible, comme le charbon anglais.

Une des caractéristiques de l'espèce de tourbe, fournie à la station de tramways électriques de Léningrad (Pétrograd) est sa grande humidité, et, dans ce cas, il est très difficile de régler le procédé de combustion. Néanmoins, quoique la quantité moyenne d'humidité de la tourbe atteignit jusqu'à 47%, la moyenne de la production de vapeur, pour le mois de Décembre, 1922, était égale à 25 kg. par m.² de la surface de chauffe de la chaudière, ce qui peut être compté, même pour un bon charbon anglais, comme un chiffre assez élevé. On a même réussi à faire fonctionner la chaudière avec une tourbe ayant jusqu'à 60% d'humidité. La combustion de toutes les espèces de tourbe, trouvées aux alentours de Léningrad (Pétrograd) et Moscou était complètement sans fumée.

Comme on l'a déjà indiqué, le foyer peut fonctionner avec ou sans soufflage. Ce dernier permet de forcer la chaudière, ce qui est surtout utile pour la combustion de tourbe humide ou en petits morceaux. L'expérience a montré qu'avec le soufflage on peut augmenter la production de vapeur d'environ 30 à 40 %. On détermina, après beaucoup d'observations, que la pression dynamique du courant d'air exerce une influence capitale. Avec un vide statique général sous la grille, le courant d'air atteint dans certains endroits, une pression dynamique égale à 3,5-4 mm. Grâce à cela, on peut forcer la combustion dans telle ou telle zone en y dirigeant un courant d'air approprié.

Essais de la chaudière " Garbe " 420m.² de surface de chauffe, avec économiseur " Green " de 280 m².

NO.	Observations.	Données.
1.	Durée de l'essai ... ... heures	6
2.	Date de l'essai	8—X—1922
	I. COMBUSTIBLE.	
3.	Constitution du combustible employé %	
	C	33·2
	H	3·8
	(O+N)	20·8
	Humidité, W	38
	Cendres, A	4·2
4.	Puissance calorifique utile de la tourbe ... ... cal./kg.	2,900
5.	Combustion horaire de tourbe ... ... kg.	5,940
6.	Idem par mètre carré de surface de combustion ... kg.	778
7.	Idem par mètre carré de surface utile de la grille (couverte de tourbe)... ... ... kg.	610
8.	Quantité de particules non consommées, tombées à travers les barreaux de la grille/en pourcent de la quantité de combustible utile	0·33
	II. QUALITÉ DE LA VAPEUR.	
9.	Pression absolue de la vapeur ... ... kg./cm.²	13·5
10.	Température de la vapeur surchauffée ... ... °C.	370
11.	Quantité de chaleur contenue dans la vapeur	765
12.	Température de l'eau d'alimentation à son début	10°C.
	III. L'EAU.	
13.	Consommation d'eau par heure	17,400 litres
14.	Température de l'eau avant l'économiseur	10°C.
15.	Idem, après l'économiseur...	110°C.
16.	Coefficient de vaporisation dans les conditions d'essais...	2·93
17.	Idem de vapeur normale	3·47
	IV. CHARGE DE LA CHAUDIÈRE.	
18.	Production de vapeur par mètre carré de la surface de chauffe	41·3 kg.
	V. ANALYSE DU GAZ DANS LA CHEMINÉE.	
19.	Avec l'appareil d'Orsa, CO_2	12·17
20.	CO_2+0	19·82
21.	Par la formule, CO.	0·2
22.	Coefficient d'excès d'air	1·58
	TEMPÉRATURE.	
23.	Température des gaz dans la cheminée	235°C.
24.	Température de l'air à son introduction dans le foyer ...	21°C.
	TIRAGE	
25.	Tirage du gaz dans la cheminée	26
26.	Vitesse du mouvement de la grille m/h	3
	BILAN THERMIQUE.	
27.	Rendement de l'installation de la chaudière	76 %
28.	Pertes dans les gaz perdus	14·15%
29.	Pertes résultant de la combustion chimique incomplète	1·03%
30.	Pertes résultant de la combustion incomplète des particules de tourbe tombées dans le cendrier à travers les barreaux	0·92%
31.	Autres pertes	7·9%

Données moyennes pour le mois de Mars 1923, pour la chaudière No. 18.

$CO_2=12·3$ $CO=0$

$CO_2\div 0=20·2$ $Z=1·58$

Le premier foyer fonctionne depuis trois ans déjà, cette période est plus que suffisante pour avoir eu la possibilité d'étudier à fond les qualités de ce foyer.

La question capitale pour le fonctionnement de la station est la sûreté du travail du foyer. Cette sécurité dépend de la régularité du travail de la grille à chaîne, de l'usure des barreaux, des dispositifs de nettoyage des grilles et de la maçonnerie. La maçonnerie, comme l'a montré l'expérience, tient plusieurs mois. Même les voûtes qui devraient être la partie la plus faible du foyer, tiennent 4-5 mois, sans réparation. Le mâchefer brûle jusqu'à la fin, de sorte qu'il n'existe presque pas de combustion mécanique incomplète. La quantité de mâchefer éloignée par les dispositifs et celle qui tombe à travers la grille, est très voisine de la teneur en cendres, déterminée par l'analyse chimique et la différence entre elles est inférieure à un pour cent.

Outre l'emploi déjà décrit, les foyers du système de l'auteur furent installés à la station provisoire de Chatoura (près de Moscou). On installa sous la chaudière No. 2 deux grilles à chaîne, dont la largeur est 1,2 m., et la longueur 3,915 m. (de centre à centre des axes). La longueur de la partie active est 3,2 m.; la surface active des grilles (couverte de tourbe) est 7,7 m.^{2} et la surface de combustion 6,4 m^2.

Pour une charge du turbo-générateur (5,000 kw.) de 1,500-1,700 kw. la vapeur était fournie par une chaudière à foyers type "Puits-chaîne à grille." Le 18 Août, 1922, le personnel de la station a obtenu quelques données essentielles, caractérisant le travail du foyer. Les résultats des essais démontrèrent, que la charge moyenne du turbo-générateur était approximativement égale à 1,900 kw., la consommation de tourbe par kwh. était égale à 1,86 kg. Le remplissage des carneaux avec des cendres entrainées n'a presque pas lieu. Pour 15 jours de fonctionnement de la chaudière à la station de Chatoura, du 5 au 20 Mai, 1922, la quantité de tourbe consommée fut de 861, 1 t. (52,570 pouds), et la quantité de cendres trouvées dans les carneaux de la chaudière, fut seulement de 368,55 kg. (25,5 pouds), c'est à dire=0,04%, et dans les carneaux sous et autour de l'économiser 90,09 kg. (5,5 pouds), c'est à dire 0.01%; total, 0,05%.

A la station des tramways électriques de Léningrad (Pétrograd) pendant un mois de fonctionnement, la quantité de tourbe consommé fut 180,8 t. (110,000 pouds) et la quantité de cendres

trouvée dans les carneaux de la chaudière et de l'économiseur fut d'une tonne (60 pouds), c'est à dire, 0,055%.

La station Chatoura, en plus de la chaudière stationnaire, fut bientôt munie de deux chaudières Babcock et Wilcox, type semi-marine, ayant une surface de chauffe égale à 340 m.² chaque.

La surface utile des grilles à chaîne (couverte de tourbe) de chaque chaudière est égale à 7,7 m.², et le rapport de cette surface à la surface de chauffe de la chaudière est 1 : 44,2.

Les essais de combustion de tourbe dans les foyers du système de l'auteur effectués par une Commission spéciale, sont caractérisés par les données suivantes :

Humidité %	Production de vapeur par mètre carré. kg.	Rendement %	Température des gaz perdus. °C.
20,78	55,1	73,3	287
20,99	49,1	74,2	265
20,00	48,5	74,6	250
25,48	41,8	75,5	267
23,63	43,2	74,3	269
26,00	55,0	75,0	250

Ces données démontrent que l'emploi des foyers type " Puits-grilles à chaîne " permettent d'obtenir par mètre carré de la surface de la chaudière 2,5-3 fois plus de vapeur qu'avec les foyers d'autres systèmes, avec un rendement de 75%, qui peut être augmenté jusqu'à 79% et plus par l'emploi de la chaleur des gaz perdus. De plus, l'accroissement de la surcharge de la chaudière ne diminue pas le pourcentage du rendement.

En comparant les résultats obtenus par la Commission mentionnée ci-dessus avec l'opinion des personnes surveillant le fonctionnement du foyer type " Puits-grilles à chaîne," on peut fixer les qualités suivantes, par lesquelles ce type de foyer se distingue d'autres types de foyers actuellement employés :

1. La combustion possible de toutes sortes de tourbe (extraite à la bêche, à la machine, hydrotourbe) ayant des pourcentages d'humidité différents allant jusqu'à 60%. La tourbe ayant une humidité pareille ne peut pas être consommée dans les foyers d'autres systèmes.

2. La combustion facile des petits morceaux de tourbe, non-utilisables avec d'autres systèmes de foyers.

3. Le rapport entre la surface de la grille à chaîne et la surface

de chauffe de la chaudière est inférieur à celui des foyers mécaniques à charbon.

4. La quantité de tourbe, consommée sur 1 mètre carré de la surface de combustion est égale à 600 kg/h.

5. Pour une tourbe d'humidité normale, la production continue de vapeur par mètre carré de la surface de la chaudière est de 45 kg. En forçant la chaudière, on peut obtenir 55 kg. et plus. Pour les foyers d'autres systèmes, lors de travail continu, la production de vapeur est en moyenne égale à 14-17 kg. par mètre carré.

6. Pour la production de vapeur donnée dans le § 5, le rendement de l'installation est de 75%. En employant la chaleur des gaz perdus il peut être augmenté jusqu'à 79%. Ayant maintenant obtenu une combustion presque complète (presque égale à zéro), on peut espérer un rendement atteignant 82%.

7. La combustion mécanique est presque complète, car la quantité résultante de mâchefer et de cendres est très proche des données obtenues par l'analyse chimique. Dans les foyers d'autres systèmes, le grand inconvénient est l'éloignement avec le mâchefer d'une grande quantité de coke et même de tourbe fraîche, ce qui a une grande influence sur la consommation de combustible par kwh.

8. La couleur du gaz à la cheminée, qui dépend de la qualité de la tourbe et de l'installation, varie d'une complète absence de fumée, jusqu'à une fumée moyenne. Il est impossible d'obtenir ces résultats avec des foyers d'autres systèmes, surtout pendant le nettoyage.

9. Le travail du foyer est absolument sûr; les barreaux des grilles ne s'échauffent pas et ne se couvrent pas de mâchefers. La maçonnerie du foyer tient plusieurs mois sans réparation. Le plus grand défaut des foyers à grilles en plan incliné est la détérioration des grilles par le feu et la démolition des parois du foyer le long des grilles.

10. Le prix de la réparation est insignifiant par suite du service prolongé des grilles et du revêtement du foyer, tandis que pour d'autres foyers le prix des réparations forme une grande partie des dépenses totales d'exploitation de l'installation.

11. Le régime de fonctionnement de la chaudière est constant. Pour d'autres foyers l'oscillation moyenne du régime est au moins de 50%, en raison de la formation de mâchefer sur la grille et du nettoyage du foyer.

12. Le réglage de la puissance de la chaudière est facile. On peut facilement régler le travail de la chaudière en élevant sa puissance jusqu'aux plus hautes limites et en la déchargeant instantanément de cette limite à zéro. Ce réglage est obtenu en changeant la vitesse du mouvement du combustible. Pour les autres systèmes il n'y a pas moyen de changer cette vitesse et, par conséquent, de régler le service de la chaudière entre de larges limites.

13. Malgré une surcharge démesurée le dépôt de cendres dans les carneaux de la chaudière et de l'économiseur est très insignifiant, égal à peu près à 0,05% du poids total de la tourbe. L'accumulation de cendres dans les carneaux des chaudières à foyers d'autres systèmes est souvent la cause de la diminution rapide de la puissance et de fréquents arrêts de la chaudière pour le nettoyage.

14. Le nettoyage de la chaudière se produit automatiquement, en débarassant les grilles du mâchefer à l'aide de râbles. Le mâchefer tombe sur une grille supplémentaire où il se refroidit et où tous les gaz dangereux qu'il peut contenir sont evacués par la cheminée. Le mâchefer sorti du cendrier est absolument pur et ne donne aucune émanation. Le nettoyage du mâchefer dans les foyers d'autres systèmes, est fait périodiquement et à la main, et représente une besogne très sérieuse, le local du foyer se remplit de gaz étouffants qui ont une influence néfaste sur la santé des ouvriers.

15. Le travail des chauffeurs est réduit au minimum et le nombre du personnel nécessaire est très limité.

L'emploi des foyers " Puits-grilles à chaîne " pour le chauffage à la tourbe permet le chargement mécanique, et en conséquence, la tourbe est devenue pour les stations centrales, un combustible de grande valeur.

Quels sont donc les avantages que l'on peut retirer de l'emploi des foyers " Puits-grilles à chaîne "?

Ils donnent une économie de combustible de 30 à 40%.

L'emploi de ces foyers augmente de 2,5 à 3 fois la puissance des chaudières; les dépenses pour l'équipement de l'installation sont au moins 2 fois plus faibles, alors que généralement elles forment la plus grande partie du prix total de la station.

Il existe une opinion que l'emploi des foyers " Puits-grilles à chaîne " n'est avantageux que pour des grandes stations, à cause du prix élevé des grilles à chaîne. Cette opinion est absolument fausse. L'installation des foyers " Puits-grilles à chaîne " est

aussi avantageuse pour une surface de chaudière comparativement petite, commençant avec des capacités de 150 m.² et même moins, suivant la quantité de tourbe consommée annuellement.

Pour de grandes installations, le prix de grilles à chaîne est à peu près 7% du prix total de l'installation ; pour de faibles puissances, il n'excède pas 15%, de sorte qu'en dépensant pour la grille à chaîne 15% du prix de l'installation, on réduit au moins de moitié le prix de l'installation elle-même, car la puissance de la chaudière sera augmentée de 2,5 fois.

Outre la réduction des prix, le plus grand avantage réside dans l'économie de combustible. Les calculs ont montré l'avantage qu'il y avait à remplacer les vieux foyers par ceux du système de l'auteur dans des installations moyennes et même petites. Les dépenses nécessitées par ce changement, sont complètement couvertes en 10-12 mois par l'économie de combustible.

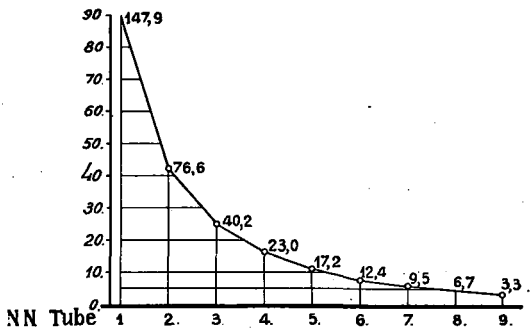
En ce qui concerne l'usure des chaudières, la tourbe a une grande supériorité par comparaison avec les combustibles de haute puissance calorifique (charbon de bonne qualité et surtout mazout).

Les combustibles de haute puissance calorifique, selon leur nature, donnent généralement lieu pendant la combustion à des températures beaucoup plus élevées que celles produites par des combustibles de faible puissance calorifique, il en résulte que les premiers rangs des tubes de la chaudière reçoivent une plus grande quantité de chaleur des gaz échauffés. De plus, pour les charbons de bonne qualité et pour le mazout, les foyers sont construits de façon à transmettre à la chaudière le plus de chaleur possible par rayonnement. La quantité de chaleur, transmise de cette façon dans les cas favorables, atteint à peu près 25% de la quantité totale. La chaleur de rayonnement est complètment absorbée par les premiers rangs des tubes. Par suite de ces deux causes, la formation de vapeur tombe surtout sur les premiers rangs de tubes, qui, grâce à cela, sont extrêmement forcés, tandis que les derniers rangs prennent dans le procédé de vaporisation une part très insignifiante. Le diagramme suivant représente la part que prend chaque rang de tubes de la chaudière (fig. 2.).

Le premier rang donne 147,5 kg. par mètre carré, tandis que le dernier—ne donne que 3,3 kg.

Cette surcharge démesurée d'une partie au détriment de l'autre est souvent la cause des avaries de chaudières : les rangs extérieurs brûlent, se courbent, etc. En outre, en forçant la chaudière on

Fig. 2.



obtient une formation de vapeur trop impétueuse, qui ébranle les rangs inférieurs des tubes.

Avec le chauffage à la tourbe, cette irrégularité dans le procédé de formation de vapeur n'existe pas, car la température des gaz dans le foyer, en raison de la nature de la tourbe, est beaucoup moindre; et la transmission de chaleur par rayonnement à cause de la nécessité de faire ces foyers mi-clos, est comparativement insignifiante (on peut la prendre égale à 5-10%). Par conséquent, avec le chauffage à la tourbe, toutes les parties de la chaudière fonctionnent avec plus d'égalité, il en résulte que la surcharge de la chaudière est plus sûre et son fonctionnement plus régulier.

En forçant une chaudière horizontale ordinaire à tubes d'eau, chauffée au mazout jusqu'à 55 kg. par mètre carré, il y a grand danger de brûler les rangs inférieurs des tubes et de détruire la maçonnerie, tandis qu'avec le chauffage à la tourbe, le fonctionnement de la chaudière pour une charge pareille est complètement sûr.

Trois annés d'expérience d'exploitation des foyers " Puits-grilles à chaîne " avec les chaudières " Garbe " et presque deux années avec les chaudières stationnaires Babcock et Wilcox, ont complètement fixé ce point de vue. Pendant tout le temps du service interrompu de ces chaudières avec un poids de vapeur de 35 à 40 kg/m.2, aucune avarie ne s'est produite.

Outre les deux stations électriques nommées ci-dessus, les foyers " Puits-grilles à chaîne " fonctionnent dans quatre usines de sucre, et dans l'usine mécanique " Krassnoyé Sormovo."

Toutes les stations actuellement en construction en Russie, à chaudières chauffées à la tourbe, munissent leurs chaudières avec des foyers du système de l'auteur comme p. ex. Chatoura, Nijni-Novgorod, " Krassni Oktiabre " (Lèningrad), Jaroslavl, Ekaterinbourg, "Electropérédatcha," etc. Les trusts de l'industrie textile de Kovroff, Orekhovo-Zouévo et " Ouraltextil," ont procédé à l'installation de ces foyers. Prochainement on se propose d'adopter ces foyers pour les stations existantes de Kiew et de Pskoff.

RÉSUMÉ.

A complete description is given of a new system of self-feeding furnace combined with a chain grate stoker, for burning peat.

The author claims that with this arrangement all the difficulties encountered in the burning of peat under boilers are eliminated and that a regular combustion is obtained, even with peat containing as much as 40% of moisture; the process follows the following regular order: Drying, gasification, combustion with formation of coke, coke combustion, formation of clinker, removal of the clinker.

Some figures give the steam produced per square metre of heating surface of the boiler for several self-feeding furnaces with inclined grates used in Russia; the Stepanow system gives 13 to 14 kg. per sq. met.; the Kovalsky system 17 to 18 kg., and the system of Prof. K. W. Kirsch 18 to 25 kg. All these systems, however, have many defects: difficulty of working with peat of different kinds or of various degrees of moisture, excessive production of smoke, absence of flexibility, etc.

From the section it will be seen that the furnace is divided into two parts: part A is the self-feeding furnace itself, part B the combustion chamber with chain grate N. Small arches (C) separate both parts, and underneath them is the opening through which the peat passes into the combustion chamber. The drying of the peat is obtained in part A with air passing through arches E, its combustion occurs in part B, where all the successive phases of the process take place; scrapers (P) have been provided to remove the clinker.

Forced draft is generally used. The speed of the chain can be modified according to the production of steam required and the quality and amount of moisture of the peat.

Information is supplied on the first furnace of this system in operation since March 1921 at the Fourth Municipal Power Plant at Petrograd using two Babcock & Wilcox chain grate stokers; the production of steam reached 50 kg. per sq. m. of heating surface. Complete results of tests are given, showing an efficiency of 76%. The experience gained during the past three years has been very valuable; arches last from four to five months without repairs, the chain grates last longer than with coal, the formation of clinker corresponds practically to the percentage of ash given by the chemical analysis.

Similar furnaces have been installed at the temporary power plant of Chatoura. Practical operating results are given.

Combustion tests made by a special Commission are tabulated, showing that with this system an evaporation can be obtained equal to 2,5 to 3 times the

evaporation obtainable with other systems of furnaces, and an efficiency of 75%.

The advantages of this system are then fully described, and mention is made of the fact that it can be applied to boilers having 150 sq. metres of heating surface and even less. The question of cost, fuel economy, and repairs are discussed; regarding repairs, it is pointed out that with coal-fired boilers the first rows of tubes produce the bulk of the steam (as shown on diagram 2); with the furnace of the author, the steam production is more evenly distributed, less repairs being the result.

All the plants now in course of erection in Russia for peat burning are being equipped with this new system of furnace.

OUTSTANDING FEATURES OF SWEDISH PRACTICE IN STEAM POWER PRODUCTION

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Thanks to the abundant water power supply and the widespread electric transmission lines, which connect the power producers with the power consumers, steam power in Sweden is mostly used for traction purposes and only in a smaller degree for the driving of mills. The power production for traction purposes will be treated in various papers at the Conference. It is, therefore, sufficient to give in this paper a general review of the trend of development.

In stationary steam power plants, the co-operation on the one hand with the hydro-electric plant and on the other hand with the steam plant of the mill for heating purposes, has created interesting types of plants and arrangements, typical of Swedish practice. It is, therefore, intended to deal more in detail with some of the problems that arise out of this co-operation.

I. STEAM POWER FOR TRACTION.

The most important consumers of steam power for traction purposes are railways and ships. Automobiles, aircraft and so on, use exclusively internal combustion engines, and can, therefore, be omitted from this paper.

The development of Swedish locomotives has run parallel with the development in other countries. The introduction of compound engines, of superheaters and of feed water pre-heaters has meant many improvements in fuel economy. Among newer constructions in this field should be mentioned the corrugated, spiral shaped boiler tube, improving the heat transmission from the flue gases to the water of the boiler. Thus a better economy is possible for the same length of the boiler. Its disadvantages are increased resistance to the flow of the flue gases, which must be overcome by a more rational arrangement of the blower, as well as a somewhat increased difficulty in removing the soot deposits, which, however, is of less importance.

At present (December, 1923), trials in regular traffic on the State railways are going on with a condensing steam turbine locomotive of the Ljungström type. The builders of this locomotive have, quite unbound by tradition, produced an engine, in which the steam turbine and its condensing plant have, very fortunately, been adapted to suit the demands of rail traffic. The engine is equipped with a pre-heater for the combustion air. All the auxiliaries, the centrifugal blower, the feed water pumps, the condenser pumps and the ventilators of the condenser, are driven by steam turbines, whose exhaust steam is used for pre-heating the feed water in two stages. The fuel consumption is about half that of a quite modern ordinary locomotive. The water consumption is practically nil.

As a marine engine, also, the steam turbine is forging ahead. Such turbines are mostly equipped with mechanical reduction gear, but sometimes with electrical transmission gear. The turbines have the well-known advantage of lower steam consumption and lower weight than the reciprocating engines. There are two main firms, A. B. de Lavals Ångturbin, Stockholm, and Svenska Turbinfabriks A. B. Ljungström, Finspong, that build turbines of Swedish design.

Air pre-heating in marine service as well as in stationary plants is also progressing. The advantage of this measure is that the air pre-heater takes the place of the economiser on board, where the latter cannot be used, and in heat consuming industries, where hot condensate is used as feed water. In Sweden, the Ljungström air pre-heater is the most common. It can be defined as a rotary heat regenerator, in which the heat accumulating mass revolves very slowly and conveys the heat from the flue gases to the combustion air.

II. STATIONARY STEAM POWER PLANTS.

The totally installed capacity of stationary steam power plants in Sweden at various dates is shown in Table I.

TABLE I.
Installed H.P. in stationary steam power plants in Sweden.

	Thousand H.P. installed.		
	1913	1917	1921
a. Sundry industries	160	146	104
b. Sawmills	84	106	101
c. Industries consuming heating steam...	72	87	107
d. Electric power stations	76	118	166
Total steam power installed ...	392	457	478
Total power installed	1,139	1,467	1,784

Such steam power plants, which do not produce steam for heating purposes, or at any rate do not do so on a large scale, and where no waste wood is available, are one by one shut down and replaced by water power from the electric transmission systems, mentioned above. The sawmills, burning their own refuse, continue to do so. Industries consuming heating steam, such as paper mills and cellulose mills, extend their back-pressure plants and produce cheap steam power in combination with the heat distribution. The electric power undertakings increase primarily their water power stations, but also simultaneously their auxiliary steam power plants. It is typical of the development, that the steam turbine very rapidly supersedes the reciprocating engine. In 1913, turbines represented 27 per cent. of the total installed steam power, they increased to 36·5 per cent. in 1917 and reached 52 per cent. in 1921. This phenomenon must be viewed in conjunction with the fact that the small separate steam engine units disappear and that modern plants, as built to-day, are generally fairly large and almost always interlinked electrically.

It is not safe to assume that all the steam power plants, recorded in statistics, are actually working. A factory, connected with a hydro-electric station, for instance, often retains the old steam power plant, at least for some time. It is very difficult to find buyers for old engines because of the fast spreading electrification. Sometimes the old plant is used as a stand-by during water shortage and interruptions in the electric power system.

In the following we intend to examine the above mentioned types of steam power consuming industries and give a few characteristics of each of them.

a. SUNDRY INDUSTRIES.

The total amount of steam power installed in all these plants, usually small, was 104,000 H.P. in 1921. Many of these plants, perhaps half of them, were not working. But some of them, such as the power plants of brickyards and dairies with an aggregate power of 20,000 H.P. are certainly used. These plants are numerous and very small, and in consequence the electric transmission lines can scarcely reach them. As to the dairies, these also use steam for heating purposes. Thus a dairy cannot dispense with the boiler and its attendant apparatus by the introduction of electric power. However, an investigation has just now been started to ascertain if the whole demand of energy of the dairies for motive power, as well as for heating, could not be supplied by electricity. Such a

combination is perhaps practicable because of the possibilities for accumulating steam during the night and using it in the daytime. With this arrangement the cost of power can be kept quite low. The general trend of development is that such small steam power plants are shut down, as soon as they can be reached by the spreading branches of electric transmission lines. New plants of this description are, therefore, very few, and their only interest, from the point of view of fuel economy, lies in their value as a warning.

b. SAWMILLS.

No less than 20 to 25 per cent. of the available steam horse-power is installed in sawmills which use their waste wood, especially sawdust, as fuel. A great number of small mills, often with portable engines of 25 to 50 H.P., are erected in the woods of south and central Sweden, but the mills that count in this respect, are the great works in northern Sweden with power plants of 500 to 2,000 H.P.

Sawdust as a fuel is rather troublesome, because of its moisture and its very low calorific value per unit of volume; 450,000 cal. per cubic metre or 50,000 B.Th.U. per cubic foot, being a common figure. This is the reason why it cannot be stored or transported, but must be burnt practically at the rate it is produced at the mills.

However, water forces its way even into this industry. If a sawmill is allied with some other steam consuming industry, the sawdust is used to produce steam for heating purposes in the latter. Such a combination is formed, if the sawmill is supplemented by a cellulose mill. The sulphate cellulose mills especially use waste wood from the sawmills and from the forests as raw material. In such cases all sawdust, and also the larger refuse of very poor quality, is generally burnt in the boilers of the cellulose mill to raise the steam needed for heating purposes. This steam is first led through a back-pressure turbine to produce power, before it is utilised in the digesting and drying plants. Before the war, the additional power needed was often supplied by condensing turbines; now, for the most part, water power is used.

Fuel economy is often a thing unknown in sawmills. Twenty years ago such mills in many cases had special yards, where the surplus of sawdust was disposed of by being burnt in furnaces, otherwise it would accumulate in great useless heaps. But nowadays this state of things has in most cases improved. The introduction of thin saw-blades and other improvements in sawing methods have done much to reduce the waste. If there are other industries in the neighbourhood of a sawmill, especially sulphate pulp mills, these

will appear as consumers of the larger refuse. In such cases the difficulty is not how to get rid of the sawdust, but how to make both ends meet, in other words, the problem of fuel economy arises here too.

The Fuel Research Board of Ingeniörsvetenskapsakademien (Swedish Institute for Scientific and Industrial Research) has made a thorough investigation of furnaces of semi-producer type, which are commonly used for firing sawdust and waste wood. It has been found that in most cases the working conditions of the furnaces could be much improved. In particular, it is to be recommended that a continuous charging, a fuel not too moist and a sufficient supply of secondary air be used. It was ascertained that with a high percentage of moisture in the fuel, 50 per cent. or more, almost complete combustion took place in the furnace, so that the gas produced by it was hardly combustible. For such moist sawdust a better type of furnace must be found, and just now a furnace with stepped grate is being installed in a sawmill for trial. Improved efficiency is also to be gained by drying the fuel and pre-heating the combustion air. These measures tend to raise the furnace temperature, and thereby the economy as well as the evaporative capacity of the boiler. Even the limited reduction of the moisture that can be effected by using the waste gases of the boiler for drying is of good service. The drying is sometimes made in drying towers, where the hot flue gases pass horizontally through a vertical fuel column, sometimes in chambers, where the gases are led through perforated wagons containing the fuel. Experiments carried out with rotary drums, in which the hot gases and the fuel are intimately mixed, have also proved the possibilities of using driers of this design. At all events, precautions must be taken that the fuel does not catch fire as it comes into contact with the hot gases. This can, however, be easily overcome.

C. INDUSTRIES CONSUMING HEATING STEAM.

The main industries of this type in Sweden are the paper mills and the cellulose mills. The sugar works and refineries, the breweries and the match-factories can also be counted among these. The other industries belonging to this group are of very small account in the power market.

The match-factories have a particular position, inasmuch as their own waste wood suffices for the generation of the needed heating steam, and out of this steam a sufficient quantity or rather a surplus of power can be generated by back-pressure steam engines or turbines.

The cellulose mills need a very great quantity of steam for

digesting and drying purposes, and they are important power consumers. At the boiler pressures at present used, their power demand cannot be completely filled by back-pressure turbines. Earlier, this lack of power was usually made up by condensing turbines, either working independently or connected to the back-pressure turbines, so as to form bleeder-turbines. During the war, however, these condensing turbines were taken out of service and water power introduced instead. This co-operation between back-pressure turbines and hydro-electric plants has given rise to a great many interesting regulating problems. The steam flowing through the turbine is regulated by the back-pressure, which thus is held constant. The turbine then delivers the exact quantity of low-pressure heating steam needed in the mill. To the bus-bars, all the energy is delivered that the turbine can generate out of this steam. As the three-phase generator of the turbine is connected to the transmission lines from the distant water power station, the speed of the turbine is kept constant by the speed governors in the water power plant. If the speed of the turbine exceeds the normal value by, for instance, only 5 per cent., its governor begins to throttle down. When this occurs the back-pressure tends to drop and the balance of low-pressure steam needed is by-passed direct from the boilers through a reducing valve. In practice it has been found quite feasible to get the turbine governors to work satisfactorily, even if the back-pressure turbine is built as a bleeder with a bleeding-pressure about midway between the admission pressure and the back-pressure. The reducing valves of the makes commonly obtainable in the market have, however, shown a distinct inability to fulfil the requirements as to precision of working and reliability that must be imposed on them for such service.

In the paper mills, various combinations are used. In a certain mill, the reciprocating steam engines for driving the variable part of the paper making machines are retained. The heating steam needed, in addition to the exhaust steam of these engines, flows through a back-pressure turbine to the common low-pressure pipe. In another mill the whole amount of heating steam passes through a back-pressure turbine, driving a three-phase generator connected with the bus-bars. The paper making machines are driven by direct-current motors fed through Ward-Leonard converters. Another mill again, has the back-pressure turbine coupled to one three-phase generator and to two direct-current generators of different voltage. The direct-current motors of the paper making machines can thus work with three different tensions, and thereby obtain a wide range

of speed regulation. The three-phase generator is connected with the water power station and works as a generator or as a synchronous motor, according to circumstances.

On the whole, efforts are made to build and install back-pressure engines and turbines with the lowest possible steam-consumption per kWh., the highest possible yield of power from a given quantity of heating steam being thus obtained. Also the efforts to build boilers for very high pressures aim at the same result. It may be worth mentioning that an "Atmos" boiler, constructed for a pressure of 60 atmospheres (850 lbs.), has been working in a sugar refinery in Gothenburg since the end of 1921, feeding a back-pressure turbine for 50 atmospheres admission pressure (700 lbs.) A new boiler of the same make with a pressure of 100 atmospheres (1,400 lbs.) was put into service in October, 1923.

Many industries consuming heating steam have found it profitable to install Ruths' steam accumulators in order to smooth the load curve of the boilers, thus increasing their economy and facilitating their operation. This accumulator also increases the power that can be obtained from the back-pressure turbine, as the steam flow through the turbine will be constant. It may here be mentioned that the firm of A. B. Vaporackumulator, Stockholm, has in an excellent way solved the problem of building reliable reducing valves, by equipping them with sensitive oil relay governors.

The fuel saving possibilities of economisers in these industries are fairly limited, as the feed water of the boilers mostly consists of hot condensates. The waste heat of the flue gases can, however, in such plants be utilised by installing air pre-heaters, as mentioned above.

d. ELECTRIC POWER STATIONS.

In the year 1921, there was a total amount of 166,000 steam H.P. installed in electric power stations built for distribution purposes. Definite reports for 1922 are not yet available, but a preliminary estimate gives a total of some 205,000 H.P. divided as shown in Table II.

TABLE II.

Large stations with more than 15,000 H.P.			
Västerås	60,000		
Stockholm	55,000		
Gothenburg	20,000		
		135,000	
Medium-sized stations between 1,500 and 15,000 H.P., numbering 14		60,000	
Small stations smaller than 1,500 H.P., numbering 20...		10,000	
Total ...			205,000 H.P

The great stations in Västerås and a couple of the medium-sized stations have for the most part to work only during water shortage. But all the others, lying as they do in towns or in industrial centres, have three different purposes:

1. To act as stand-by during water shortage.
2. To act as stand-by for disturbances in the transmission system.
3. To take the local peak loads off the water power stations and the transmission lines.

All these stations work with a very low load factor, but nevertheless it has generally been found profitable to equip them with boilers and turbines of the most economical design.

The more modern stations are usually built on about the same lines, with the main axis of the boiler room perpendicular to the turbine room axis. The Stockholm central, the oldest part of which was built in the year 1900, has boiler room and turbine room running parallel. Thanks to the excellence of planning, the arrangement is still very convenient there. Even the medium-sized stations, often containing only one generating unit and one or two boilers, are usually built to a design similar to that of the big modern stations, as this plan gives almost unrestricted possibilities for extending the whole station or the main parts of it, such as boiler house, turbine room and switchgear.

The experience of the author, who has planned or co-operated in the planning of half of these medium-sized plants, is that such must be built with special consideration for the necessity of being run by as small an experienced permanent staff as possible. Thus the coal handling apparatus must, in an eight-hour day, transport the total amount of coal needed during 24 hours. The capacity of the bunkers must be large enough to keep a coal supply for at least 16 hours. The removal of ashes must be made as easy as possible. The boiler room and the turbine room should be put close to one another on the same level, and the door-way between them should be so situated that a view of the working places of the boiler room, turbine room and switchboard may be possible from this point. The switchboard should be placed on the same level as the turbines.

It is also an advantage to place the floor of the condensing room (it should not be a dark cellar but a well-lighted room) on the same level as the ash handling room of the boiler house even if, thereby, the latter room is made a trifle higher than is necessary. A sufficient number of convenient, not too steep, stairs must also be provided for.

The purpose of these stations to take the peak loads and to act as stand-by plants in case of disturbances, makes rapid starting indispensable. It is usually the time necessary to get the boilers under steam that settles the length of time required for the starting of the station. This time can, of course, be materially reduced if the boilers are continuously kept under pressure. With the Stockholm plant, this is accomplished with the aid of an electrically heated boiler of 2,000 kW. capacity, fed with water power during periods of sufficient water supply. Other stations too, have adopted the same arrangement or keep one boiler under steam in order to keep them all warm. Oil burners are also often installed in order to accelerate the starting-up process of the boilers.

At two plants, recently built in Malmö and in Halmstad, the time for starting the station has been still more reduced by installing Ruths' steam accumulators. The turbine can be run at full load with steam from the accumulator, until the boilers are heated up to overtake the load. The accumulator, when loaded, is always ready to supply immediately. At these plants it is, thus, the turbine that settles the length of time necessary for starting the station.

At Malmö, this time is about three minutes plus the time necessary for synchronising. At the official trials, a turbine of 3,750 kW., starting cold but with a vacuum in the condenser, was fully loaded in 6½ minutes after starting. The vacuum is maintained by a small 10 H.P. condensing machine that is always running.

At Halmstad, a turbine of 800 kW. was, at trials, started cold, in 18 seconds, with the condenser machinery running, and was fully loaded in 120 seconds after starting.

These turbines, manufactured by A. B. de Lavals Ångturbin, Stockholm, work with a normal admission pressure of 13 to 14 atmospheres (185 to 200 lbs.), but when using steam from the accumulator they can give full load at a pressure of 1·5 atmospheres (22 lbs.). This is made possible by a series of by-passes, automatically governed. The steam economy of the turbines, working with normal boiler pressure, is nevertheless almost unimpaired.

If the generating set is kept running by water power with the alternator used as synchronous motor for improvement of power factor, the set, with the aid of the accumulator, automatically takes over the load, if the transmission line breaks down.

I have dwelt at some length on these auxiliary steam-plants, because they are typical of and necessary for towns supplied with power through transmission lines from a distant station. If a transmission system is designed so as to operate with good economy

at normal load, the loss of power at peak load will be considerable. Thus the machinery installed in a distant station must have some 20 per cent. greater output, than if it were installed in the town it is intended to supply. And in these days a town of 20,000 people or more cannot tolerate an interruption in the electric lighting due to fault on the transmission lines. Help of short duration can be given by a storage battery, but for greater power demands, internal combustion engines for smaller units, and quick-starting turbine sets for larger units are indispensable. And it is, in this sense, of no consequence whether the distant power station is driven by water or steam.

RÉSUMÉ.

Les points essentiels concernant la pratique Suédoise de production de force motrice par la vapeur, peuvent être résumés comme suit :—

1. La multitude de petites centrales séparées disparaissent rapidement et leur service est assuré par les centrales hydrauliques.

2. Les scieries conservent leurs centrales à vapeur, chauffées à la sciure de bois, mais si elles sont combinées avec des fabriques de cellulose ou autres usines, elles sont souvent électrifiées et alimentées par les centrales hydrauliques.

3. Les industries consommant de la vapeur pour le chauffage, continuent à installer des turbines à contre-pression, ou dans les cas de petites usines de machines à contre-pression, et cooperent généralement avec les stations hydrauliques.

4. Les centrales électriques à vapeur se développent rapidement et sont utilisées comme centrales auxilliaires, pour suppléer à la force motrice pendant les périodes de basses eaux, pour fournir les pointes de charge et pour servir de réservoirs en cas de dérangements sur les lignes de transmission.

Les problèmes qui se présentent par suite de la coopération intime entre la force hydraulique et la force à vapeur, coopération si fréquente en Suède, sont souvent résolus avec tant de succès, que leur étude est d'un intérêt général dans tous les cas où les conditions existent pour une coopération semblable de deux ou plusieurs sources différentes d'énergie.

COMPLETE AND INCOMPLETE COMBUSTION WITH REFERENCE TO COMBUSTION ECONOMY

OLOF RODHE, STOCKHOLM

Satisfied that there is no interest or use in writing about the elementary principles of combustion for the readers of this paper—that carbon when burning forms carbon dioxide or carbon monoxide, and so on, I start upon this subject where the real combustion problem is brought before my mind.

COMPLETE AND INCOMPLETE COMBUSTION.

Let me draw your attention to a bucket perforated with holes, distributed uniformly over the sides. If I want to fill this bucket with water up to the brim, I find that I have to use a good deal of water *in excess* of the normal capacity of the bucket. A lot of the water pours out through the holes and the more completely I want to fill the bucket, the more water is wasted in excess. The quantity of water in excess depends on the number of leaks and their size.

If the bucket had *no leaks* I should need a quantity of water just equivalent to the capacity of the bucket: the *complete* filling of the bucket then would take place *without any excess* of water.

Let us apply this metaphor about the bucket to what happens in the combustion chamber. In order to obtain a *complete* combustion of a solid fuel, we have to use a certain amount of *excess air* and the amount of this excess of air is, independent of the construction of the furnace, dependent on different varying factors. If, for instance, the coal is burnt in larger pieces, the excess of air must be increased to attain complete combustion, and this also is applicable if the temperature in the combustion space is decreased. With the same coal, but in smaller pieces, the excess of air can be decreased almost to the theoretical amount of air necessary for complete combustion, as in the case of powdered coal, liquid fuels and gas fuels.

These factors, having the same effect on the combustion economy as the escape of air not used for the combustion, can thus be considered as *leaks* in the fuel bed.

When we recognise that combustion economy is dependent on a reduction of the heat losses, and that the most important loss of heat is the one due to heat escaping up the chimney stack, we then have to look to our " leaks " and to realise above all that there are " leaks " which are unnecessary and avoidable. This being clear we shall be able to decrease the " leaks " and obtain a higher degree of combustion economy.

As already mentioned, the " leaks " are indicated by the quantity of excess of air used for complete combustion. It is claimed that this indication can be realised by analysing the flue gas for its content of CO_2, and the object of this paper is to prove that the CO_2 readings do not tell the whole story of how to obtain combustion economy and a saving of coal. The CO_2 indication may, in this respect, be misleading, and may even result in an unnecessary waste of fuel because of its ambiguity.

This ambiguity of the CO_2 indication is illustrated in Figs. 1, 2 and 3, which refer to a solid fuel containing

Carbon	(C)	80 per cent.
Hydrogen	H_2	4 ,,
Sulphur	S	1 ,,
Oxygen	O_2	9 ,,
Nitrogen	N	1 ,,
Moisture		4 ,,
Ashes		1 ,,

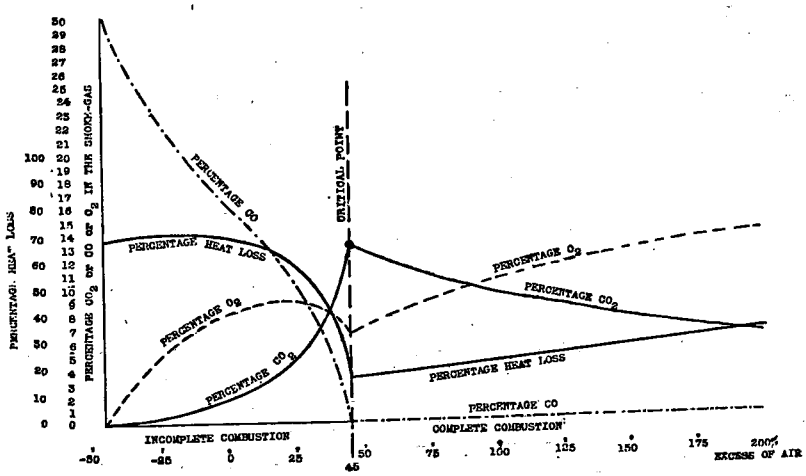

Fig. 1.

The curves show the variation of CO_2, O_2, CO and heat losses, calculated from well-known formulæ[1] which I think it is unnecessary to repeat here. The loss due to sensible heat is computed for a temperature of the flue gas, leaving the boiler, of 330° centigrade.

Fig. 1 shows the curves for an extraordinarily hard burnt coal, in fact a sort of coal which requires a considerable excess of air for complete combustion. The part to the left of the ordinate, extending from the 45 per cent. point (excess of air) includes the period of incomplete combustion and complete combustion is not obtained without an excess of air of 45 per cent., corresponding to a content of CO_2 of about 13 per cent. A higher CO_2 percentage cannot be reached with this kind of fuel, for if the quantity of air is decreased for the purpose, it will immediately result in incomplete combustion. This CO_2 percentage I have denominated THE CRITICAL POINT OF COMBUSTION, indicating a minimum of " leaks " and resulting in a minimum of heat losses.

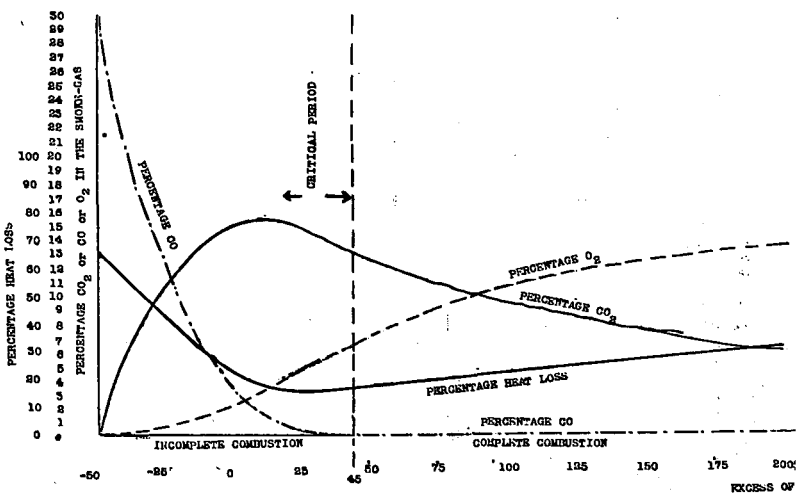

FIG. 2.

It is of interest to compare Fig. 1 with Fig. 2, answering to a very easily burnt coal, only requiring a small " leak " for complete combustion. It is of particular interest that for this type of coal the critical point is, so to say, extended over a varying excess of air and that the heat loss within the space covered by said variation is the

[1]See : " Unvollkommene Verbrennung und Feuerungskontrolle " by Ingenieur D. Haarmann, Hamburg, Feuerungstechnik, Jahrgang 10, Heft 16.

same, even when a small amount of combustible gases is present. As far as combustion economy is concerned, it is, in fact, not risky with such a fuel to have perhaps up to one or two per cent. of CO present in the smoke gas and, as we are here working with an extended critical period, it is much easier to maintain an economical combustion with such a fuel.

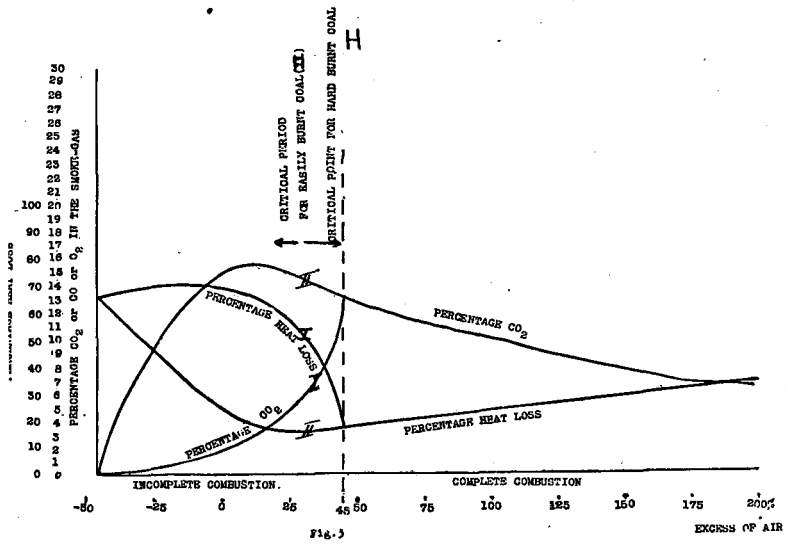

FIG. 3.

In Fig. 3 the two preceding figures are brought together, showing the different results of combustion obtained with different kinds of fuel. The combustion process of all kinds of coal is included within these two limit curves. In fact, it is in a measure possible to classify the different fuels after the " leaks " at combustion, stating critical points or critical periods. (Hard burnt and easily burnt coal obviously refer to different kinds of coal burnt under the same conditions. The furnace conditions can, of course, make a hard burnt coal comparatively easily burnt, and *vice versa*.)

The actual point of the above curves and the most interesting one is, however, that with a mere CO_2 reading one never knows when the critical point is reached, *i.e.*, if the flue gases contain combustible gases or not. There may be more or less combustible gases or there may not. In order to obtain the best combustion economy by keeping the critical point, we must absolutely possess means for a double indication, both of CO_2 and CO.

There is no doubt that realisation of the CRITICAL POINT means an important step forward to an economical combustion and if watched by an intelligent and interested fireman, will help to bring about the saving of fuel we want to arrive at in our boiler plants.

RÉSUMÉ.

La lecture des indications sur la teneur en CO_2 ne nous dit pas tout ce qui est nécessaire pour réaliser l'économie maximum de charbon.

Les indications sur le CO_2 peuvent être trompeuses sous ce rapport; elles peuvent même, par suite de leur équivoque, aboutir à un gaspillage inutile de combustible car la lecture des indications sur le CO_2 peut être interprétée de plusieurs manières.

Le point indiquant le moment où les pertes de chaleur sont au minimum, est dénommé "le point critique de combustion." Il faut que nous connaissions ce point là et, pour cette raison, nous devons avoir dans nos installations de chaudières des moyens d'obtenir une indication double, c'est-à-dire à la fois sur le CO_2 et sur le CO.

STEAM ACCUMULATION

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INTRODUCTION.

The efforts made in the last few decades in the development of the economical use of energy have had in view the co-ordination of the various plants for the generation and use of mechanical and heat energy, in such a way as to enable excess and waste energy to be utilised as completely as possible.

The construction of the individual elements of those plants has been carried through, it is true, in excellent manner, but nevertheless it has comparatively seldom been the case that an exact investigation has been made of the influence that the *variations* in the rate of production and consumption of heat and mechanical energy exercise on the working methods and the overall efficiency obtained. On the contrary, the heat balances of such installations have invariably been laid down, as if the source of energy to be used on the one hand, and the consumers of energy on the other, were delivering and absorbing energy at a constant rate without any variations.

In practice those variations have been accepted as an unavoidable nuisance, the partial counter-action of which is generally attempted by means of forcing the boilers. This method, however, causes considerable losses, owing to the fact that the supply of heat on the one hand and the consumption of heat or power on the other are by no means equivalent in quantity nor coincident in time. Alternatively, attempts have been made to equalise the variations by the introduction of large gasometers, of gigantic lead accumulators, or of Ilgner flywheels, etc.

There is, however, an excellent means available for the accumulation of energy up to any desired amount, viz., that of storing steam under increasing pressure and temperature in hot water confined in a closed vessel and discharging it by re-evaporation from the water under falling pressure and temperature. The variation of the heat content of the water with the temperature is thus utilised for heat accumulation purposes. Although this method is fairly generally known, it has not

hitherto, owing to certain prevalent prejudices, been applied in practice to the extent that it deserves.

On account of the fixed relation between the boiling temperature and the pressure on the water, the utilisation of this method in a rational manner pre-supposes that variations of pressure ranging up to several atmospheres should be permissible. As a matter of fact, every steam boiler of very large water content could, in principle, work as an accumulator of this kind, but in order that the boiler may act as an equaliser, it must be constructed for a pressure far above the normal working pressure, so as to provide a range for presssure variations between the maximum and the normal working pressure. The fact that no such increased pressure has been provided for, but that, on the contrary, the boilers are usually constructed for a pressure only so much higher than the steam pressure required, as corresponds to the pressure drop in the pipe lines, proves that the value of the principle referred to has not been fully appreciated.

Instead of aiming at accumulation by permitting variations of pressure, efforts were and are still, on the contrary, directed towards keeping the boiler pressure as constant as possible. It is usually considered as evidence of good management if the boiler pressure diagrams approximate as closely as possible to straight lines.

As, however, with constant boiler pressure, no accumulator action of the boilers is possible, it follows that the quantity of heat conveyed from the fire to the heating surface per unit of time must in each moment exactly correspond to the amount of steam that the boiler is required to supply. It is therefore evident that the variations in the steam demand must cause corresponding variations in the fuel supply to the boiler. As already mentioned, however, boilers of older systems possess a certain, but, as will be shown below, limited capacity for equalisation. In boilers of more modern types, however, the water space is far too small for any equalisation of variations worth mentioning. Attempts have been made to increase the water space in water-tube boilers (e.g., in the MacNicol type); owing, however, to difficulties encountered in construction, this result could only be attained at the expense of the height of steam pressure, so that boilers of that kind are, in fact, merely a sort of compromise between the old cylindrical boiler and the new water-tube boiler, and are a product of unscientific

thinking. Thus, on the one hand, attempts were made to obtain equalisation in the boilers, and on the other, it has been tacitly assumed that the pressure should be kept constant, which meant, of course, that no accumulation was possible.

The only correct solution of the problem of rational steam plant design is to employ the steam boiler exclusively as the steam generating agent, and to dispense entirely with the use of the boiler as an accumulator. Accordingly, the steam generator would be built with very small water space, or even with none at all—in the latest constructions the steam generator is, practically speaking, simply a coiled pipe—and worked at an absolutely constant and very high pressure. Instead of (as at present) every boiler of common type having its own water tank, which consequently must be built to stand the full boiler presssure, the water spaces of all the individual boilers should be, so to say, united into one tank, entirely separated from the boilers and well insulated against loss of heat. In such tanks, usually built for pressures lower than those of the boilers, a much larger variation of pressure is permissible than in boilers. Furthermore, these tanks can be built of any size, irrespective of the type of boilers used or of the size of their heating surface.

In order to illustrate the importance and scope of this idea, an analogy from a different invention may be cited. I refer to the well-known success that was obtained by Ilgner in the equalisation in power plants by separating the energy storing flywheel from the main engine and driving it by a separate engine. In this way, Ilgner succeeded in overcoming great variations of short duration in the rate of power consumption of certain types of machinery, such as rolling mills, hoisting plants in mines, etc., which variations it had not been possible to overcome by the use of flywheels arranged in the usual way.

This same principle has been applied by the author to the production and use of steam, and he has thereby succeeded in eliminating all variations in the rate of supply as well as in the consumption of steam. In the same way as Ilgner separated the flywheel from the main engine, the writer has separated the water space from the boilers and placed it in a separate container, in which the steam is accumulated or stored under pressure. By this means the mass of accumulating water

working in the steam system, representing a large "flywheel effect," can be increased to any desired extent. As it is not necessary that the accumulator should be built to stand the high pressure of the boilers, full use can be made of the property of hot water to accumulate much more steam at low than at high pressures for a given pressure drop.

The importance of this may be clearly seen from Fig. 1, in which the amount of steam evaporated per unit of volume (1 m.^{3} or 100 cu. ft.) of boiling water for a certain pressure drop (1 kg/cm.^{2} or 10 lbs. per sq. in.) is shown for various

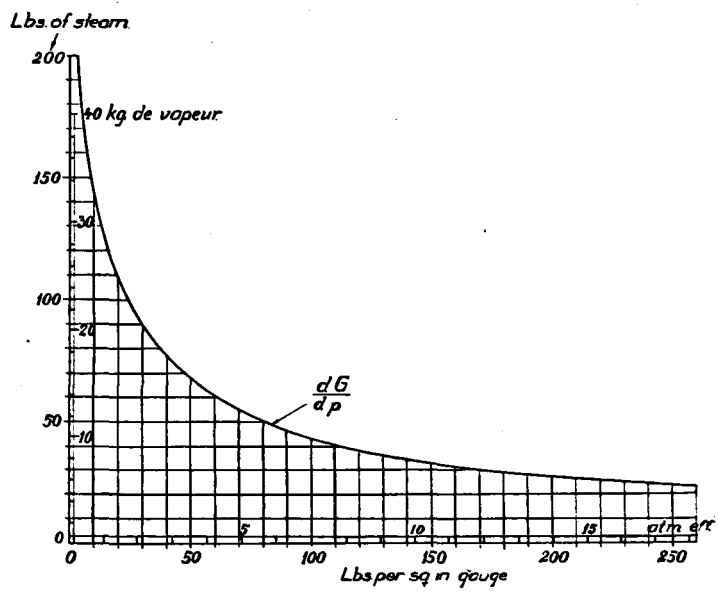

Fig. 1.

The amount of steam produced by 100 cu. ft. of water of high temperature by a pressure drop of 10 lbs. per sq. in. at various levels of steam pressures.

steam pressures. It must also be observed that the accumulator, when separated from the boiler, can be so arranged that a very much greater pressure-range may be permitted in it than is possible in a boiler.

The accumulation of steam in water and its subsequent re-evaporation is a well-known principle and has for a long time past been used by practical engineers; in this connection

reference may be made, for instance, to the Rateau accumulators and also the feed water accumulators by Druitt Halpin and others. The direct storage of steam *without* water has also been tried in practice both in containers of constant volume and in containers of variable volume.

In all the cases just mentioned, however, with the exception of the feed water storage systems, the definite aim in view has been that of accumulating the exhaust steam of hoisting engines, rolling-mill engines, etc., which work intermittently, so as to make it possible continuously to pass the exhaust steam from these engines into low pressure turbines, even during the intervals when the main engines are at rest. The author, however, did not want to confine himself merely to the saving of exhaust steam, as Rateau and other engineers had done, but set himself the problem of overhauling the entire heat and power economy of industry, from the point of view of the accumulation of steam in water.

A survey of the literature on this subject shows that the conditions affecting this general question have not been fully recognised earlier, so that there was not only the task of solving the problem to be done, but first of all to work out a clear and definite formulation of it. That this was necessary is conclusively proved by the fact that the number of cases is very small in which the *variations* in the production and use of energy, especially heat energy, in the various branches of industry have been systematically studied.

In researches extending over many years in a great variety of industries, the author has made a large number of measurements of the rate of heat supply and steam consumption. Out of the results of that work the problem of *general steam accumulation* was formulated and its subsequent solution evolved.

The diagrams in Figs. 2, 3 and 4 give a few typical examples of how the steam consumption varies in different industries.

A study of such diagrams, representing the actual conditions in industry, will show that in by far the majority of industries it is a question of accumulation of a comparatively large body of steam if real elimination of the cumbersome variations is to be attained.

I. THE EQUALISING ABILITY OF STEAM BOILERS OF VARIOUS TYPES AS COMPARED WITH THAT OF THE ACCUMULATOR.

As a consequence of the fact that the amounts of the variations

actually existing in industrial plants are not generally known, there is a tendency to believe that sufficient accumulation of

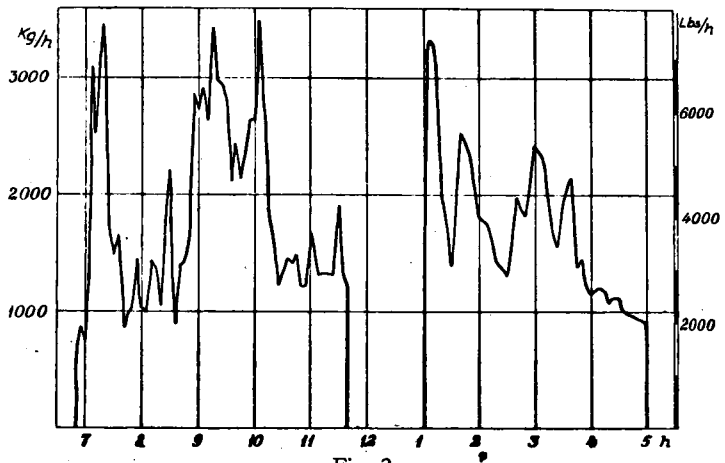

Fig. 2.
Steam consumption in a dye works.

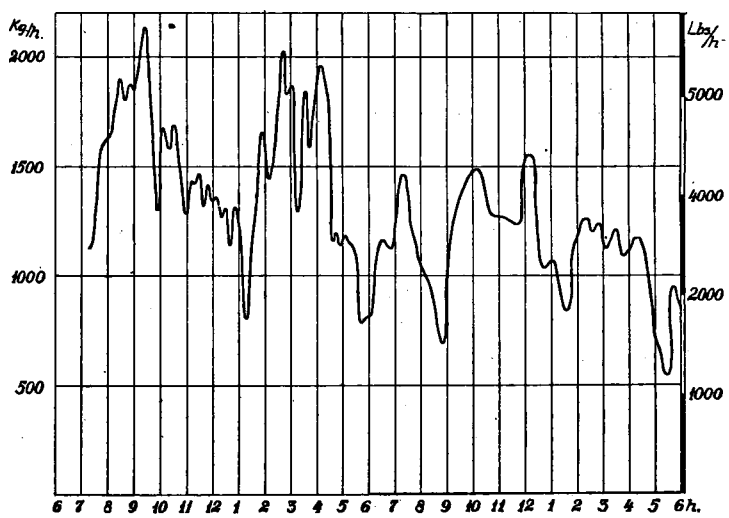

Fig. 3.
Steam consumption in an oil-hardening factory.

steam could be made in the steam boilers themselves. In order to make the matter clear, there are shown below some

calculations, based upon a typical diagram of steam consumption as obtained in practice.

The demand of steam varies in a particular case (see Fig. 5) between 8,800 and 31,000 lbs. per hour, with an average of about 19,400 lbs. per hour. The diagram shows how large are the areas between the curve and the line of mean consumption, i.e., the amounts of steam in lbs., which have to be equalised in such a typical case, if the boilers are to work economically at the constant average load of 19,400 lbs. per hour.

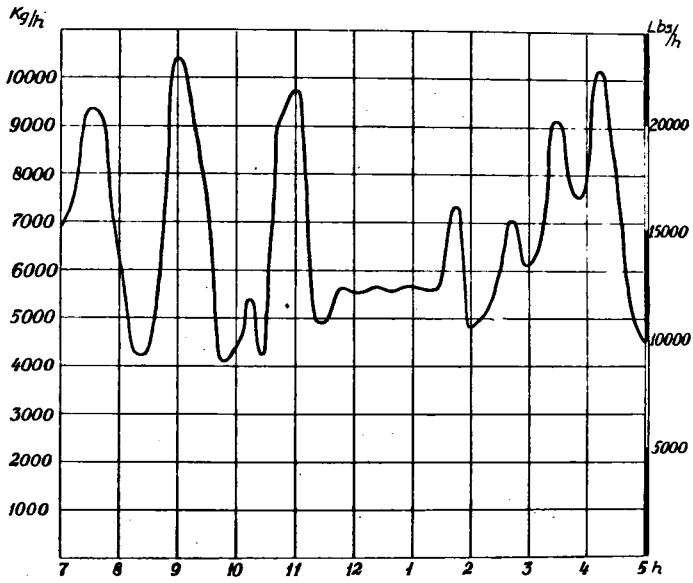

Fig. 4.
Steam consumption in a rubber factory.

A boiler plant big enough to deliver the maximum amount of steam required, 31,000 lbs. per hour, would, when using normal boilers of the Lancashire, the MacNicol and the common water-tube type, have an approximate size of 5,800, 5,800 and 4,500 sq. ft. respectively.

If as big a pressure drop as 20 per cent. could be permitted at peak-loads the *extra* steam given off by the water of the boilers on such occasions would, however, amount to only 3,900, 2,400 and 825 lbs. respectively, whereas if the system of

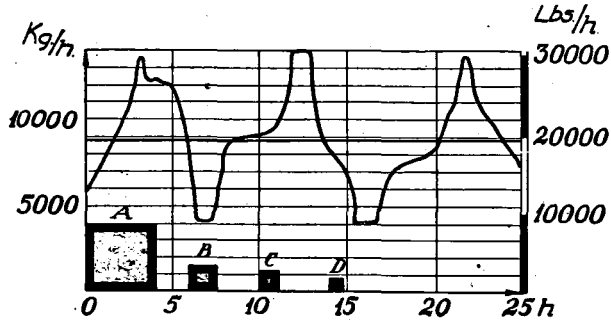

Fig. 5.

Diagram of steam consumption in a factory and the size (A) of the accumulator capacity that has to be installed for complete elimination of the variations, as compared with the accumulative capacity of (B) flue boilers, (C) MacNicol boilers (D) and standard water tube boilers. In the first case the boiler pressure remains constant, in the other it varies by 20 per cent.

steam accumulation here discussed were adopted, an accumulator of a capacity corresponding to the 35,000 lbs. of steam, needed for the full equalisation of the boiler load, would be installed.

In Fig. 5, the storage capacity of the accumulator needed, and that of the boilers specified above, is represented by four squares A, B, C and D, drawn to the same scale as the steam diagram, showing that in the particular case under review the equalising effect of the accumulator must not be less than 8-10 times that of the Lancashire boilers, 14-15 times that of the MacNicol boilers, and about 35-40 times that of the standard water tube boilers.

From this it is evident that when great variations exist in a steam system the equalisation problem can never be solved by boilers alone, but only by means of a steam accumulator working in conjunction with, although separated from the boilers. This method offers the additional advantage that the pressure in the boilers remains perfectly constant, whereas, in the case of the direct storage or accumulation of steam in the boilers as in cases B, C and D, the pressure, as mentioned, is bound to vary considerably more than generally can be admitted in practice.

Even the Druitt Halpin accumulators and others of similar system, containing feed water which is to be heated by surplus steam from the boilers and which is subsequently to be fed into

the boilers during peak loads, are of very little value for practical steam accumulation in industry, as the highest peak loads that can be overcome by them amount only to some 10-15 per cent. of the average steam production, or even less if, according to general practice, the feed water is pre-heated in economisers by the flue gases.

The system of heat accumulation to be described below, however, permits the equalisation of any peak loads in the steam system, regardless of their size, height or "shape," or of the size or type of the boilers, etc., used.

It is true that this new kind of steam accumulator may have to be built in sizes hitherto unusual. Thus, for instance, the Swedish firm "Aktiebolaget Vaporackumulator" of Stockholm, has built tanks up to a capacity of 12,000 cu. ft. In one works an accumulator of a capacity of no less than 37,000 cu. ft. had to be installed, but it was subdivided into three separate tanks. Whereas the Rateau accumulators and the accumulators of constant volume or constant pressure, in view of the special purpose for which they are used, work with variations of pressure of some 3 to 5 lbs. per sq. in., accumulators of the system here described are usually built for very much larger pressure ranges, e.g., from 100 to 30, from 60 to 20 lbs. per sq. in., and so on. Owing to the larger volumes employed and the much greater pressure variations that can be admitted, these accumulators generally possess a very much larger storage capacity than those of the other types. Whilst the latter are built with a storage capacity of only a few hundred lbs. of steam—an amount quite sufficient for their particular purpose—these accumulators are generally built to hold from 5,000 to 40,000 lbs. of steam, and a plant has actually been built to store as much as about 150,000 lbs. There is, of course, practically no maximum limit to the size of such tanks. I may refer to the very big steel "tanks" used as supply pipes for water turbines. Such pipe-lines sometimes have a length of several miles, a diameter of 17 ft. or more and work under pressures of several atmospheres. Similarly, there is no minimum limit to the size. Accumulators of only 70 cu. ft. capacity are actually in operation.

II. DESCRIPTION OF THE ACCUMULATOR SYSTEM.

General Arrangements.—The accumulator system of the author consists of two main parts; the steam accumulator proper,

containing the heat storing hot water under pressure, and the automatic valves, etc., which control the co-operation of the boilers and the accumulator and which also govern the steam distribution in the whole steam system of the works.

The Accumulator.—The accumulators are built in the form of cylindrical containers with hemispherical ends, being the safest and in other respects most favourable form. They are filled with water up to 90-95 per cent. of their capacity. Fig. 6 shows a sectional view of an accumulator.

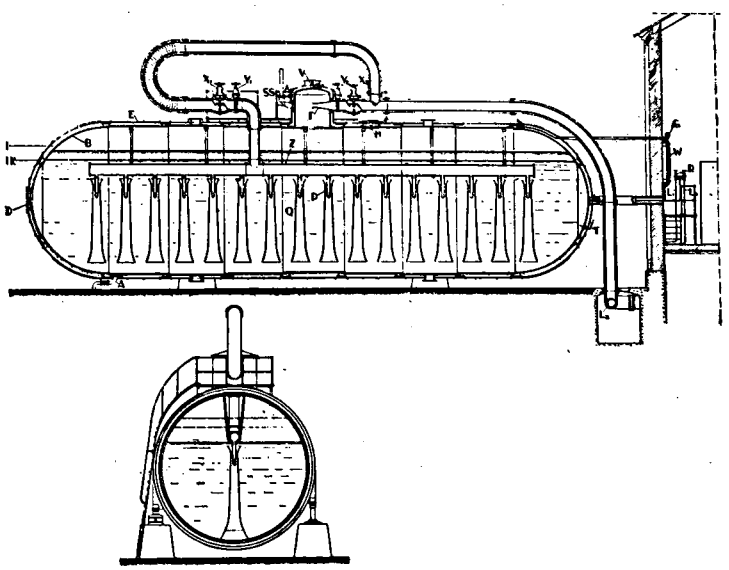

Fig. 6.
Sectional view of an accumulator.

B is the vessel constructed of riveted steel plates. I is a covering of non-conducting material, usually consisting of 3 to 5 inches of infusorial earth (Kieselguhr) or infusorial earth mixed with cork, or of a magnesia composition. J-K are insulation blocks covering the riveted seams of the shell. They are often made removable, so as to enable the inspection of the seams to be readily carried out. The lagging is protected by a sheet iron cover, E, when the accumulator is erected out of doors.

The accumulators are equipped with the fittings usual in boiler practice and further with arrangements for the charging and

discharging of the steam. The non-return valve X_1 admits charging steam to the internal steam distribution pipe Z and the charging nozzles P, which are equipped with the circulation pipes Q to ensure a uniform heating of the water. Through the non-return valve X_2 attached to the steam dome the discharge of steam takes place.

By this arrangement of non-return valves only the steam quantities corresponding to the variations in the steam demand or supply pass through the accumulator. The average steam demand is supplied by the boilers. The accumulator is, therefore, connected to the steam system by a single pipe L_3. A free and strainless expansion of the accumulator shell at variations in the pressure and temperature of the water inside is provided for by supporting it on roller bearings.

Heat Losses of the Accumulator.—The heat losses of the accumulators are considerably less than is generally imagined, and as a matter of fact so small, that they are of no practical consequence. Results of insulation tests made on accumulators in practice show that with the thicknesses generally adopted the heat losses only correspond to from 0.1 to 0.5 per cent. of the coal consumption of the boilers, and are therefore of no practical importance. That being so, and as they need practically no attendance, the accumulators are usually erected in the open air, and often at some distance from the boiler-house, in factory yards, etc.

Accumulator for Superheated Steam.—From the description above it is evident that the accumulator, although it can be charged with superheated as well as with saturated steam, can only deliver saturated steam.

In certain cases, however, it is desirable to have an accumulator that can also deliver superheated steam. This is of great value, especially in plants where the accumulator has to feed such consumers as steam engines, steam turbines, steam hammers, etc., which utilise the energy of steam for the production of motive power.

The possibility of feeding such consumers with superheated steam means a considerably lower steam consumption and hence also a reduction in the accumulator capacity needed.

This problem has been solved by adding to the steam accumulator a second tank containing cast-iron plates and so designed that it works on the same principle as the well-known

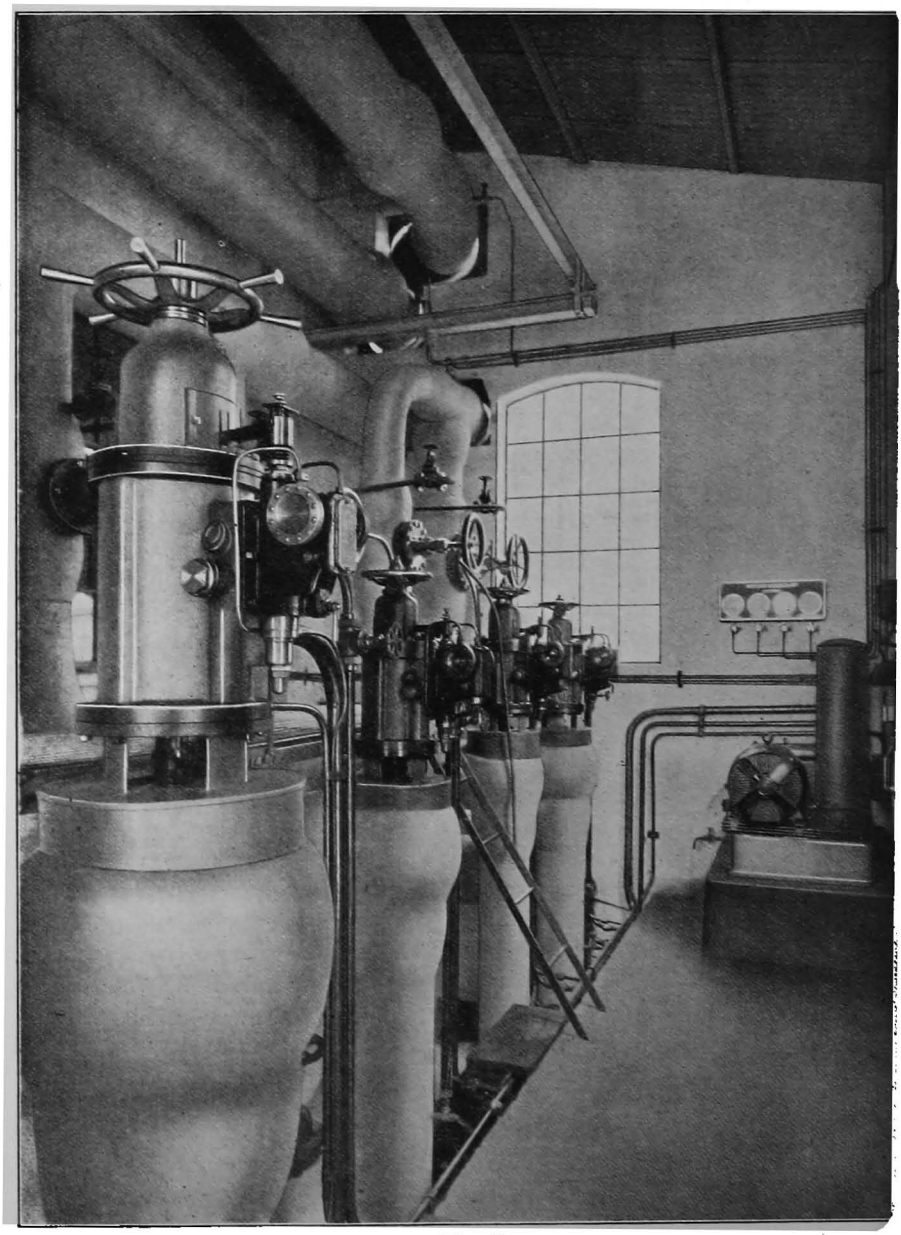

Fig. 7.

Siemens regenerative heater used in connection with metallurgical furnaces for preheating the gas and the air of combustion.

The accumulator for *superheated steam* thus consists of two separate containers, one for storing the *superheat* and one for the storage of the *latent heat* of the steam.

Control Valves.—The automatic control valves referred to above are controlled by servo-motors, which are hydraulically operated. The supply of pressure liquid to the servo-motors is regulated by pilot valves, which are operated by various relays. These relays are actuated by the steam pressures to be controlled in different ways so as to ensure the proper steam distribution.

Generally, the various control valves, gauges, etc., are centralised and arranged in an accessible way, much on the same lines as used for the meters and switchgear in electric power stations.

Fig. 7 shows a photo of the control gear of an accumulator plant installed in a sugar factory.

III. MODE OF OPERATION OF AN ACCUMULATOR PLANT.

How the accumulator, acting as a gigantic flywheel, absorbs all peaks in the steam consumption in a simple steam distribution system and keeps them away from the boilers, will be shown by a practical example.

Fig. 8 shows a diagrammatical drawing of a typical steam plant of a factory (textile, paper, chemical, etc.) where steam is used for process work only, the power being supplied from an outside source (or by condensing steam engines not shown).

As usual in such factories, the different steam consumers are divided into a couple of groups, according to the steam pressure needed. Those which need high pressure are fed directly from the boilers by the pipe L_1; the low-pressure apparatus connected to pipe L_2 are supplied with steam *via* the pipe L and the reducing valve R at an absolute steam pressure of, say, 40 lbs. per sq. in. If there is no accumulator installed, the variations in steam consumption on both ranges fall back on the boilers. The accumulator is connected to the pipe L, and by the insertion of the special pressure operated valve X an intermediate pipe range L_s (thick lines) is formed in which the pressure can be allowed to vary considerably, in this case, say, between 100 and 42 lbs. per sq. in. absolute. The accumulator is connected to L_s by the two non-return or back-pressure valves, BV_1 and BV_2.

Valve X is a compound valve of treble action. Usually it is operated by the pressure in the boiler range L_1 (indicated by the

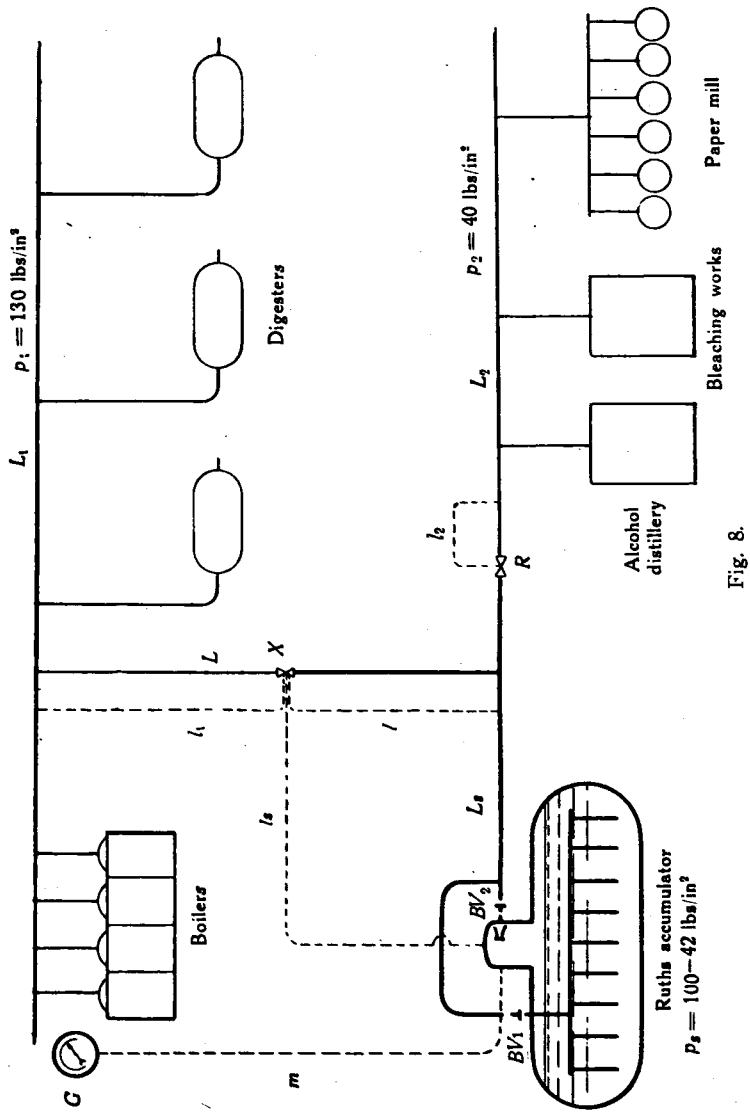

Fig. 8.

dotted line l_1) and that in such a way that as soon as the boiler pressure tends to rise above the normal pressure of 130 lbs.

the valve opens and permits the surplus of steam to flow into the intermediate range in order to charge the accumulator (*via* BV_1) if it is not for the moment required for supplying the low-pressure consumers fed by L_2.

The action of the accumulator makes it possible to fire the boilers at a constant rate corresponding to the *average* demand of the consumers conected to L_1 and L_2.

The regular constant flow of steam from the boilers thus divides into two branches, the one flowing directly into L_1, the other through L, valve X, a part of L^s and valve R to L_2. Valve X is therefore normally more or less open, and the pressures in L_1 and L_2 are all the time on the top point of 130 lbs. and 40 lbs. respectively.

If the steam consumption in L_1 falls below the average the boiler pressure rises at once, but very little, as the valve X will immediately open further and pass the surplus to the accumulator, i.e., charge it. On the contrary, a peak load in L_1 causes the pressure to sink a little, which brings X into operation in the opposite sense, i.e., it throttles the steam flow more than before the start of the peak load in L_1. The normal steam supply to L_2 from the boilers is thus reduced, but the lack of steam is immediately made up with steam discharged from the accumulator at a gradually sinking pressure. In the same way, if the steam consumption in L_2 decreases, valve R shuts somewhat, and the surplus from the boiler range, released by X, charges up the accumulator under gradually rising pressure. Variations in the steam demand in L_2 cause R to open more or to throttle and the accumulator to discharge or charge accordingly.

If, by unavoidable causes, the steam generation is subject to variations (e.g., by uneven fuel, by lower steaming rate during the periods when the fires are cleaned, etc.) such variations are also automaticaly compensated by the accumulator and the pressures in L_1 and L_2 kept constant.

All variations in the steam quantities produced and consumed are thus transferred to the accumulator, which, in the way described, compensates all peak loads in the high-pressure system as well as in the low-pressure system, although being built for a pressure lower than that of the boilers, it can only supply the low-pressure range. The accumulator thus serves as a big flywheel for the whole steam plant. In order to make it

do this service successfully its storing capacity is made of ample size, so that in normal working it is seldom or never fully charged or completely discharged. If, however, either of these things occur, e.g., by the boiler load being abnormal or something else occurring, the supercharging of the accumulator is prevented by a second pressure impulse l_s influencing the valve X and the third impulse l makes the valve X function as a pure make-up or reducing valve, when the accumulator is fully discharged down to 42 lbs., in order to guarantee a continuous supply of steam to the low-pressure system.

The boiler pressure, being made constant by the action of the accumulator plant, can no longer serve the boiler-room staff as a guide for their work. A special pressure gauge G is therefore installed in the boiler house to show the operation of the accumulator by indicating its steam pressure. This pressure is normally slowly varying up and down between the maximum and minimum limits of 100 and 42 lbs., and is a sign that the load of the boilers is correct, and that the firing can be carried on at a constant rate. Only if the hand of the instrument becomes more or less stationary at the highest or lowest pressure permitted in the accumulator should the rate of firing be somewhat reduced or increased accordingly. It has been found in practice that the boiler-room staff very easily takes up the new method of running the boilers.

As in most plants equipped with accumulators the practical equalising effect of the accumulator is some twenty to sixty times as great as that of the boilers, all changes in the rate of firing necessary, which formerly by the boilers alone had to be effected quickly, can now be extended over much longer periods, usually hours.

In industries running continuously with a fairly constant day and night output, and using fuel of even quality, practical experience has shown that the dampers and fuel feed to the boilers have only to be altered a few times per week.

IV. SPHERE OF APPLICATION OF THE ACCUMULATOR.

The accumulator system is not merely applicable in simple steam plants as the one described above, but just as well or with even greater success in connection with plants where the steam needed for process work like digesting, boiling, drying and general heating is generated at high pressure, and prior to distribution

in the factory is first passed through an engine or turbine to produce cheap power. The power production in such "back-pressure" or "pass-out" engines will, of course, depend on the amount of steam passed through the engines to the factory. As both the total demand for power as well as the demand of steam for process work vary and are independent, there is a great field for steam accumulation in such systems. The arrangement

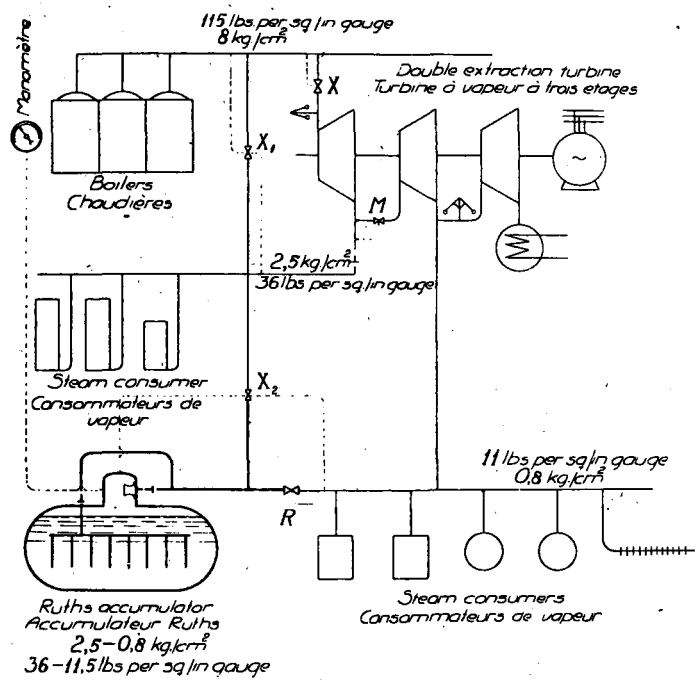

Fig. 9.
General arrangement of the Accumulator Plant in the sugar factory of Messrs. Svenska Sockerfabriks A/B, Arlöv (Sweden).

of accumulator plants is in such cases somewhat more complicated and needs careful study, but by arranging the control valves of the accumulator plant to co-operate intimately with the regulating valves of the engines or turbines the special requirements can always be met by simple and reliable means. Several plants are in operation where an accumulator is co-operating with "pass-out" turbines built with as much as three stages, "passing out"

steam at two different pressures for process work. Fig. 9 shows a diagram of such a plant working in a sugar factory.

As stated above, the accumulator affects fundamentally the whole operation, as well as the working economy of the steam and power plant into which it is installed. The accumulator can be used not only to supply steam for covering peak loads, and thus completely equalise the steam generation, but also to store, in the form of steam, the large quantities of excess heat (available in the form of exhaust steam, hot exhaust gases, etc.) which are prevalent in certain industries.

This is especially the case in the "heavy" metallurgical industries (e.g., in iron and steel works), where a co-equalisation has to be maintained between the variation in the supply of energy (surplus gas from blast furnaces and coke ovens, waste heat from furnaces and engines) and the fluctuations in the consumption of energy for power purposes. The steam accumulator is here of greater commercial and technical value than the expensive Ilgner type plants and the storing of the low grade blast furnace gas in gasometers. It is interesting to note in the latter connection that one pound of steam, which, when stored in a steam accumulator, occupies 0.2 of a cubic foot, corresponds in thermal value to about 16 cubic feet of blast furnace gas, when used for steam generation.

V. SPECIAL USES OF THE ACCUMULATOR IN POWER PLANTS.

Apart from the above mentioned general value which a steam accumulator has in the numerous plants where there are variations in the demand of steam for heating or for power purposes, or where there are variations in the supply of heat, the accumulator can with advantage be used in power stations especially in connection with long distance power transmission systems, e.g., those utilising water power.

The combination of a steam accumulator with one or more steam turbines is a very useful means of maintaining a local stand-by, working with very small no-load costs and other working expenses. Even in cases of sudden interruptions in the supply of current from the power transmission system the local load can, if required, be taken over without any delay by a steam turbo-generator, fed by the accumulator, and without the necessity of keeping the boilers permanently under steam. The steam

accumulator plus the steam turbine will in such cases take the place of lead batteries, or Diesel motors.

VI. RESULTS OBTAINED IN PRACTICE.

(i) *Increase in the output of a factory by the fact that the working of the manufacturing plant as well as the power plant is rendered independent of the working of the boiler plant.*

In a factory or power plant equipped with an accumulator,

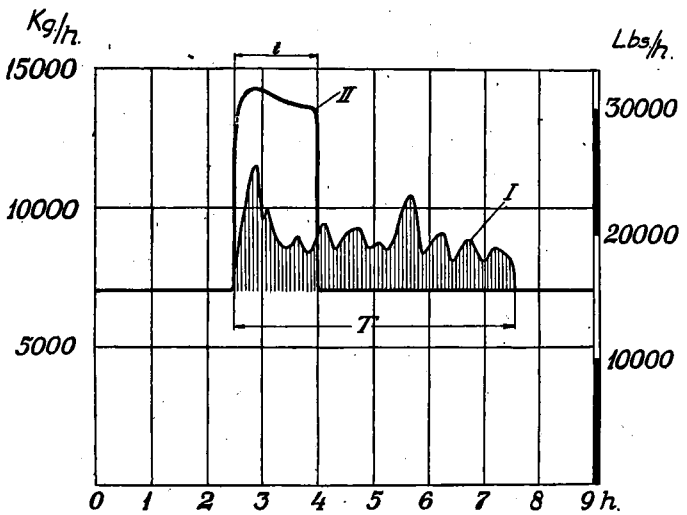

Fig. 10.

Reduction in the time for starting-up a manufacturing process after installation of a Ruths accumulator. Curve I.: *"protracted"* steam consumption before installation of accumulator. Curve II.: the same process intensified and shortened by steam from the accumulator.

steam can at will be supplied at *any* time at an *unlimited* rate should it be required in the manufacturing operations or through peak loads in the power distribution system. For example: a heating-up process normally consuming steam at the rate shown by Curve 1 in Fig. 10 (which rate is dependent on the steam supply from the boilers) can, without affecting either the boilers or encroaching upon the steam supply to other steam consumers, be intensified by accumulated steam to the high rate shown by

Curve II., whereby the time T—t is saved, and can be used for starting up another heating-up process.

The accumulator thus directly effects an *increase in the output of the factory,* not only of the boilers, and is probably the greatest economical advantage of the accumulator. In practice it has been found possible to increase the output of factories by 10-30 per cent. by the installation of an accumulator.

(ii) *Saving of Installation and Upkeep Costs.*

The manufacturing processes and the power production in factories equipped with accumulators thus being made "free" and independent of the boilers, the productive apparatus, as well as the boilers, can be fully utilised. Material economy is therefore effected in the costs for installing or extending such plants, or such expenditure is wholly avoided by the intensified use of existing installation. In most places where accumulators are now working it has been possible to reduce the boiler heating surface by 25-35 per cent.; sometimes more.

On account of the constant load, boiler plants are subjected to less wear and tear, and their upkeep costs consequently lowered.

(iii) *Improved and More Uniform Quality of the Product.*

Lack of steam often occurs in factories just when an increased supply of steam is badly needed for carrying through a manufacturing process. The process is then delayed or the quality of the product lowered.

It must be borne in mind that, as a rule, of two operations proceeding simultaneously, the cruder process, such as "heating-up," etc., will generally use steam to the detriment of the more refined operations, like drying or chemical processes. By impediments of this kind, the conduct of the manufacture, from the point of view of obtaining high quality, is rendered very much more difficult, and, as a matter of fact, irregularities of this nature in the steam supply to the individual apparatus are frequently the cause of the production of so-called "second-class qualities." By the adoption of the accumulator the different processes can be conducted quite independently of one another, without any mutual interference whatever, and with something like the same degree of exactitude as in a laboratory, thus giving products of high and even quality.

(iv) *Increase Economy in the Consumption of Fuel.*

By the action of a steam accumulator the peak loads are taken

off the boilers and their pressure kept constant, which means that mechanical stoking can be generally adopted and the boiler room staff able to devote all its time and attention to keeping up the most economical combustion of the fuel. Full advantage can be had of the CO_2 recorders, as the stokers get full opportunity to conduct their work in accordance with the indications of such or other instruments. It is, therefore, not surprising that a fuel economy of 15 to 30 per cent. is the regular result obtained in practice by installing accumulators of this system.

(v) *Increased Yield of "Back Pressure Power" from Heating Steam.*

The accumulator furnishes the possibility of keeping the boiler pressure constant, and just below the blow-off pressure of the safety valves, which fact has a very favourable influence on the output of back-pressure and "pass-out" turbines or engines.

Moreover, the output of the high pressure stage of a "pass-out" turbine or of a simple back pressure turbine is materially increased by the equalising influence of the accumulator, as with the constant steam flow from the boilers through the turbine, very small losses by throttling occur in potential energy of the steam. If a back-pressure or "pass-out" power system does not comprise an accumulator and the fluctuating steam flow to the consumers is as usual led through the back-pressure turbine or the high-pressure stage of the "pass-out" turbine, it must be run at a variable load and consequently great throttling losses result.

The action of the accumulator effects a further gain in the output of such a turbine from the fact that, despite all the variations in the steam demand, practically *all* the steam produced by the boilers is conveyed through the turbine. It

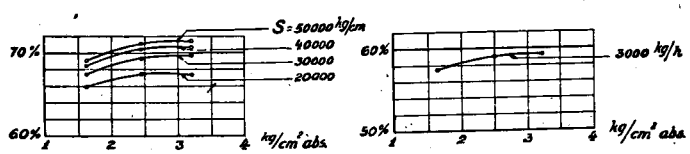

Fig. 11.

Typical curves of the thermodynamical efficiency of back-pressure turbines and of high-pressure stages of "pass-out" turbines of different systems and sizes at different back pressures.

very often occurs in such plants, when not provided with an accumulator, that large quantities of heating steam have to be by-passed direct from the boilers without power generation, as it is usually not of advantage economically to make the turbine of such a size that it can pass the maximum demands of heating steam which occur, for instance, when digesters are started, dyeing vats are heated up, etc.

In practice the total gain in power by the accumulator amounts to 20 to 40 per cent.

Even in the case of a steam power plant, from which no steam is abstracted or exhausted for heating purposes, as for instance in an ordinary power station, there is no loss of power by the insertion of an accumulator (which might be arranged for super-heated steam) between two turbine stages.

This can be seen from Fig. 11, which shows typical curves of the value of the thermo-dynamic efficiency of back-pressure turbines and of high-pressure stages of "pass-out" turbines of different systems and sizes at different back-pressures.

As the boiler pressure as well as the super-heat are automatically kept at their maximum values by the accumulator and as, further, the efficiency of the high-pressure stage is practically constant, though the accumulator pressure varies, and as also the low-pressure stage—especially if it is equipped with automatic nozzle control—utilises the steam from the accumulator without extra losses, the total heat drop available is not less with an accumulator introduced between two turbine stages than it would be without it. At most, the heat drop is reduced by an amount corresponding to the extra back pressure caused by the water-head above the nozzles in the accumulator. This head, however, is small, so that the loss entailed is of no practical importance.

RÉSUMÉ.

Dans les efforts modernes tentés pour augmenter la production économique, ou l'utilisation de l'énergie mécanique et calorifique, ou l'utilisation de l'énergie en excès ou perdue, peu d'attention a été accordée à l'influence des variations dans le taux de production de l'énergie et de sa consommation; les variations qui se rencontrent fréquemment sont en général acceptées comme des maux inévitables et la manière habituelle de les traiter est de forcer les chaudières, d'où pertes considérables.

Les excellents moyens qui existent d'égaliser les variations à l'aide de la capacité d'accumulation de l'eau chaude sous pression, n'ont pas été

utilisés comme ils le méritaient. La méthode généralement adoptée d'emmagasiner la chaleur dans l'eau des chaudières ou dans une certaine quantité d'eau d'alimentation ne permet qu'une accumulation très limitée et est beaucoup trop faible pour les besoins pratiques.

Ce rapport indique comment, en adoptant une masse d'eau active suffisamment grande, séparée des chaudières mais coopérant avec celles-ci, le problème de l'équilibrage général dans les systèmes de production de vapeur ou d'énergie peut-être résolu; l'accumulateur de vapeur faisant, de cette manière l'office d'un gigantesque volent.

L'accumulateur de vapeur établi par l'auteur est brièvement décrit, ainsi qu'une modification réalisée pour emmagasiner de la vapeur surchaffée. On cite les usages généraux et spéciaux de l'accumulateur dans les systèmes de distribution d'énergie, dans les stations centrales et dans les usines métallurgiques.

Les résultats principaux obtenus dans la pratique sont indiqués et comprennent:

Une grande indépendance dans le fonctionnement de l'appareil de fabrication ou de la station centrale par rapport au fonctionnement des chaudières, résultant en une utilisation intensifiée de l'appareil de fabrication et des machines et une augmentation de production.

Une qualité meilleure et plus uniforme du produit.

Une èconomie de consommation de combustible, en supplément de celle que l'on obtient peut être déjà à l'aide de dispositifs modernes d'économie de combustible déjà installés. Une augmentation de rendement du "Travail de contre-pression" de la vapeur utilisée pour le chauffage.

STEAM POWER PRODUCTION: GENERAL REVIEW OF CURRENT PRACTICE

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This paper deals with current practice rather than history of the past or prophecy of the future, but it has been necessary to indicate very briefly the progress of the art during the last forty years and to show in some measure the trend of Central Station design. The typical plants which we quote have gone into service since July, 1922, or are in process of design and construction.

As at January 1st, 1924, the total installed central station generating capacity in the United States was 22,895,000 kVA., of which 7,390,000 kVA. was hydro-electric and 15,505,000 kVA. steam electric generating plants. Of this 15,505,000 kVA. of generating capacity, two-thirds, or something over 10,000,000 kVA., is located in the district north of the 39th parallel and east of the 100th meridian, which also produces a large portion of the manufactures of the United States. In 1923, something over 50,000,000,000 kWh. were generated in this district. Central stations of 350,000 kW. rating are in operation with plants designed for 500,000 kW. or 600,000 kW. under construction at the present time.

CLASSIFICATION.

We may classify steam power plants in accordance with the available fuel supply as follows :—

(*a*) *Low Volatile Bituminous and Semi-Bituminous Coal.* This region includes most of the Atlantic Coastal Plain and those regions west of the Allegheny Mountains served by the Central Pennsylvania, Pocohontas and Eastern Kentucky coal fields. In this region the amount of available hydro-electric power, except in favoured localities, is not large.

(*b*) *High Volatile Bituminous and Semi-Bituminous Coals.* These coals are found on the western slope of the Allegheny Mountains

and in the Mississippi Valley, and are used in the district to the west of these mountains possibly as far as the 100th meridian. Relatively few water powers and relatively few sources of ample condensing water exist in this region, and the central stations near large centres of population usually serve or are interconnected with large surrounding territory.

(*c*) *Steam Sizes of Anthracite.* The use of this fuel is limited to Eastern Pennsylvania and a portion of the adjoining states. The total supply does not exceed 3,000,000 tons per year, and there are no very large stations using this fuel.

(*d*) *Lignites.* This fuel is used largely in the west and south-west, but is comparatively poor fuel and the stations are relatively small.

(*e*) *Oil Fuels.* Used only in favoured localities such as the Atlantic and Pacific Seaboards, Texas, Oklahoma, and certain favoured seaports where imported oils may be obtained advantageously.

This classification lends itself rather admirably to the type of load on the central station since groups (*a*) and (*b*) are a mixed power and light service with little available water power and large interconnected systems.

That portion of the United States lying south and south-east of the Ohio River and east of the Mississippi is a region particularly favoured with water power. Here many of the steam stations are of the standby variety, most of the energy being generated by water, and this statement is also true of the Pacific Coast, and particularly of the inter-mountain region. A large portion of this region is also favourably situated for the use of oil, which works in well with the standby conditions of operation.

CONDENSING WATER SUPPLIES.

Condensing water conditions affect the design of a station quite seriously. The summer water temperature in the United States is usually about 75 degrees, but in some cases as high as 90 degrees. Such plants as are located on the sea-front often require screening apparatus for seaweed. The river plants have another problem in the fine sand and silt, and frequently leaves and driftwood, as well as the great variation of water level between the spring freshets and the minimum flow. In some cases this variation is 70 feet. From 650 tons to 1,000 tons of condensing water are used per ton of coal burned.

ARRANGEMENT.

Central station designs may be roughly classified as follows in the matter of general arrangement :

(*a*) The early arrangement of two rows of boilers with the engine or turbine room alongside and the electrical galleries at one end and coal handling at other end.

(*b*) Same as (*a*) with electrical galleries alongside turbine room and coal handling alongside boiler room.

(*c*) Same as (*b*) except that groups of three or more boilers are each placed at right angles to the turbine room and approximately opposite the particular turbine they normally supply.

(*d*) Same as (*b*) except one row of large boilers operated at high ratings.

There are to-day being installed innumerable variations of the above general classifications, among which might be mentioned, turbine shafts crosswise of turbine room, turbine shafts in line one row, turbine shafts in line two rows, turbine rooms with basement and with no basement and narrow platforms only around turbines, coal handling largely inside boiler plant and coal handling largely outside of boiler plant overhead or underground.

Electrical galleries or bays are in adjacent or in detached buildings, sometimes on turbine room and sometimes on boiler room side of plant. In plants where the output is transmitted over a few lines, as distinguished from distribution direct to many sub-stations in a large city, the entire switching and transforming equipment is frequently out of doors.

As the growth of load on a central station is usually continuous there is need for a design (often called the unit system) under which the station can be extended properly, step by step, and the unproductive investment, or investment for future steps, kept at a minimum, and also permitting the taking full advantage in each step of advances in the art between steps. Considerable attention is given to this requirement.

STATION DATA.

On Plate I. are tabulated some particulars of a number of the latest and most economical central stations. About half of these plants are in operation and the others are in the construction stage.

PLATE I-A

NUMBER	PLANT AND LOCATION: NAME	CITY	STATE	PROBABLE ULTIMATE CAPACITY	FUEL: HANDLING: DELIVERY	UNLOADING	ELEVATING	DISTRIBUTING	WEIGHING	FUEL: ANALYSIS: KIND	B.T.U. PER LB. AS FIRED	MOISTURE	ASH	VOLATILE MATTER	PULVERIZATION: BURNER	MILL	STOKERS: MAKE	TYPE	FURNACES: CUBIC FEET PER RATED B.H.P.	DEVELOPED B.H.P.	AVAILABLE B.H.P.	MAXIMUM RATING PER CENT.	LBS. FUEL PER HR. PER SQ. FT. GRATE	DRAFT LOSS INCHES OF WATER	ASH REMOVAL	WATER SCREEN AREA SQ. FT.	WATER SCREEN AREA SQ. FT.	BOILERS: TYPE	MAKE	TUBES: HIGH	WIDE	TUBE: LENGTH	DIAMETER	TOTAL SURFACE SQUARE FEET	FLUE GAS PASSES	LBS. GAUGE PRESSURE	DRUM DIAMETER	DRAFT LOSS INCHES OF WATER	SUPERHEATER: PER CENT. BOILER SURFACE	DEGREES SUPERHEAT F.	ECONOMIZERS: TYPE	PER CENT BOILER SURFACE	CLEANING	DRAFT LOSS INCHES OF WATER
—	CAHOKIA	E. ST. LOUIS	ILL.	300,000	RAIL	GAR DUMP	BUCKET	BELT	SEPARATELY	COAL	9,950	2.50	17	17	UNDERFEED	RETORT	—	—	615	205	300	147	.30	SLUICES	5,600	YES	CROSS DRUM	B.&W.	20	38	20	4	48,010	3	60	350	1.80	22.6	260	—	—	—	—
—	COLFAX	PITTSBURGH	PA.	360,000	DO	DO.	DO.	DO.	TOTALLY	DO	13,000	3.88	9.8	40	DO	DO.	—	—	650	188	350	.91		DO	927	YES	DO	DO	20	47	24	4	27,660	3	60	275	2.30	13.1	230	—	—	—	—
—	CRAWFORD	CHICAGO	ILL.	500,000	DO.	DO.	BELT	DO.		DO	10,100	4.50	16	14	—	—		CHAIN GRATE							NO	NO	DO	DO					15,600	3		650			246	SEPARATE			
—	DELAWARE	PHILADELPHIA	PA	200,000	BOAT	CLAM SHELL	CLAM SHELL	BELT	TOTALLY	DO	13,760	6.66	9.1	27	—	—	TAYLOR	UNDERFEED	467	146	330	134	7.5	RR CARS	—	NO	STIRLING	DO	—	55	—		15,080	4	42	255	1.67	11.9	202	WHEELER	26	HAND	.55
—	HELL GATE	NEW YORK	N.Y	335,000	DO	DO.	TOWER	CAR	SEPARATELY	DO	14,150	6.31	6.9	30	—	—	DO	DO	398 407	100 72	400 570	444 610	6.0	SLUICES	4,400	NO	CROSS DRUM	SPRINGFIELD	20 16	54	20	3	16,900 5,200	3	54	265	1.00 3.38	11.3	200 150	SEPARATE	84	WATER STEAM	200
—	HUDSON	BROOKLYN	N.Y	400,000	DO	DO	CLAM SHELL	LARRY	DO.	DO	13,750		9.0	40	—	—	COMBUSTION WEST	DO	365	90	400	164	6.0	DO	NO	NO	DO	B.&W	20	42	20	4	19,650	3	54	300	1.80	12.8	200	—	—	—	—
—	KEARNY	SOUTH KEARNY	N.J	400,000	DO.	DO.	BELT	BELT LARRY	DO.	DO	13,500	6.38	13	27	—	—	TAYLOR RILEY	DO	370	106	350	170	5.5	DO.	NO	YES	DO	DO.	20	48	21	4	23,600	3	54	360	2.76	12.5	271	—	—	—	—
—	LONG BEACH	LONG BEACH	CAL.		PIPE	PIPE	PIPE	PIPE	TOTALLY	OIL GAS	18,600 to 19,000				—	—	—	—	400	133	300	200		—	NO	YES	STIRLING	CONNELLY B.&W.	—	58	—	3½	14,920	3	42	375	1.60 1.50	36.5 23.4	253	SEPARATE	74	WATER STEAM	—
—	MIAMI FORT	CINCINNATI	OHIO	320,000	BOAT			BELT		COAL					FULLER	FULLER	—	—							NO	NO	CROSS DRUM	B.&W.					15,110	3		650				DO.			
10	PHILO	ZANESVILLE	OHIO	300,000	DO	CLAM SHELL	BELT	BELT	SEPARATELY	DO	12,500	2.25	12	40	—	—	COKE GRATE	CHAIN GRATE	400	135	300	140		SLUICES	NO	NO	DO.	DO	25	34	15	3	14,090	2	48	600	1.35	17.9	250	DO.	63	STEAM	1.25
11	SEAL BEACH	SEAL BEACH	CAL.		PIPE	PIPE	PIPE	PIPE	TOTALLY	OIL	18,500				—	—	—	—	360	126	300	140		—	NO	YES	DO.	B.&W.	20	43	24	4	25,450	3	60	375	2.10		256	—	—	—	—
12	TORONTO	TORONTO	OHIO	240,000	BOAT	CLAM SHELL	BELT	BELT	SEPARATELY	COAL	12,000	2.50	10	40	UNDERFEED	RETORT	—	—	700	175	400	69		SLUICES	2,000	YES	CROSS DRUM	B.&W.	20	39	22	4	20,470	3	54	375	3.00	17.3	260	—	—	—	—
13	TRENTON CHANNEL	DETROIT	MICH	300,000	RAIL	TRACK HOPPER	BUCKET	DO.	TOTALLY	DO	12,750	5.00	11	47	DO	DO	—	—	630	277	300	129		DO	1,270	YES	STIRLING	DO	—	53	—	3½	29,000	4	48	415	2.70	20.7	252	SEPARATE	65	STEAM	1.50
14	WEYMOUTH	WEYMOUTH	MASS	300,000	BOAT	CLAM SHELL	BELT	DO	DO.	DO	14,000		7.0	35	—	—	TAYLOR	UNDERFEED	450 470	150 180	300		5.0	TRUCKS	NO	NO	CROSS DRUM	DO	17 22	48 80	20 15	4 2	19,740 15,738	3	54 48	375 1,200		14.7 56.2	265 334	DO.	56 74	DO.	—
15	DEEPWATER	HOUSTON	TEX	150,000	DO	PIPE	PIPE	PIPE	DO.	OIL	18,000	1.93 BBL	—	—	—	—	—	—	2.90	1.05	270	1.60		—	NO	YES	DO	DO.	20	42	20	4	19,900	3	54	350	1.65	15.3	240	—	—	—	—
16	DEVON	DEVON	CONN	200,000	RAIL	CAR DUMP	SKIP HOIST	BELT	DO	COAL	13,500	6.00	7.3	1.2	—	—	WEST	UNDERFEED	339	123	285	189	5.5	RR CARS	NO	NO	DO	SPRINGFIELD	22	48	20	3	16,800	3	54	310	1.00	12.0	200	—	—	—	—
17	PEORIA	PEORIA	ILL	110,000	DO	DO	BUCKET		DO	DO	9,700	3.40	15	14	UNDERFEED	RETORT	—	—	155	355	325	73		SLUICES	1,264	YES	DO.	DO.	15	56	20	3	13,920	3	54	400	1.40		250	SEPARATE	60	STEAM	3.50
18	SAGINAW	ZILWAUKEE	MICH	100,000	DO	DO	SKIP HOIST	BELT	DO.	DO	13,300	6.10	10	2.5	—	—	TAYLOR	UNDERFEED	790	131	600	87		DO.	YES	NO	DO.	B.&W.	10	36	20	4	9,300	3	54	375	2.29	26.8	240	DO	91	DO.	1.00
19	SAXTON	SAXTON	PA	100,000	DO.	TRACK HOPPER	BUCKET	LARRY	SEPARATELY	DO	14,000	3.25	10	2.0	—	—	DO.	DO	331	95	350	176	4.5	RR CARS	NO	NO	STIRLING	DO.	—	40	—		11,120	4	42	275		13.5	210	DO	61	DO.	1.30
20	SOMERSET	FALL RIVER	MASS	50,000	BOAT	PIPE	PIPE	PIPE	TOTALLY	OIL	15,000				—	—	—	—	632	236	352	.94		—	NO	YES	DO	DO.	—	58	—	3½	14,920	3	42	375	1.20	27.2	253	DO.	62	WATER STEAM	2.75
21	SUSQUEHANNA	MIDDLE TOWN	PA	200,000	RAIL	TRACK HOPPER	BELT ELEVATOR	BELT	DO	COAL	13,500	5.10	9.0	2.0	UNDERFEED	FULLER RETORT	—	—	745	220	350	.88	.15	SLUICES	500	YES	DO	CONNELLY	—	43	—	3½	14,770	4	42	350	1.55	14.4	220	DO.	50	WATER STEAM	1.94
22	WABASH	TERRE HAUTE	IND	200,000	DO.	DO	CLAM SHELL	LARRY	SEPARATELY	DO	11,160	2.25	14	8.5	—	—	B.&W	CHAIN GRATE	231	90	250	473		RR CARS	NO	NO	CROSS DRUM	B.&W	20	36	20	4	17,260	3	54	350	.80	14.0	215	—	—	—	—

PLATE I-B

NUMBER	PLANT NAME	CHIMNEYS: MATERIAL	HEIGHT (FT)	DIAMETER (FT)	BOILERS PER STACK	DRAFT	TEMPERATURE BOTTOM STACK	DAMPER DRAFT INCHES OF WATER	TURBINES: MAKE	NUMBER OF UNITS	SINGLE UNIT CAPACITY KW	SPEED R.P.M.	LBS. THROTTLE PRESSURE	TOTAL TEMPERATURE ABOVE SATURATION	NUMBER OF BLEEDING POINTS	HEAT CYCLE	CONDENSERS: TEMPERATURE MAXIMUM	TEMPERATURE MINIMUM	NUMBER PASSES	WATER SOURCE	SQUARE FEET PER KW CAPACITY	GALLONS PER SQUARE FEET	TUBE LENGTH FEET	PUMP: SPEED	PUMP: DRIVE	BOILER FEED WATER: SOURCE	EVAPORATORS: PER CENT MAKEUP	AUXILIARIES: A.C.	D.C.	NUMBER	KW RATING	HOUSE GENERATORS: CAPACITY	HOUSE GENERATORS: DRIVE	PRESSURE REGULATOR DRIVE	GENERATORS VOLTAGE: POWER FACTOR AT RATING	COOLING MEDIUM CIRCULATING WATER	TRANSFORMERS: TYPE	OIL CIRCUIT BREAKERS: COOLING	TYPE	PHASE SEPARATION	KVA RUPTURING CAPACITY	MECHANISM RELATION TO G.C.A.	BUS	FEEDER
1	CANONIA	TILE CONCRETE	375	19	4	NATURAL	487	1.75	WEST. G.E.	1	30000	1800	300	690	7	R	87	32	2	FRESH	1.77	1.02	20	VARIABLE	A.C.	RIVER	YES	1.5	100	0	2000	TURBINE	DUAL	13000	65	SURFACE	3 PHASE	OIL	ISOLATED	VERTICAL	375,000	BELOW	3	3
2	COLFAX	STEEL	400	21	4	DO.			WEST. WEST.	3	60,000 30,000	1800 1200	265	650	4	R.	86	34	2	DO.	1.85	1.27	15	CONSTANT	A.C.	DO.	YES	1.5	100	0	1250	DIRECT	MOTOR	12,000	80	DO.	OIL INSULATED 1 PHASE	WATER	MULTI-PHASE	—	360000	ABOVE	0	0
3	CRAWFORD	DO.	175	19	10	MECH.			G.E. WEST.	2	5000 2500	1800 1200	330	725		R.R.	75	32	2	DO.				VARIABLE	A.C.	CITY			100	0				12,000				ISOLATED	HORIZONTAL						
4	DELAWARE	DO.	142	18	3	DO.	403	.82	G.E.	1	30,000	1800	235	576	1	R.	83	32	2	SALT	1.67	.85	21	CONSTANT	A.C.	RIVER	NO	2.5	60		0	—	MOTOR	13,200	90	—	—	—	MULTI-PHASE	—	330,000	ABOVE	3	3
5	HELL GATE	DO.	250	22	6	DO.	550	1.50	WEST. G.E.	2 3	40000 30,000	1200 1500	250	606	2	R.	85	32	2	DO.	2.25 1.63	1.40	19	VARIABLE	A.C.	CITY	NO	3.0	95		2000	TURBINE	MOTOR STEAM	13,800 11,400	80 100	—	—	—	ISOLATED	HORIZONTAL	900,000	DO.	3	3
6	HUDSON	DO.	350	22	8	NATURAL	555	1.65	WEST. G.E.	2 1	50,000 30,000	1200	265	611	2	R.	80	33	2	DO.	1.40	1.45	20	DO.	A.C.	DO.	NO	3.0	65	35	4500	DO.	MOTOR	13,800	80	WATER	AUTO 1 PHASE	OIL	DO	VERTICAL	360,000	DO.	10	3
7	KEARNY	DO.	250	25	6	DO.	530	1.00	WEST. G.E.	1 1	40000 30,000	1800	325	700	4	R.	80	32	2	DO.	1.35	1.32	19	CONSTANT	A.C.	DO.	NO	3.0	100	0	0	—	DO.	13,800	91	TIDE LOCK	1 PHASE	SELF	DO.	DO.	300,000	DO.	14	0
8	LONG BEACH	CONCRETE	176	12	2	MECH.	455		G.E.	1	35,000	1500	350	700	4	R	72		2	DO.	1.57	1.27	20	VARIABLE	A.C.	WELL	YES	5.0	95	0	2600	DIRECT	DO.	11,000	90	SURFACE	OUTDOOR 1 PHASE	OIL	MULTI-PHASE	—	750,000	DO.	0	0
9	MIAMI PORT								G.E.	2	40,000	1800	550	725		RR.				FRESH				DO.	A.C.	RIVER								13,200										
10	PHILO	STEEL	155	23	4	MECH.	300		G.E.	1	35,000	1800	550	725	2	RR.	80	36	2	DO.	1.30	1.30	21	CONSTANT	A.C.	DO.	YES	2.0	90	0	2000	DIRECT	MOTOR	11,000	65	FANS		WATER	ISOLATED	VERTICAL	350,000		0	0
11	SEAL BEACH	DO.	375	23	6	DO.			WEST	1	30,000	1800	350	700	4	R.			2	SALT	1.50	1.11			A.C.	SEA WELL	YES	1.3	100	0	1250	DO.	DUAL	13,200	80	SURFACE	OIL INSULATED	DO.	MULTI-PHASE	—	375,000		0	0
12	TORONTO	DO.	110	10	1	DO.	250	1.00	G.E.	1	5,000	1800	350	650	3	R	80	34	2	FRESH	1.67	1.20	20	VARIABLE	A.C.	RIVER	YES	3.0	100	0	1500	TURBINE	MOTOR	11,000	60	WATER	OIL INSULATED 1 PHASE	DO.	DO.	—	500,000	BELOW	0	0
13	TREATON CHANNEL	DO.	235	21	3	DO.	300	3.00	G.E.	1	50,000	1200	375	725	3	R.	88	33	1	DO.	96	2.08	24	DO.	D.C.	DO	YES	1.3	10	150	12000 4000	DO.	DO.	12,200	80	SURFACE	1 PHASE	WATER OIL	DO.	—	300,000		0	0
14	WEYMOUTH	BRICK	220	18	4	DO.			G.E.	2	30,000	1800	350	700	2	RR	75	32	2	SALT	1.67	1.20	20	DO.	A.C.	CITY	YES		100	0	2000	DO.	MOTOR STEAM	14,000	100	DO.	—	—	ISOLATED	VERTICAL	875,000	ABOVE	0	4
15	DEEPWATER	CONCRETE	335	18	6	NATURAL	490	2.00	G.E.	1	20,000	1800	325	625	3	R	90	60	2	FRESH	1.75	1.10	22	CONSTANT	A.C.	WELL	YES	3.0	100	0	1200	DO.	MOTOR	12,000	80	SPRAY	OIL INSULATED 3 PHASE	WATER	MULTI-PHASE	—	320,000	DO.	0	0
16	DEVON	STEEL	324	17	4	DO.	550	1.75	WEST.	1	25,000	1800	285	625	2	R	80	35	2	SALT	1.77	1.08	20	DO	A.C.	RIVER	YES	3.0	85	15	600	DO.	DO.	13,500	90	FANS	1 PHASE	SELF	DO.	—	360,000	BELOW	0	0
17	PEORIA	DO.	150	15	2	MECH.			ALLIS-CHALM.	1	25,000	1800	350	682	4	R.	81	32	2	FRESH	1.75	1.20	20	DO.	A.C	DO	YES	3.0	100	0	1000	DIRECT	DO.	12,200	90	DO.	OIL INSULATED 3 PHASE	WATER	DO.	—	350,000	ABOVE	5	5
18	SAGINAW	DO.	50	8	1	DO.	315	.55	G.E.	1	2,000	1800	350	700	3	R.	80	33	1	DO	71	1.80	20	DO	A.C.	DO	YES	1.0	95		0	—	—	—	12,000	80	DO.	AUTO 1 PHASE	WATER	DO.	—	100,000		0	0
19	SARTON	DO.	96	12	2	DO.	300	2.00	WEST.	1	12,500	1800	260	625	0	R.	80	32	2	DO	1.75	1.57	19	DO.	A.C.	DO.	YES	2.0	100	0	750	TURBINE	STEAM	13,200	100	—	OUTDOOR 1 PHASE	DO.	DO.	—	210,000	ABOVE	0	0
20	SOMERSET	CONCRETE	250	17	4	DO.	366 506		GE	1	30,000	1800	350	700	4	R	75	32	2	SALT	1.41	1.33	19	VARIABLE	D.C	CREEK	YES	4.0	95	0	2000	DIRECT	DO.	14,000	80	SURFACE	OUTDOOR 1 PHASE	SELF	DO	—	370,000	DO.	0	0
21	SUSQUEHANNA	DO.	200	16	4	DO.	315		G.E.	1	30,000	1800	325	670	3	R.	77	32	1	FRESH	1.50	1.44	21	CONSTANT	A.C.	WELL	YES	3.0	100	0	0	—	DUAL	13,200	80	—	1 PHASE	WATER	DO.	—	450,000	DO	0	0
22	WABASH	STEEL	275	17	4	NATURAL	535		WEST.	1	70,000	1800	350	700	2	R	78	34	2	DO.	7.00	1.00	20	VARIABLE	A.C.	RIVER	YES	4.0	95	0	7000	TURBINE	DO.	13,200	80	SPRAY	OUTDOOR 1 PHASE	SELF	DO.	—	700,000	DO.	0	0

R = REGENERATIVE RR = REGENERATIVE - REHEAT

Notes to accompany Plate I.

Station.	*Operating Company.*	*Location.*
1. Cahokia	Union Electric Light & Power Co.	St. Louis, Mo.
2. Colfax	Duquesne Light Co.	Pittsburgh, Penn.
3. Crawford	Commonwealth Edison Co.	Chicago, Ill.
4. Delaware	Philadelphia Electric Co.	Philadelphia, Penn.
5. Hell Gate	United Electric Light & Power Co.	New York, N.Y.
6. Hudson	Brooklyn Edison Co.	Brooklyn, N.Y.
7. Kearny	Public Service Electric Co., of New Jersey	Newark, N.J.
8. Long Beach	Southern California Edison Co.	Los Angeles, Calif.
9. Miami Fort	Columbia Power Co.	Cincinnati, O.
10. Philo	Ohio Power Co.	Philo, Ohio.
11. Seal Beach	Los Angeles Gas & Electric Co.	Los Angeles, Calif.
12. Toronto	Penn Ohio Edison Co.	Toronto, Ohio.
13. Trenton Channel	The Detroit Edison Co.	Detroit, Mich.
14. Weymouth	Edison Electric Illuminating Co., of Boston	Boston, Mass.
15. Deepwater	Houston Electric Light & Power Co.	Houston, Texas.
16. Devon	Connecticut Light & Power Co.	Devon, Conn.
17. Peoria	Illinois Electric Power Co.	Peoria, Ill.
18. Saginaw River	Consumers Power Co.	Zilwaukee, Mich.
19. Saxton	Penn Central Light & Power Co.	Saxton, Pa.
20. Somerset	Montaup Electric Co.	Fall River, Mass.
21. Susquehanna	Metropolitan Edison Co.	Middletown, Pa.
22. Wabash River	Indiana Electric Corporation	Terre Haute, Ind.

In all pulverised coal installations the fuel is blown into the furnace from a bin; the feeders are of the screw type with variable speed; and the feeders are Lopulco with the exception of Miami Fort, which are Fuller.

All stokers are motor driven with the exception of Saginaw, which is hydraulic drive. The speed range of underfeed stokers is 1-4 in all cases except Weymouth, which is 1-4½, and Devon which is 1-5. The chain grate stokers all have a speed of about 45 feet per minute.

All Stirling boilers have four drums except Trenton Channel, which has five and are type XIII. with the exception of Trenton Channel type W; Delaware, type M, and Susquehanna, type R-43.

All boilers are fired from one side except Trenton Channel, and twelve boilers at Hell Gate.

All superheaters are of the convextion type except Saginaw, which is radiant.

Half of the stations equipped with economisers have them located above and half in the rear of the boilers.

All chimneys are of the superimposed type except Deepwater and Susquehanna, which are independent of the building.

Five stations have cinder catchers. Weymouth and Somerset have Carty type; Trenton Channel, Cottrell precipitator; Hell Gate and Hudson Avenue, Metropolitan; Philo, gravity; and Susquehanna, Cindervane.

Two-thirds of the plants work at 29 in. vacuum and the remainder at 28·5 in.

All condensers are of the surface type and have tubes 1·0 in. in diameter except Saginaw and Susquehanna, which have tubes ·75 in. in diameter. Philo and Deepwater have one pump per condenser and Colfax three, while all the rest have two.

All reserve exciters have manually operated switches, except Seal Beach, which is automatic.

All generators are 60 cycle except Hell Gate, which is partially 25 cycle, and Long Beach, which is 50 cycle.

All generators have A.I.E.E. standard performance except Saginaw, where armature rises of 60°C. and field rises of 95° are allowed.

Instead of economisers, Colfax, Toronto, and Seal Beach have air preheaters and Somerset is equipped with an air preheater on one boiler.

STEAM PRESSURE, TEMPERATURE, AND TURBINE PRACTICE FOR VARIOUS HEAT BALANCE AND STATION SERVICE POWER CONDITIONS.

At the present time the dividing line between standard construction and special work probably lies at or about 400 pounds and 720 degrees F. Below these limits, boilers and superheaters, valves and piping are almost standardised and can be purchased at a moderate increase in price above the old 200 pounds standard. Beyond these points, new and untried designs and much higher prices rule. In this present year, at least two 550-pound stations will be put in service, and at least three 1,200-pound installations are being constructed for service in 1925.

The introduction of the house turbine auxiliary sets or the bleeder type of turbine have introduced complications into station design. While resulting in very good economies, the difference in total economy through the multiplicity of designs is not as large as sometimes expected. In this connection the type of service given by the central station must be taken into consideration, as there are very few systems in this country running on a higher annual load factor than 50 per cent., while the majority may be rated at about 40 per cent. Certain central stations furnishing current largely for metallurgical purposes or for chemical industries, or plants run as auxiliaries to water power when water is scarce, have much higher load factors. The all-steam drive using the exhaust steam to heat the feed water has been extensively used in this country. The all-electric drive direct from the bus or from a house turbine or otherwise is now usually installed.

STOKERS AND POWERED FUEL.

Multiple retort underfeed stokers of extra length, with clinker grinder pits, are in general use for burning the eastern bituminous and semi-bituminous coals. These stokers have single fuel feeding rams and auxiliary pushers, both adjustable for different speeds and length of travel over a wide range. The clinker grinder drive is separate so that the amount of ash discharged and the level of incandescent coke over the grinder can be controlled. These units have as high as seventeen retorts per stoker and a feed capacity of 2,500 pounds per hour per retort, with a total grate area of 440 square feet.

Furnace volume per 10 square feet of boiler heating surface averages

3 to 4·5 cubic feet. This type of stoker burns up to 60 pounds of coal per square foot of grate area (clinker grinder pit included) per hour and is operated to evaporate 7 to 11 pounds of water per square foot of heating surface.

Forced draught travelling grate stokers are in general use for burning the small-sized anthracite and the mid-western and sub-bituminous coals. They are constructed with from six to ten forced draught zones throughout their length with air pressures at a maximum where the coal enters upon the grate, decreasing to a minimum at the end of discharge into the ash pit. For mid-western bituminous coals this stoker has been built up to 25 feet in width and 22 feet in length, having a total grate area of 440 square feet. Furnaces for this stoker usually include ignition and combustion arches when burning anthracite and a combustion arch with bituminous coal. Additional arches are now being installed extending over the rear end of the stoker to reduce the ash pit losses and increase the mixing of furnace gases. The average furnace volume is from 2 to 4½ cubic feet per 10 square feet of boiler heating surface. This type of stoker is burning up to 50 pounds of mid-western bituminous coal per square foot of grate area per hour and is evaporating 7 to 10 pounds of water per square foot of boiler surface.

A number of central stations are now burning pulverised coal in suspension under boilers and other stations with this type of fuel-burning equipment are in process of erection. It has been demonstrated that high continuous combustion efficiency and capacity can be maintained when burning pulverised coal in properly designed furnaces with a low percentage of excess air, a low draught loss through the boiler and low flue gas exit temperatures with consequently high overall efficiency. This fact coupled with the ability of this equipment to burn low grade coal and various grades of coal from time to time has been a large factor in favour of pulverised fuel under many conditions. Preparation equipment is installed in an isolated section of the boiler plant or in a separate building, and includes the raw coal storage, driers, and the pulverising mills. The pulverised coal is delivered to the individual bunkers at each boiler and thence to the multiple feeders and burners. Many furnaces are designed with air-cooled walls and equipped with water screens for the absorption of radiant heat and reduction of furnace temperature. The average furnace volume is 4·5 to 6·5 cubic feet per 10 square feet of boiler heating surface. A pulverised fuel furnace will burn upwards of 2½ to 4 pounds of mid-western bituminous coal per cubic foot of furnace volume per

hour and evaporate 11 pounds of water per square foot of boiler heating surface.

The boiler and furnace efficiency when burning pulverised coal has been found to be higher than when burning the same raw coal on either of the two types of stokers. The annual fixed charges on two boiler plants of equal capacity, one with stokers, the other with pulverised fuel, vary with different conditions and design, but in many cases such fixed charges are about equal.

COAL AND ASH HANDLING.

The chief examples of efforts to reduce labour are rotary car dumpers, coal breakers of the Bradford type and in a few cases bridges equipped with high speed grab buckets covering large storage yards. A few stations which receive coal by rail are using rotary car dumpers and additional installations are planned. Other stations receive coal in hopper bottom cars of side or bottom dump types unloading into track hoppers. Magnetic pulleys are an essential feature of the raw coal handling systems in plants burning pulverised coal on account of the necessity of removing tramp iron from the raw coal before feeding it into the mills for pulverising. Some stations distribute and weigh coal to individual stoker hoppers by travelling weigh lorries. Other stations feed stokers from overhead bunkers without weighing. Some of the pulverised coal stations are equipped to weigh pulverised coal before transporting it to the individual boiler bins.

A frequently used method of ash disposal from stoker plants is to discharge it directly from furnace hoppers into railroad cars. Another is gravity discharge from stokers or furnaces into water-sealed pits from which ash is withdrawn and loaded into cars by a grab bucket. A third method is sluicing out with water into a pit from which the ashes are pumped for local fill or otherwise withdrawn and loaded into cars or barges.

OIL AND GAS BURNING.

Boilers for oil and gas burning are equipped with mechanical forced draught oil burners which spray the oil into the furnace in a short conical flame, the air for combustion entering through the burner registers which impart to it a whirling motion for effective mixing. The oil pressures used in this system average 175 pounds per square inch. The temperature of the oil to the burners averages 250 degrees F., depending on the viscosity of the oil. This type of burner gives a flat boiler efficiency curve of over 80 per cent. under loads varying from 3 to over 15 pounds of water evaporated

per square foot of boiler heating surface, and the efficiency only fell to 76 per cent. when as much as 22 lbs. of water were evaporated. Furnaces are now designed having hollow air-cooled walls through which the combustion air is drawn and then forced through the burner registers into the combustion space. The average cubic foot of furnace volume per 10 square feet of boiler heating surface is 1 to 3 and the individual burner has an oil burning capacity of up to 4,000 pounds of crude oil per hour. The gas-fired boiler and furnace setting is similar to that of the oil burner design with furnace volumes varying from 3 to 5 cubic feet per 10 square feet of boiler heating surface. These burners generally have a multiplicity of small orifices to insure a proper mixing of the gas with the combustion air.

CONDENSING EQUIPMENT AND CONTROL OR CIRCULATING WATER.

Condensing equipment proportions and characteristics are dependent upon the following factors among others :

(*a*) Load factor and capacity factor,
(*b*) Fuel cost,
(*c*) Temperature and quality of injection water,
(*d*) Station heat balance.

The following table gives the proportions of several large public utility stations in which one or more units of the size given is installed :

Size Turbine, kW.	Max. Temp. Circulating water deg. F.	Size Condenser, Sq. Ft.	G.P.M. Injection water.	Ratio Sq. Ft. per kW.	Ratio G.P.M. per kW.
60,000	85	100,000	132,000	1·66	2·2
60,000	—	80,000	80, 00	1·33	1·33
50,000	—	65,000	70,000	1·30	1·4
50,000	—	52,000*	100,000	1·04	2·0
50,000	72	70,000	100,000	1·40	2·0
40,000	72	50,000	70,000	1·25	1·75
35,000	72	50,000	70,000	1·43	2·0
32,000	—	50,000	60,000	1·56	1·87
30,000	87	53,000	54,000	1·77	1·8
30,000	70	52,000	55,000	1·73	1·83
30,000	—	30,350*	80,000	1·01	2·66

* Single pass condensers—all others two passes of injection water

The condensers listed above, which are typical of current practice, are all of cast iron shell construction and with the two exceptions noted have two passes of the circulating water.

Auxiliaries consist principally of two circulating water injection pumps, two condensate removal pumps and reciprocating dry air removal pumps or multi-stage air ejectors or hydraulic air removal pumps, all except air ejectors usually driven by direct coupled motors. Efficiencies of circulating water pumps average 80 per cent., condensate pumps 60 per cent. to 65 per cent., and hurling water pumps 75 per cent. The power requirements for air removal equipment vary considerably with conditions, and the following figures are subject to this variation: Slow speed reciprocating dry air pumps about 25 H.P., multi-stage condensing air ejectors 1,500 to 3,000 lbs. of steam per hour. Condensers of the size listed are normally supplied with injection water by two water pumps, both motor driven. These pumps, depending upon conditions, each consume about 250 to 350 H.P. when running at full load. Some plants have a seasonal variation in temperature of injection water of 60°F. between annual extremes and annual load factors on test units up to 70 per cent. for a few years. The circulating water pumps present an opportunity for a large saving in auxiliary power under such conditions. Justification for and degree of speed control depends upon load factor, annual variation in circulating water temperature, turbine economy, price of fuel and character of the injection water.

STATION VOLTAGE AND FREQUENCY; CHARACTER OF SERVICE POWER FOR VARIOUS CONDITIONS (A.C. OR D.C. AND SOURCE) GENERATOR VENTILATION; AIR COOLING AND FIRE SMOTHERING.

The rated voltage of main generating units rarely exceeds 13,800 volts. The generators are either connected to the main station busses at generation voltage or through auto-transformers delivering about double generation voltage to main station busses. Higher distribution voltages are obtained with step-up transformers connected to individual feeders or to high voltage busses. The main generator frequency is usually 60 cycles per second. A frequency of 25 cycles per second is continued where present investment in converting or utilising equipment is too great to warrant a change to 60 cycles, but the general growth is met with 60-cycle capacity where practicable.

Station auxiliaries are practically all motor driven. Power for auxiliaries is usually obtained from house transformers, supplemented by separate house turbo generators for emergency starting. Station auxiliary motors are generally 2,300 or 440 volt squirrel cage

induction type, with wound rotor or brush shifting motors for variable speed. In some instances 500 or 250 volt direct current-motors are used. Main generator excitation is obtained from 250 volt exciters direct coupled to the main units or by motor generators driven from the house service busses. Reserve excitation capacity is obtained from separate steam or motor driven exciters or storage batteries.

Main generators are cooled by recirculating the air in the generator casing with fans on the rotor through air coolers below the generator and admitting only enough air into the casing to make up for leakage at the bearings. Condensate is often circulated through the air coolers to absorb the heat. To smother a generator fire a few companies use carbon dioxide forced into the generator casing. Permanent piping is provided in the end casings of the generator through which steam or water can be injected into the windings to quench a fire not yielding to the inert gas. Hand holes with wired glass ports are placed in generator end-casings for observation of fire and for inserting a fire hose as a last resort.

OIL CIRCUIT BREAKER AND BUS BAR ARRANGEMENTS FOR METROPOLITAN DISTRICTS AND FOR PLANTS TRANSMITTING MOST OF THEIR OUTPUT AT 66,000 OR HIGHER VOLTAGE.

Metropolitan stations, from which the bulk of the output is distributed at generator voltage, have isolated phase bus and oil circuit breaker arrangement whereby each phase of the bus is in a separate room with single pole element of each oil circuit breaker and the disconnecting devices for that phase. This permits the insertion of a current limiting reactor in each phase lead from the bus before that lead is brought near a lead from another phase of the bus. The busses are either placed with the separate phases on separate floors of the switch house to form a vertical isolated phase arrangement or the busses are placed on the same floor with each phase of the bus in a separate room to form a horizontal isolated phase grouping. With the vertical phase isolation the motor or solenoid operating mechanism of the oil circuit breakers are located on a floor either below or above the phase rooms. The oil circuit breaker operating mechanism for horizontal phase isolation are placed on a floor above the phase rooms. The devices for disconnecting the oil circuit breakers from the busses and outgoing feeders are remote, group operated and interlocked with the oil circuit breaker mechanism. The oil circuit breakers in use have a short-circuit rupturing capacity ranging from 600,000 to 1,500,000 kVA. at generator

voltage. Rupturing capacity is determined on a duty cycle starting with the oil circuit breaker open and closing and opening twice with a two-minute interval between the first opening and the second closing. Duplicate station busses are provided and provision is made for quickly removing oil circuit breakers from the compartments for examination or repair. Generating stations transmitting the output at 66,000 volts or at higher voltage have transformer banks of individual capacity corresponding to the main generator units. The main generators are connected to a generator voltage bus or the equivalent through selective oil circuit breakers. Outdoor type of transformers, high voltage busses and oil circuit breakers are usual, the last-mentioned with rupturing capacity up to 1,500,000 kVA. at 220,000 volts on a duty cycle similar to that for lower voltage oil circuit breakers and a normal carrying capacity of 400 amperes at this voltage.

INSTRUMENTS AND CONTROL.

All of the larger and more modern installations pay especial attention to control of operations of main equipment and auxiliaries, employing both visual and recording instruments of varying design for this purpose. Thermometers, weighing scales and electrical measuring instruments are frequently calibrated with standard instruments checked by the Bureau of Standards at Washington, and certain official Testing Laboratories. The fuel is weighed and automatically sampled while being unloaded and in addition is frequently weighed to individual boilers or groups of boilers as hopper weights or shift weights. Calorimeters for determining heat contents of the fuel are in almost universal use. Water is metered entering the station as well as to individual boilers and groups of boilers with blow-off and drip meters in general use. Steam flow meters are usually supplied for each boiler which may be equipped with additional pens for recording draught, air flow, flue temperature and steam temperature. CO_2 recording apparatus is by no means universal, but where not used, continuous sampling and the Orsat apparatus takes its place. Boiler auxiliaries are usually equipped with remote control either by hand or automatically from the steam pressure. Curve drawing instruments keep continuous records of pressures, temperatures, vacuums and flows of steam, circulating and condensate water in the turbine room, and the electrical records are kept as fully and even in more detail. All these records are preserved and averaged over the day, month and year and the procedure is becoming more standardised. (See

work on Instruments and Standards of Power Test Code Committee A.S.M.E., and the American Society for Testing Materials).

DEVELOPMENT INSTALLATIONS.

(*a*) *Mercury Boilers and Turbines.*

The possibilities of the use of binary fluids for power generation, particularly with reference to the use of mercury and steam have received considerable study. Much interest has been taken in such a plant now in operation at Hartford, Conn. While experiments have been conducted on this unit for some time, no test data have been made public.

(*b*) *Gasification of Coal.*

Many recent developments in gasification of coal have been studied by engineers, particularly in regard to their relation to power operation. The Piron process at the Ford plants in Detroit and Walkerville aims to produce motor fuels, tars, creosotes, and gas for commercial purposes, while the resultant semi-coke is to be used as pulverised fuel under boilers. Other processes attempt to gasify completely the coal at low temperatures so as to secure maximum yields of liquid by-products. Among the more recent, are low temperature processes to provide a substitute fuel for smokeless anthracite with oils, tars and lean gas as a by-product. The latter may be used in power plants, Smokeless operation of furnaces in residences, apartment buildings, heating plants, power plants and locomotives of all kinds, and freedom from ashes and cinders would have a great social and economic value in our cities, where raw bituminous coal is the prevailing fuel.

(*c*) *Air Preheaters.*

Air preheaters of the plate, tubular and Ljungström type have recently been installed in American power plants. Sufficient experience has not been had with the various types to permit any discussion of their relative merits. Such test data as are available indicate that air preheaters cause larger gains in boiler efficiency than would be expected from the preheating of the air alone. This is due to the high furnace temperature and the greater heat transfer by radiant heat resulting therefrom. Air preheaters are rapidly growing in favour and their extended use is to be expected.

(*d*) *Metal-lined Furnaces.*

The effect of radiant heat on boiler and furnace efficiency has recently received considerable attention. An analysis of boiler and furnace construction indicates that improved efficiency can be

secured where combustion is completed in large furnaces and where additional heat absorbing boiler surfaces are exposed to the action of radiant heat from the burning fuel in the furnace. In some of the earlier designs, water tubes forming a part of the circulation system of the boiler, were placed in the brick-work of the side walls to keep them cool. At present several boilers are in service with the side walls of the furnace made wholly of metal heat-absorbing surfaces, the tubes of which form a portion of the water-heating surface of the boiler. These metal-walls have shown no deleterious effect on combustion and increased boiler and furnace efficiencies have resulted from increased radiant heat absorption. Tests of some of these boilers and furnaces were reported at the A.S.M.E. meeting in New York on March 24th, 1924, as indicated in the bibliography appended hereto.

INDICES OF RELATIVE QUALITY OF SERVICE.

The increasing dependence of industry, of transportation, and of domestic users of electric current upon large power companies and increasingly exacting requirements demand extraordinary attention against interruption of service. Although the service department and distribution system of the large power system, including sub-station operation, are large factors in the quality and continuity of service, we are concerned here with the generating station only. The problem of the central station designer is to attain the utmost economy, but only so far as is consistent with dependable service.

Radically higher steam pressures, 500 to 1,200 pounds per square inch have been adopted in a few instances, with promise of greater economy in steam consumption. However, the added complications of operation and maintenance may affect the quality of service rendered. Pulverised coal has recently been adopted for some important stations, and may improve to some extent the quality of service due to the rapidity with which the load on a furnace can be increased. The increasing capacities of generating units make it all the more imperative that essential equipment auxiliaries and connections shall be simple and dependable. Simplification of piping connections and simplification of electrical equipment and wiring and the separation of phases in high-tension conductors and switching equipment tend toward this end.

The most important indices of the probable relative quality of service from central stations are:

(*a*) The ease of operation from the standpoint of least amount of

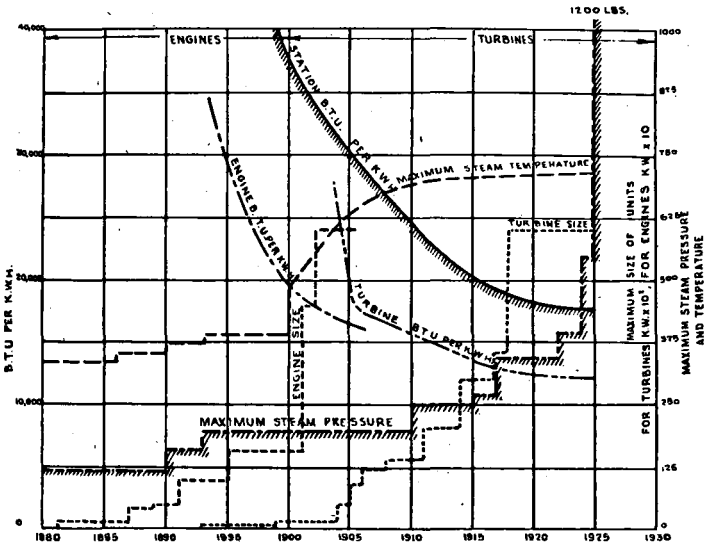

PLATE II

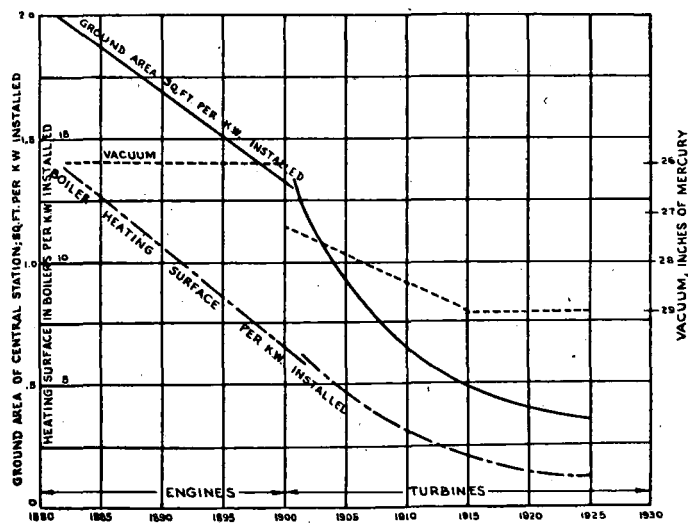

PLATE III

apparatus that requires manual operation and its convenient location and grouping.

(*b*) The sustained reliability of the station as a whole, and

(*c*) The attention given to selection, and to constant and proper training and encouragement of *personnel* in operating proficiency.

The Illinois Public Service Commission has recently inaugurated a system of rating power companies according to quality of service. The rating is a composite figure made up from percentage ratings on many elements contributing to the quality and satisfaction to the customer of the services rendered.

INDICES OF RELATIVE INVESTMENT COSTS.

In Plates II. and III. we have plotted for the years since the beginning of central station practice, that is, since 1881, certain data regarding central stations which may be termed "Indices of Relative Investment Costs." On Plate II., for instance, the maximum steam pressure used has grown from 125 pounds in 1881 through successive steps to 400 pounds for 1923, with 550 pounds and 1,200 pounds coming into service in the near future. During the same time the maximum steam temperature has risen rather slowly during the years when steam engines were in use, but, with the advent of the steam turbine and superheat, rapidly creeping up to about 600 degrees, and then increasing slowly up to the present time when 725 degrees and 750 degrees are contemplated in a few stations under construction. Two different scales were necessary to plot the size of units. The turbine curve, starting with the first De Laval units in 1893, rapidly increases in size until 1918, when a 60,000 kW. unit was first put into service. Engine guarantees in B.T.U.'s per kW. hour; turbine guarantees at the best point; and an approximate curve of station economy, B.T.U.'s per kW. hour average for each year, in stations of good thermal efficiency are also shown.

On Plate III. we have shown the ground area of the station in square feet per installed kW., and the boiler heating surface in square feet per installed kW. The ground area curve is not a true index of the cost of the station, since many of the urban stations have been built with two and sometimes three floors of boilers, and otherwise adapted to expensive land or foundation conditions. A curve of cubic feet of building per kW. installed is, however, more spread than the floor area curve, and we have not included it in the

plate. The boiler heating surface curve is a better index of cost. A curve of grate surface per kW. installed would have practically overlaid the boiler heating surface curve, with scale about 1/50 of the boiler heating surface scale. The coal burnt per square foot of grate area for maximum installation has varied from about 20 pounds in the very early installations to 30, 40 and 50 in the later ones, the main differences being in the length of the grate and the larger proportion of heating surface placed above it.

About seven times as much work is obtained out of some boilers to-day as in the earlier central stations, while on an average the ratio runs from three to four. The earlier installations evaporated from 2 to 4 pounds of water per square foot of surface. The present-day installations evaporate from 4 to 15 pounds and even higher under peak conditions.

THE COST OF CENTRAL STATIONS.

Some attempts have been made to show that the cost of a central station followed some law which was more or less indicated by such curves as have been shown in Plates II. and III. During the last thirty years, and also during each decade of that period, the average cost of a large number of completed central stations including land, buildings and condensing water facilities, has not been far in excess of $100 per kilowatt of installed capacity, notwithstanding wide variations in the purchasing power of the dollar, but during that time central stations have been built at a cost as low as $60 and as high as $200 per kilowatt installed. Local conditions, such as electric distribution, real estate values, fuel and condensing water deliveries, foundation and substructure, as well as the machinery, material and labour market, the urgency of demand, and other factors, and the merit of the design and construction under these varying conditions and under the fuel, load factor and other economic requirements make any other generalisation of little value.

In addition to the foregoing the " Cost per kW." is largely influenced by the divisor used. For example, did the station in question have a spare generating unit, and was it included in the divisor, or was the station fully boilered? If the latter, what allowance is available for boilers out of service during peak hours for washing or repairs, and at what rating will the remaining boilers have to operate, 200 per cent. or 400 per cent., or what other rating? Additional examples influencing the divisor might be cited. The design of station for the particular conditions may be proper in each case, but the " Costs per kW." are obviously far from comparable.

INDICES OF RELATIVE TOTAL ANNUAL COSTS.

The criterion by which any steam power station should be judged is its commercial efficiency or total average annual costs per unit of output including fixed charges on investment over a considerable period of years under all the limiting conditions imposed upon its design, its construction and its operation. For instance, one station with very high price of coal is warranted in installing air preheaters or economisers and other fuel saving devices, and securing low B.T.U. per kilowatt hour. But such devices increase first costs and fixed charges. Another station, with very low price of coal, would have few or none of these refinements with low first cost of plant and low fixed charges but with higher B.T.U. per kilowatt hour. However, the net total annual cost per kilowatt hour in the two cases may be the same. This indicates the possible error of judging the excellence of design of any station by its performance only as measured by B.T.U. per kilowatt hour.

In previous paragraphs we have already pointed out how idle it is to generalise in comparing investment costs per kilowatt of steam power stations. It is even more idle to generalise in comparing fixed charges, because these contain additional variables such as annual total cost of use of money, financial accounting requirements and advances in the art. There remain the maintenance and operating expenses. Both of these are limited as to best obtainable results by the design of the station, but for any result short of that point maintenance and operating results are largely a matter of management and operation. It is not so much a matter of " a stitch in time saves nine " as a proper stitch at the proper time in operation, in maintenance, and in extension of the station.

The operating and maintenance portion of the total annual costs which are also subject to many variables lend themselves somewhat better to generalisation than does the fixed charge on investment portion. This is particularly true of the fuel consumption. Quality of coal can be indicated roughly in B.T.U. per pound, an approximate index of its steaming capacity. Thermal efficiency can thus be roughly compared between stations using different coals. Thermal efficiency is an easy method, even though incomplete, for comparing results from different stations, and it is widely used in the United States.

Thermal efficiency is sometimes secured at the expense of commercial efficiency. As hereinbefore stated, the criterion should be dependability of service and commercial efficiency under all the conditions existing in each case.

There are a number of stations in operation at this writing that have for a few months done better than 18,000 B.T.U. per kWh. net send-out from coal as received from mine. There are several under design or construction that will probably give a better performance.

Among the latter are some designed with due regard for dependable service and commercial efficiency that should give a year-in-year-out performance better than 18,000 B.T.U. per kWh. Under so-called ideal conditions, which never obtain and are useful only for comparison of calculated results, some of these steam stations are rated by their designers at 14,000 B.T.U. or less per kWh. of net send out. There is hope for considerably better thermal efficiency from some of the developments actually under way and which will have an influence also on improving commercial efficiency. In the meantime the average ultimate user of electric service is most interested, first, in dependable service and, second, in lowest total cost to himself.

The authors gratefully acknowledge the co-operation and assistance of many Executives and Engineers in collecting and permitting the use of data and reviewing the data in Table I. on the particular station or stations with which each is identified, of Mr. F. M. Gentry in the preparation of tables and illustrations, and of Prof. A. G. Christie in reviewing and editing the paper.

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RÉSUMÉ.

La capacité génératrice des Usines Centrales installées aux Etats-Unis est de 22.895.000 kVA. parmi lesquels 15.505.000 sont produits par des stations thermiques à vapeur.

La Pratique courante montre qu'il y a une augmentation progressive dans la capacité des turbines, dans la pression de la vapeur, dans la température de la vapeur, et dans le vide ; et qu'il y a simultanément une diminution dans l'usine, en surface de terrain par mètre carré de kW. installé, et en surface

de chauffe de la chaudière par kW. installé, et pour la turbine une réduction de poids de charbon par kWh.

La question des frais est discutée et quoique une moyenne générale des frais pendant les 30 dernières années est indiquée les caractères insuffisante et trompeurs d'un semblable indice sont mis à jour.

L'eau de condensation est approximativement de 650 à 1.000 tonnes d'eau par tonne de charbon brûlé, et varie en été de 24°C. (75°F.) jusqu'à 32°C. (90°F.) de temperature. Les condenseurs à surface sont généralement en usage. La tendance actuelle tend vers une pression de vapeur d'environ 28 atm. (400 lbs.) et de 388°C. (720°F.). Des usines à haute pression sont mises en service, mais l'équipement n'est pas encore adopté d'une manière générale.

Le réchauffage de l'eau d'alimentation au moyen de vapeur extraite des turbines à amené une économie, mais aussi une complication dans l'équipement.

La commande éléctrique est adoptée pour toutes les machines auxiliaires ordinairement installées.

Des foyers à cornues multiples alimentées par la partie supérieure sont d'un usage général pour brûler le charbon bitumineux, ainsi que le tirage artificiel et des grilles à chaîne automatique pour brûler le charbon moins bitumineux. Le volume de foyer par metre carré de surface de chauffe de la chaudière varie de 00,521 à 0,118 M^3 (par 10 sq. ft. il varie de 2 à 4½ cu. ft.) et évapore de 34 à 54 kg. d'eau par mètre carré de surface de chauffe (7 à 11 lbs. par sq. ft.). Le foyer à charbon pulverisé vient d'être installé dans un grand nombre d'usines. Le charbon de qualité inférieure ainsi que de différentes qualités peuvent y être utilisés, et un bon rendement de la combustion et une grande capacité peuvent être maintenus. Un foyer à combustible pulvérisé consomme de 40 à 64 kg. de charbon par heure et par mètre cube de volume de foyer (2½ à 4 lbs. par heure et par cu. ft.), et la vaporisation atteint jusqu'à 54 kg. d'eau par mètre carré (11 lbs. par sq. ft.) de surface de chauffe de la chaudière. Le volume moyen du foyer est de 0,118 à 1,171 M^3 par mètre carré (4,5 à 6,5 cu ft. par 10 sq. ft.) de surface de chauffe de la chaudière. Les frais fixes pour le chauffage par grille chargé automatiquement ou pour le chauffage à combustible pulvérisé de la même capacité sont dans la plupart des cas à peu près les mêmes.

Les volumes des foyers à huile lourde varient de 0,079 à 0,132 M^3 par mètre carré (3 à 5 cu. ft. par 10 sq. ft.) de surface de chauffe de la chaudière, et donnent un rendement de 80 pour cent.

Le voltage des génératrices dépasse rarement 13.800 volts. La fréquence est ordinairement de 60 périodes par seconde. Les disjoncteurs à huile et les varres collectrices sont fréquemment isolées de manière que chaque phase des barres est placée dans une chambre séparée ainsi que les disjoncteurs à huile et les interrupteurs correspondant à chaque phase.

Les calorimètres sont d'un usage presque universel. L'eau est mesurée au point d'injection et les compteurs sont d'un usage général. Des compteurs pour mesurer la quantité de vapeur sont habituellement installés sur chaque

chaudière, souvent avec des plumes additionnelles pour enrégistrer le tirage et le volume d'air, ainsi que température de la vapeur et des gaz dans la cheminée.

L'appareil pour enrégistrer le CO_2 n'est pas universel, mais est employé dans le cas où des essais continus et des appareils d'Orsat font défaut. On emploie des enrégistreurs de pression, de température, de vide, de circulation de la vapeur, de l'eau de circulation et de l'eau condensée. Les enrégistreurs électriques sont employés encore plus largement.

Les installations récemment mises au point qui méritent d'être notées, sont : Les chaudièrs et les turbines à mercure, la gazéification du charbon, les réchauffeurs d'air, et les foyers avec garniture interieure en métal.

Les réchauffeurs d'air indiquent la possibilité d'un plus grand rendement de la chaudière, qu'il n'en résulterait si l'on ajoutait la chaleur à l'air.

Les conditions les plus importantes pour obtenir un bon service sont jugées être ; (*a*) fonctionnement facile des appareils, (*b*) l'assurance d'un service continu et (*c*) l'attention demandée pour la sélection du personnel de service.

L'augmentation des capacités des génératrices demande essentiellement que les auxiliaires et les connections soient simples et sûres. La simplification des tuyauteries et la séparation des phases des conducteurs à haute tension sont également considérés comme nécessaires.

Le problème principal de l'ingénieur établissant un projet de centrale doit être celui de la plus grande économie, pourvu qu'il soit conséquent d'un service continu et certain.

STEAM GENERATION—UTILISATION OF FUELS

DISCUSSION

Chairman: MR. W. H. PATCHELL (GREAT BRITAIN)

Thursday, July 3rd. *Morning Session*

THE CHAIRMAN, in opening the session, stated that in order to deal with the fourteen papers in two and a half hours, he had sorted them into three groups, and proposed to take the discussion on each group separately. The discussion on the papers would be taken first, and the authors would be given an opportunity of replying and adding anything they might desire at the close of the discussion.

The first group consisted of the papers by Col. Junkersfeld and Mr. Orrok, Mr. Lebnard Harvey and Mr. W. M. Selvey, which the Chairman then summarised, remarking that the authors alone were responsible for the opinions expressed in the papers.

With regard to Mr. Selvey's paper on *Pulverised Fuel for Boilers*, which was in the nature of a review of the question up to the present time, the Chairman referred to the author's suggestion that the wires of which the test screens were woven should be standardised, and pointed out that the Institution of Mining and Metallurgy already had a standard test screen. That had been established and used since 1907, so that they were already covered on that point.

PROF. A. R. GREIG (*Canada*), said he happened to be in a location distant from water power, and about 300 miles from the nearest coal mine. The coal used was highly volatile, fairly high in moisture, probably 8 to 14 per cent. from aoout 24 to 35 per cent. volatile, and from 35 to about 52 per cent. fixed carbon.

He found the Underfeed stoker was supplanting the chain grate stoker for complete combustion of this kind of coal, also that the high type of firebox was better for their conditions. In a new installation in the University of Saskatchewan, the height from the floor to the lower tubes was 12 feet. There were two boilers each of 4,020 sq. ft. heating surface, eighteen tubes wide and ten high, with six Underfeed stokers. He had had the good fortune to run a trial for the City of Edmonton on a much lower grade of coal than that outlined, with four boilers running at 165 per cent. of the rating. The efficiency was 72 per cent. with the coal as fired, (2 per cent. above that guaranteed by the makers). The flame was about 4 ft. in height; there had been no ignition arches, or anything of that kind, and the trial had been very successful.

MR. CHARLES H. MERZ (*Great Britain*), said he suffered, with others, in not having had the papers for a sufficiently long time to study them at all adequately, but he thought they were much indebted to Col. Junkersfeld and Mr. Orrok for having presented in such an able way, this survey of American practice up to date. Their paper really contained an enormous amount of valuable information, and he imagined it would form a sort of textbook for designers for some years to come.

There were, of course, a great many interesting questions raised by their paper. When the important group of power companies which served the north of England decided some six years ago, that the standard conditions

of steam pressure of 200 lbs. and 150°F. to 200°F. superheat had been standard for long enough, and—not in any particularly original way, but following really the lead of Dr. Ferranti, who had suggested the general principles many years before—decided to adopt a much higher pressure, there were a great many questions which at that time at any rate, many engineers considered uncertain, which to-day fortunately they could positively answer. The general cycle adopted then of progressive feed-heating, coupled with reheating and air economisers, left in many people's minds a great deal of uncertainty. Dealing with the boiler end, there had been doubt expressed as to whether air heaters would prove satisfactory in practice, in fact he was told they would have very serious trouble with air economisers compared with water economisers. He would say positively from their experience at North Tees that even with low stack temperature, air heaters gave very much less trouble than the average water economisers. The possibility of bad conditions for them was much less likely to occur, and in ordinary practice they gave really no trouble.

The next question was whether the use of hot air under the grate would give trouble with the grate. On that point also, he could reassure them. Of course since then, there had been the introduction of pulverised fuel, in a much more definite form as regards practice, and that had introduced a new factor. But at the time when this change in practice had been inaugurated, practically speaking, the stoker was the only possibility, and it was satisfactory to know that they had no trouble there. Mr. Merz did not think the same thing could be said about the boiler furnace, and he imagined that the different speakers who he hoped would touch on this question, would agree that whether for pulverised fuel or for stokers, the question of the boiler furnace was not yet settled. It was following largely, he presumed, on that difficulty that it was proposed to use the furnace walls for steam raising, either by the insertion of tubes or in some other way.

He would like to ask whether, if they were to use the furnace walls as part of the heating surface for raising steam, it would not result in an entirely different form of boiler construction. If, as was indicated in Col. Junkersfeld and Mr. Orrok's paper, there was no deleterious effect upon the efficiency of combustion by surrounding with iron the furnace used for steam raising purposes, as distinct from surrounding it largely by brickwork, it would seem that they would have materially to modify their ideas of boilers. It was, perhaps, partly with this in mind that his firm had tried the Yarrow boiler, which had been employed very much more for marine purposes than for land purposes. While not complying completely with the possible development which he had outlined for future boilers, this came nearer to it than some of the standard boilers used for station work.

Another question dealt with in the paper was the use of pulverised fuel. He said that in England they were somewhat nervous about adopting pulverised fuel, because they were boldly told that one great argument for using it was that all the dirt in the coal went into the atmosphere, and was got rid of free of expense to the power station. Speaking not from the point of view of economy in generating electricity, but from a national point of view, was not this a retrograde step? Could they say definitely that they need not trouble about trying to cleanse the chimney gases? Or were their friends in the United States only doing this and claiming the advantages of such a course, while in their usual energetic way they were solving the question? That was a question which, if it could be definitely answered, would, he thought, be extremely beneficial to the whole central station industry.

MR. B. POCHOBRADSKY (*Great Britain*), said that while in the past the high pressures and temperatures had not been considered of great advantage, owing largely to the fact that the turbines did not utilise high pressures with high efficiencies, to-day great improvements in this respect were an accomplished fact, and, therefore, the question of increased steam pressures and temperatures had a much more decisive bearing on economy of power production. The only difficulty that could be foreseen was that of high temperatures. He thought, however, that Sir Robert Hadfield had given them in his paper a solution of that difficulty.

Materials possessing high strength at high temperatures were to-day available, From the point of view of economy of power production, it was necessary more than ever to consider the application of high pressures and temperatures.

Dealing with the question of pulverised fuel, and in the first place with the questions raised by Mr. Merz, the furnace was probably the principal difficulty, but to-day successful results had been obtained, due chiefly either to the furnace volume having been increased, or to the walls being cooled, or to the application of both methods. Whatever was being done, the volume of the combustion chamber should not be reduced. The results of small combustion chambers were disappointing.

He considered that the thermal efficiency put forward in some papers as the foremost factor was not the final criterion for the steam plant, or in fact for any plant. The thermal efficiency was only one of the factors of the overall economy; capital cost, cost of maintenance and repairs, wages, auxiliary power, all had their influence on the overall economy which, expressed in money units, must remain the final criterion.

In the United States, central pulverising plants were favoured, while in Great Britain the unit pulveriser was likely to prove more advantageous. The important difference between the two systems was the storage. In the British system, if he might so call it, because it originated in Great Britain, storage was eliminated, and with it the consequent risk of explosion. Further, the unit pulveriser showed very great advantage in respect of capital cost. A certain type of pulveriser produced in Great Britain consumed not more than 27 kWh. per ton of coal; that power included not only the pulverising of coal, but also the delivery of coal dust and all the required air into the furnace. The power consumption had been obtained on a size of pulveriser dealing with one ton of coal per hour, and smaller consumption per ton would undoubtedly be obtained with larger sizes of the same type of pulveriser. The central pulverising plant, according to publications within his knowledge, required 35 kWh. and more per ton of coal for the same performance, namely, pulverising and delivering of coal dust and all air into the furnace.

In respect of maintenance and repairs, and, of course, efficiency of performance, the unit pulveriser referred to was certainly in no way behind central pulverising plant.

Mr. W. S. Monroe (*U.S.A.*), remarked that in a station far removed from any large city, the dust problem was not so serious. The dust from a pulverised coal institution was very fine, and if it were spread over a large number of square miles under any condition of wind, it was very small per unit of area in the year.

Mr. John Anderson (*U.S.A.*), said the furnace difficulties could be considered solved, as far as the United States was concerned. He had some furnaces two years old, which had experienced as much as eight months uninterrupted service at 200 per cent. rating, and no repairs had been necessary.

The overall economy, as already mentioned, was certainly the thing they should all regard as most important. He had been operating the Lakeside plant for three and a half years, had burned, in pulverised form, over one and a quarter million tons of rather low grade coal, and the figures for that time, which were well substantiated, ran consistently about 17,200 B.Th.U. per net kilowatt hour.

With regard to the question of explosion; when he first took up this matter in 1918, he had had very considerable anxiety on this point, but his experience over a period of five years indicated that explosions were no more to be expected than was found to be the case with stokers or any other form of burning coal.

Speaking of ash dust, they were sending about 90 per cent. of their ash out of the top of the stacks. When the wind was off the lake, the dust blew over most of the southern part of the State of Wisconsin. He did not know whether the dust fertilized the soil; he thought it unlikely. There had, however, been no complaints about it. For psychological reasons, they had installed a smoke washer which they did not have to operate. This smoke washer was a device

which permitted of passing the smoke through a water spray. This procedure, by actual test, was found to settle out 75 per cent. of the solid particles in the smoke. About 20 per cent. of the ash settled in the bottom of the furnace and the chamber at the back of the boiler. The particles of ash from pulverised coal were extremely light in colour, and as they did not contain any unburned carbon, they did not have any tendency to smear the buildings in the neighbourhood. The dust was decidedly less unpleasant and troublesome than that from stoker fired boilers. This had been attested to by the local smoke inspector.

With regard to the cost of the individual unit plant, he had made a recent study of this design, and had found that the cost was slightly more than that of the central preparation plant.

At the Lakeside station, economisers, fans and breeching for all boilers were arranged in such a way as to give a very low building of only 65 feet from the lowest level to the skylight. The cost of the Lakeside station complete with land, tracks, circulating water basin, coal handling and pulverising equipment, with all steam generating equipment, prime mover equipment and electrical equipment, complete with all structures necessary to operate a well balanced station of 160,000 kW. capacity, was $82·90 per kilowatt of capacity installed.

MR. CHARLES ERITH (*Great Britain*), said that with regard to water-cooled walls of boiler furnaces, he would point out that they had long been used on a large scale in locomotive fireboxes. The modern development was to apply them to water-tube boilers having large rectangular furnaces; but the only tests so far available for this type of furnace with water-cooled walls, applied to archless furnaces fitted with retort type stokers, fired with untreated coal, were made at the Hell Gate station of the New York Edison Co., and their test figures were extremely interesting. With a 14-retort stoker, under each 15,900 sq. ft. boiler, their claim for an eleven hours' test for capacity was 461 per cent. rating, which, he thought, was superior to any test made with pulverised coal firing; while the stoker investment cost just about half as much as the pulverised coal plant. On the point of thermal efficiency, also, the claims for recent tests of direct firing of untreated coal on the retort-type stokers at Hell Gate station, were fully equal to, if not ahead of, any claims made for the more complicated method of firing with dried and pulverised coal.

MR. A. E. DOUGLASS (*U.S.A.*), stated that in the United States the unit system had been used quite extensively for a great many years on boilers, particularly in the steel industry and for central station plant, but had now been practically replaced by the central system. The power for a unit system was 25 to 50 per cent. higher than for a central station. The fixed charges on a large plant were very little, if any, higher on a central station than the unit system, due to the necessity of spare units in case of breakdown.

MR. ANDERSON, in connection with the unit system, said that for the past three months their testing of the unit system against central station indicated that even if it were less in investment and everything else, it was probably 6 per cent. less efficient.

COL. P. JUNKERSFELD (*U.S.A.*), referring to the remarks on pulverised fuel, pointed out that while pulverised fuel in large central stations had only been used for about five years, stokers had been used for about thirty years; it was to be expected that further improvements in pulverised fuel furnaces and equipment would be made from year to year. It was most significant that in the United States the first large station to adopt pulverised fuel exclusively had created a record from a purely economic standpoint for two years or more, and that the second large station to do so had now been in service a number of months, and had made an equally good report.

The cost of coal per ton at that time was very low compared with any time back to 1912. That meant that in striving after better economy, there should be no appreciable sacrifice of fixed charge, and certainly no sacrifice of dependability, in his judgment the most important thing before the power industry to-day.

DISCUSSION

MR. GEORGE A. ORROK (*U.S.A.*), in answer to Mr. Merz's question regarding steel furnaces, referred to the experiences at Hell Gate, where those furnaces were installed, there being a number of them also at Sherman Creek station. At Hell Gate, there were three boilers which had been running for nearly a year with no repairs to the brickwork, other than two bricks around one of the doors, within the first two weeks of starting up. They had been able to run these boilers from an evaporation of about 4 lbs. per sq. foot of surface to as high as 19 lbs. of water evaporated per sq. foot of surface. At the lower ratings, which they termed about 150 per cent., or about 4½ lbs. of water per sq. foot, they had got an efficiency of boiler, superheater and economisers, on a twenty-eight hour test, of over 92 per cent. The average of two twenty-eight hour tests gave an efficiency of over 91 per cent. From that they ran down to about 86 per cent. or 87 per cent. overall, over a week or month. On the very high power test, which lasted for three hours, with all the coal the stoker would push into the furnace, the efficiency was round about 78 per cent. With the new arrangement of stoker rams they would be able to go up to 23 or 24 lbs. of water evaporated per sq. foot of surface. That would not be a record, because some of the small tube boilers had, he understood, gone up to 28 lbs. The steel lining of the furnace extended round three sides, leaving the fourth side with a brick wall. It was their intention, if necessary, to put up a radiant heat superheater in the wall; and in some of the boilers at Sherman Creek, they had radiant heat superheaters in that position, and he would be able to say something about that next year.

The steel lined furnace, as already pointed out, was similar to a locomotive boiler, but they had taken a little better care of the circulation in the tubular furnaces.

The question of dust in the flue gas came up whether they used hand-firing, stokers, or powdered coal; a certain proportion of the coal went up the stack, no matter how it was burned. They installed dust catchers or cinder catchers in their smoke stacks, and caught 97 per cent. of the flue dust in those catchers. If they used powdered coal, they installed a dust catcher in the stack, no matter whether the dust were noticeable or not, even if only for Mr. Anderson's psychological reason. The figures given in the paper for the cost of central stations were made up from accurately known costs of about eighty different central stations, built in all parts of America, with some few from England and the European Continent. While the averages were more or less alike, the variations were of the order of 250 per cent.; those were due to geographical and business conditions, to differences in skill in management, to local strikes and interruptions of labour and to difficulties through bad weather. These variations would sometimes make a difference of 40 or 50 per cent. in the cost of the power station.

MR. LEONARD C. HARVEY (*Great Britain*), remarked that his paper on pulverised coal had been written from the wider aspect of national fuel economy. He thought the one and only danger to be borne in mind was that connected with the transportation of the pulverised fuel. He had always been a very strong opponent of mixing pulverised fuel with air and transmitting it to the furnace in that manner. The present-day method of transmitting pulverised coal, either by air pressure from a blowing tank or by a screw pump, was an absolutely safe and reliable method of transmitting fuel from the place where it was produced to the place where it was to be used.

After drawing attention to the various points touched on by the speakers who had preceded him, he directed special attention to the rapid progress in the utilisation of pulverised fuel in America, and expressed his conviction that the engineers of Great Britain would not lose time in making use of this great advance in economical fuel burning.

THE CHAIRMAN, announced that the next group consisted of four papers, those by Sir Robert Hadfield, Mr. E. W. Nicol, Prof. T. Makariew and Mr. Olof Rodhe; he gave a summary of each before throwing open the discussion.

MR. DAVID BROWNLIE (*Great Britain*), pointed out the absolute necessity for an International boiler test code. In London, they were now stated to be

getting 88 per cent. efficiency on a boiler plant with mechanical stoking. Mr. John Anderson was running the most efficient station in the world (Lakeside, Milwaukee) at an average all the year round efficiency of 86 per cent., and he could get 92 per cent. efficiency on short trials. When they arrived at such figures as those, it was clear that the whole question of testing boilers and expressing the results became of the greatest importance, as the efficiency figures depended to a large extent on how they were calculated. There was no standard method of doing that, and a variation of at least 3 per cent. in efficiency was represented by the different methods of calculation.

The world was burning about 1,250,000,000 tons of coal and lignites per annum. Probably at the very least 500,000,000 tons of that was burned for steam generation in stationary land boilers, apart from marine and locomotive boilers. The net working efficiency of the stationary steam boiler plants of the world was less than 60 per cent., and it was relatively easy to work such boiler plants at 75 per cent.; in other words, the world was throwing away 100,000,000 tons of coal per annum on steam boilers alone, through the lack of scientific methods. There was no question that this was a very bad blot on the whole science of engineering. He had carried out 400 to 500 boiler tests in Great Britain, representing 1,513 boilers in forty-one different industries, and the average net working efficiency of the boiler plants of Great Britain, based on those tests, made over a period of fifteen years, was 58 per cent. The corresponding figure for the United States was probably less than 60 per cent., and the same applied to Germany. Therefore, to put it into a few words, Great Britain was losing 20,000,000 tons of coal per annum on stationary land boilers alone.

One of the reasons was that they had no proper scientific method of testing boiler plants, and no accredited system of expressing the records. What they needed was an international test code. There were three boiler test codes in the world at the present time, those of the American Society of Mechanical Engineers, what was known as the "Continental" code of the German Society of Engineers, and the British code of the Institution of Civil Engineers (revised in 1913). He had made rather a detailed study of the latter code, and had no hesitation in saying that it was a disgrace to British engineering. He hoped the visitors would not think that this code was a measure of British knowledge of steam generation.

He suggested that at a future World Power Conference, one of the first subjects to be discussed should be an international boiler test code. A second subject of equal importance was the carbonisation of coal, and the proper utilisation of the volatile matter of the coal instead of burning it as at present merely as a fuel. A third matter was a consideration of the fact that probably at least 50,000,000 tons of high grade coal were waiting to be saved on the world's steam boilers, by the scientific utilisation of the inferior fuels now thrown away, such as washery settlings, high ash content and small coals, together with kit sweepings at the collieries, coke breeze, factory refuse, and vegetable material of every description. A fourth subject, he suggested, was the consideration of the well-known fact that electricity stations were wasting about 60 per cent. of the heat in the raw coal in cooling water. They were now getting within sight of the 500,000 kW. station, and the biggest river in Great Britain was hardly sufficient to supply the cooling water for a station half that size. Stations of the above character would require a river twice as big as the Thames to supply the condensers. What was really required was a detailed examination of the whole subject of the utilisation of exhaust steam for heating and process work, so as to avoid the latent heat loss, on the lines being developed in the United States.

He took exception to one or two items in Sir Robert Hadfield's paper. The saving to be obtained on the boiler plants of the world was more like 25 per cent. than the 10 per cent. mentioned, and the average efficiency was nothing like 75 per cent. of even 60 per cent. With regard to the "Cornish" boiler, invented about 1797, by Richard Trevithick, his first installation had been at the Cook's Kitchen tin mine in Cornwall in the year 1800. This had been a landmark in the history of steam generation. It had operated at 25 lbs. pressure, but by the year 1810 there had been many Cornish boilers working up to 40 or 50 lbs. pressure.

Further, the whole principle of the mechanical stoker had been invented long before the water tube boiler, the first practical stoker being that of William Brunton, 1819.

Mr. Brownlie maintained that high CO_2 did not necessarily mean high efficiency; what they nedeed was maximum CO_2 consistent with the absence of CO and unburnt gases, or what Mr. Rodhe in his paper had so truly called the "critical point of combustion." The invention of gas analysing machines of the duplex type giving both gases, was a very important advance in the science of steam generation.

SIR ROBERT HADFIELD, Bart. (*Great Britain*), explained that his paper had partly been written for rather an exceptional reason; it was because of Turner's picture (Mt. Vesuvius in eruption in 1817), which stood on the easel before them. He happened to be the fortunate owner of it, and he had thought if a great artist like Turner could depict colours in the magnificent way he had done in that picture, why could not metallurgists also have a colour chart, which would enable them to determine temperatures, when it was not possible to use either optical or electrical pyrometers. For that reason he had had prepared the colour chart hanging on the wall. It represented an attempt to depict from the first visible red at 550°C., up to a temperature of 1,600°C. It proved that there was really no such thing as white heat in ordinary temperatures. In fact, until exceedingly high temperatures were reached, probably the temperature of the sun, they did not get really what could be called a white heat temperature. He had carried out this idea in his works, and in the course of a few months they had been able to educate a number of their employees to be able to judge accurately from the colour the temperature of the heated article with which they were dealing, or with the furnaces at high temperatures, given that there were no whirling gases present which would interfere with the results. His men, after some training, could look at a certain heated article when the pyrometer was not handy, and could tell approximately the temperature. Of course, in metallurgy the pyrometer must be used for accurate temperatures, but there were a large number of preliminary processes in which it was a very good thing to know approximately what the temperature was, without the use of the pyrometer. In the case of experienced employees, the temperatures they estimated were not more than 15° or 20° C. out, which he thought was a very creditable performance.

The question of dealing with high temperatures, with which metallurgists had so much to do, had led to the knowledge as to whether it were possible to obtain material which would stand high temperatures. It was rather a trade matter and he had great delicacy in introducing it, but it seemed so apt to the paper that he had brought a number of specimens of material with which they were working, and with which a tensile strength up to 18 tons at 900°C. was obtainable. If a thin sheet of the copper shown were subjected to an oxidising flame, the melting point of the copper would show practically no oxidisation. The material would be very useful, perhaps not on a large scale, but for purposes where it was important to avoid oxidisation.

MR. E. KILBURN SCOTT (*Great Britain*), said he wondered whether all who were there appreciated the full significance of the special material to withstand high tensile tests at such high temperatures as 900°C., which Sir Robert Hadfield and his staff had been able to make. One great significance of this new work lay in the fact that for the production of synthetic ammonia, it was necessary to use catalyst bombs having great tensile strength at high temperatures.

For example, the work of M. Georges Claude, in France, required catalyst bombs each about 7 ft. long and a foot in diameter for a working pressure of 900 atmospheres (or 14,000 lbs. per sq. in.), at a temperature of about 500°C. Also the bombs used for the Haber-Bosch process in Germany worked at 200 atmospheres and a temperature of about 600°C., and were 42 ft. long and 3½ ft. in diameter. Sir Robert Hadfield has come along at an opportune moment with his investigations, because Great Britain was going to have synthetic ammonia plants and would not have to go to the Continent, if the catalyst bombs and other vessels, piping, etc. could be made in Sheffield.

MR. W. L. R. EMMET (*U.S.A.*), expressed himself much interested in the subject of high temperatures, because he had been wanting a boiler with a temperature of over 500°C., and was anxious to find a material which would be free from oxidisation under those conditions.

MR. SANDFORD RILEY (*U.S.A.*), said that the subject raised by Sir Robert Hadfield was of very great interest to manufacturers of stokers. One of the problems in any stoker operation, apart from the question of efficiency about which so much was heard, was that of maintenance, and that was very dependent upon the material of which the plant was made. He thought that Sir Robert's paper was a very valuable contribution in that direction, and it opened up possibilities for decreasing the cost of maintenance of stokers.

SIR ROBERT HADFIELD, in reply to a question, said that the bars exhibited on the table showed a tensile strength of 15 tons at 900°C., 23 tons at 800°C., and 29 tons at 700°C. The material would not warp much.

If the furnace rack shown had been of ordinary cast iron or steel, its life would have been not more than about three months, whereas in the new material it had already run for about eighteen months and could still be used.

MR. J. J. LASSEN (*Great Britain*), on being requested by the Chairman to speak in place of Mr. Rodhe, who was unable to attend, pointed out how dangerous it was to consider CO_2 alone, as a guide to the efficiency of combustion economy. Mr. Rodhe had adopted a new term, the " critical point " in connection with combustion, and the importance of this would be seen from the diagram in his paper, where, if the 10 per cent. CO_2 were at one point, the heat loss would be, say, about 38 per cent., whereas if the 10 per cent. CO_2 were on the other side of the critical point, the heat loss might be as low as 22 per cent.

The papers presented dealt very largely with the question of economy in super power stations and very large installations, but he pleaded that in any papers that might be read at future conferences, some stress should be laid upon producing economy in the smaller power stations, which included a considerable proportion of the 47,000 boiler installations in the country, He also asked for consideration of the question of improving the personnel responsible for looking after all these installations. It was unwise to give a man with no knowledge at all of the problems which he had to handle, CO_2 instruments, meters, or any other instruments.

THE CHAIRMAN, stated that the last group of papers at this session was a large group comprising papers by Dr. Tomaïdes, Mr. Moritz Gerbel, Mr. Lundberg, Dr. Ruths, Mr. Treitel, Dr. Rummel and Mr. Kind. The papers dealt with waste heat economy, and it was a little noticeable that there was not a single English paper in the group, the whole of them being Continental.

After summarising the papers, the Chairman said he thought Britishers should recognise that not one single item had been mentioned in any of them that they had not got in Great Britain, but the point that struck him very forcibly was that on the Continent they were paying so very much attention to these methods, and were putting them to more general use than were the British.

MR. A. J. GERMAN (*U.S.A.*), recommended that at future conferences, papers should be presented on the possibility of factory power plants working in with central stations, in order to make the best use of condensed steam and avoid the losses through having to use cooling water.

MR. ORROK, drew attention to one point which was of great importance. A man running a manufacturing establishment calculated on turning over his capital six, or eight or even ten times a year, and every time he turned it over he made a profit ; while on the other hand, a man that ran a power generating plant turned over his capital once in six years, or thereabouts. It, therefore, followed that it did not pay any industrial undertaking to put in their own power plant, because the same amount of money invested in their own business

brought in returns very much larger than would be produced from any power plant that might be put in. Where, therefore, they had the use of a considerable amount of steam, it was much better from an economical point of view to put in low pressure boilers making their own steam, and buy their power from somebody who made a speciality of making it, and could furnish it to them in such quantities and at such times as they needed it.

DR. A. F. ENSTRÖM (*Sweden*), remarked that in Sweden they had no coal and that was the reason why they had considered so deeply the question of steam economy, although their biggest source of energy was water power. The predominant problem before them was to provide all the heat needed for industrial purposes, for instance, in the paper industry. There was also the question of generating steam for the purposes of power and heat at the same time, and there were a large number of plants running on those lines, producing at the same time steam for power and steam for heat. This problem of the generation of steam for combined power and heat was very important, and he was convinced that in the future the combination would be used to a great extent all over the world.

The most serious drawback they had to deal with, was the fact that the demand for power and the demand for heat did not coincide. In order to arrive at a successful solution of the problem, they found that the remedy was to put in steam accumulators. The accumulators had been used in Sweden in connection with a great many plants, and it was that that had made it possible to produce steam for heat and power at the same time, in an economical way.

Another problem before them, was the providing of a reserve station for transmission lines from hydro-electric sources, which were situated far away from the centres of consumption. They were now working on the solution of the problem of a reserve station, and in that case too, they had found steam accumulators of great use. In some plants, the steam accumulator was installed, and in case of failure the accumulator immediately took the load for half an hour or so, sufficiently long to bring the boilers into operation and put on thé reserve station. It was quite an interesting example of the use of the steam accumulator, and it had proved of very great advantage to them in their water power plants.

DR. G. KLINGENBERG (*Germany*), said that he thought that in advocating a separate low pressure boiler installation Mr. Orrok was quite right, as long as only a small amount of steam power was required, but there were many cases where steam power, instead of being used for heating was required for other purposes. Wherever that was the case, he did not agree with Mr. Orrok.

If an accumulator such as Ruths accumulator was adopted, they got the advantage of a more even load on the boiler with the result of, first, a very much better overall efficiency; secondly, a smaller boiler plant, and third, the production of steam was made entirely independent of the amount of power required at each moment, in the form of electricity and in the form of heat. One manufacturing process could therefore be carried through independently of another process in the same factory. Another advantage, and one which he considered to be the greatest, was that if different processes of manufacture in different parts of a factory could be carried out independently of electric power requirements, the manufacturer was able to increase his production by a very large percentage. If the financial position of Germany were not so bad as it was at present, an enormous number of Ruths accumulators would have been installed; as it was, during the last year, about thirty Ruths' accumulators only had been installed. They were not all working yet, but those which had been put into commission were working to the greatest satisfaction of their owners.

In the combination of electric and steam production, the amount of capital required for an electric plant was relatively small, because only the high pressure part of a turbine was required, which could be obtained at a very low cost; on the other hand the accumulator was comparatively cheap, because it was not operated at the high pressure of the boilers, being generally designed for a medium pressure; any steam that might be required at a higher pressure than that in the accumulator, could be obtained directly from the steam

raising plant. That would, he thought, be the future system in all cases where a reasonable amount of power was required for heating purposes. He was fully convinced that the advantage would be recognised not only in Sweden but in Great Britain, in Denmark (where already more than 120 Ruths' accumulators had been installed), and also in other countries.

DR. J. RUTHS (*Sweden*), in presenting his paper on *Steam Accumulation*, said the Chairman had mentioned that his paper omitted figures showing actual results obtained in practice. The paper as originally drafted had contained a series of figures, and he now took the opportunity of restating them.

The A/B Vaporackumulator of Stockholm, the company which had acquired his patents, had, partly itself and partly through its licensees, consisting of leading engineering firms in the various countries, sold more than 160 accumulator plants during the last five years, representing a total value of about £1,000,000, which must be considered very creditable for a new invention, and a good proof of its value.

Of these 161 installations, about 100 were working; many had been the subject of official expert examination, while for others, testimonials had been given by the various purchasers. In all such cases, it was shown that a fuel economy varying from 15 to 30 per cent. had been obtained. A further result was an increased output of the factory of from 10 to 30 per cent. from the day of the installation of the accumulators, and in most cases, it had been possible to reduce the boiler heating surface by 25 per cent., and in one particular case, even by 60 per cent.

The invention was protected by patents in all civilised countries, but unfortunately the particulars in connection therewith had also been left out, so that the paper hardly conveyed an adequate idea of the patent value of the invention.

Mr. Brownlie had mentioned the fact that in a great number of boiler houses, the overall working efficiency only amounted to 60 per cent. This was due to the fact that, owing to the fluctuating loads, the figure was considerably below that gained by the makers on delivery tests, or that obtained from boilers under constant load, and it was exactly for such cases that the accumulator was of very great value. He and his colleague had examined up to date more than 2,000 steam plants in different branches of industry in many countries. As a result, it had been shown that in order to obtain the best working results, it would be necessary to install Ruths accumulators in 70 per cent. of all steam installations.

With regard to what Mr. Orrok had said, he did not agree with him. He remembered that Dr. Klingenberg two years ago, in Germany, in speaking about his accumulator, had said just the same as Mr. Orrok, but they now saw that Dr. Klingenberg was in his favour.

Dr. Ruths pointed out that industry not only needed power but must also have heat, and that a joint production of these two gave the best economy. If for that purpose, high pressure boilers and reducing or " pass out " turbines were installed, great difficulties were caused by the heat, or power was not used at an equal rate all the time, but at a variable rate. There was only one possibility of securing good economy from a plant of that type and that was by the use of steam accumulation.

Very much had been said about heat economy and efficient production of heat, but that was not the main question. They arranged their boilers to raise steam as economically as possible, and built their engines and generators to produce electrical energy in the most suitable and efficient manner, instead of devoting the energy to the most important matter, *viz* :—the raising of the overall efficiency of the factory itself.

It was dangerous to try in a one-sided way, to increase the efficiency of the boiler and power plant alone. They had no reason whatever to single out the question of fuel economy from the whole process of manufacturing, and to consider the solution of that problem to be the main factor in obtaining profitable results. They must not forget that although by such a one-sided procedure they often obtained steam under perfect conditions, the principal value of the factory lay in the *quantity and quality of its products*, as the factories existed

only for the purpose of producing such goods as cloth, paper, sugar, chemicals, etc. The fuel consumption represented only a part of the manufacturing costs. He thought that in a few years hence people would say that what they needed was a World Material Conference or World Production Conference.

The value and efficiency of the steam accumulator lay in the fact that the problem of the factory was considered as a whole, and with the accumulator all the parts of the factory worked together, so that it worked really as a gigantic flywheel for the whole of the works. In industry, the cost of coal was only some 10 per cent. of the whole cost of production. If they had boilers of 90 per cent. or 97 per cent. efficiency, it did not matter very much; what mattered was whether they had a profit on the industry or not. He hoped that at the next World Power Conference or, as he might say the next World Material Conference, he would be allowed to show that in very many cases, the fact of regarding the power as the capital thing in the factory had the effect of making the profits of the factory drop. He could demonstrate that by figures, in connection with undertakings in Sweden, Finland, Norway, Denmark, Austria and Germany.

He would go so far as to say that they would have sold just as many accumulators, even had the accumulator caused an increase in the consumption of fuel, instead of a decrease—in consideration of the importance of the accumulator to the working of the factory *as a whole*.

The accumulator formed a storage between the boiler house and the factory, so that the generation at the boilers and delivery of steam to the storage could be made as desired, while notwithstanding this, steam for the various purposes of the factory was at all times available from the accumulator, quite independent of the boiler supply. He hoped at some future time to have the opportunity of going further into this most important question, and could only just touch upon the matter now owing to lack of time.

He added that his experience had shown him that in nearly all cases, the factories themselves could to their advantage produce power under back pressure, in which case 20 to 50 per cent. more power was obtained *with* the accumulator than *without* it.

Although they had large power mains in the various countries distributing electricity, until they had also found a way to transport steam, every factory would have to produce its own heating steam, and here again the Ruths accumulators showed to full advantage, by enabling the activities of the factory to be conducted in a manner quite independent of the power supply from the mains.

As a flywheel was considered to be an indispensable part of a power engine, so, within a few years, would the accumulator be considered to be an indispensable part of a steam or power installation, as it performed exactly the same function as the flywheel.

This had more and more become the opinion of engineering scientists, as he had been very glad to see from more than two hundred scientific articles in many languages that had appeared during recent years concerning his invention, and he would say that in those countries where the accumulator had already been introduced, no doubt whatever existed as to its practical value.

The Chairman had pointed out the peculiar fact that no English papers had been presented concerning the combination of power and steam economy. He dared to prophesy, in view of the highly developed technical efficiency of the English speaking people, that there would be no shortage of such papers at the next Conference, and that the steam accumulator would be mentioned in all of them.

THE CHAIRMAN then closed the session.

STEAM GENERATION

CHAIRMAN: DR. A. F. ENSTRÖM (Sweden)

Direktor, Kungl. Ingeniörsvetenskapsakademien

HIGH PRESSURE STEAM, ITS PRESENT AND FUTURE APPLICATION IN POWER AND HEATING PLANTS

O. H. HARTMANN,
Cassel - Wilhelmshoehe.

By the studies and experiments of the late inventor, Dr. Wilhelm Schmidt, of Cassel-Wilhelmshoehe, made during the last 15 years, a new development in the art of steam engineering has once more been initiated with the introduction of very high steam pressures, this development being comparable to that started by Schmidt's earlier work in connection with the introduction of superheated steam in the nineties of the last century. Since the publication of the high pressure test results at the 1921 meeting of the " Verein Deutscher Ingenieure " by the author, it can be noticed that everywhere working pressures in power plants are being raised by leaps and bounds. Though the use of high steam pressures for steam engines had been proposed as early as in the 19th century by Perkins, Alban, Wilhelm Schmidt, de Laval and others, these endeavours were necessarily without result, as neither science nor engineering were advanced sufficiently at that time.

PROPERTIES OF HIGH PRESSURE STEAM.

The total heat of high pressure steam up to 60 atm. (854 lb. per sq. in.) has not yet been thoroughly investigated. But several attempts have been made, first by W. Schüle, to determine these figures by extrapolation. The most reliable values seem to be those given by Knoblauch-Raisch-Hausen in 1923. According to their tests at 60 atm. (854 lb. per sq. in.) and 400°C. (752 deg. Fahr.) the total heat above 0°C. (32 deg. Fahr.) is 762 kg. cal/kg. (1372 B.T.U. per lb.). Though these figures are not absolutely reliable from a scientific point of view, the very small difference possible will not affect the practical calculation of engines. The saving of steam in an ideal engine using steam of 60 atm. (854 lb. per sq. in.) initial pressure and 400°C. (752 deg. Fahr.) temperature at 95 per cent. vacuum, in comparison with an engine using steam of 15 atm. (214 lb. per sq. in.) pressure, all other conditions being equal, will be 13.6 per cent. This gain (with condensing engines) appears so small that the use of high steam pressures was generally rejected until a short time ago.

The Schmidt trials, extending over many years, have shown that the usual working methods and the steam temperatures of about 350°C. (662 deg. Fahr.) are not sufficient for high pressure engines, and that with high initial pressures both high superheat and proper re-superheating become necessary. Initial steam temperatures may be considerably higher at high pressures than is advisable at low pressures, for high pressure steam has, on account of its density, a good cooling effect on the superheater tubes and when properly arranged these, even with steam of 475°C. (885 deg. Fahr.) will not become overheated and will stand up to long service. Such high temperatures can also be applied in the high pressure stages of reciprocating engines without using an extra high grade lubricating oil, because by the prevailing pressures, the boiling point of the normal cylinder oil is raised.

RESULTS OF TESTS MADE WITH HIGH PRESSURE ENGINES AND HEAT CONSUMPTION OF CONDENSING HIGH PRESSURE ENGINES.

At the first tests condensing engines consumed about 2,600 kcal/PS. ind. (10,400 B.T.U. per I.H.P.). By further improvements this consumption was reduced to 2,400 kcal (9,650 B.T.U.). These first results seemed to justify the objections raised on the grounds of theoretical conclusions. But by the use of prolonged expansion down to 0.2 atm. (2.85 lb. per sq. in.) and by proper re-superheating, ultimately a heat consumption of 2,070 kcal/PS. ind. (8,300 B.T.U. per I.H.P.) with a 150 H.P. four-stage engine was attained. The quantity of steam used was 2.33 kg/PS. ind. (5.2 lb. per I.H.P.) the steam having 55 atm. (783 lb. per sq. in.) pressure 435°C. (815 deg. Fahr.) temperature and the vacuum in the condenser being 95 per cent. The working steam was re-superheated before the second medium pressure cylinder to 250°C. (482 deg. Fahr.) and before the low pressure cylinder to 220°C. (428 deg. Fahr.) by saturated high pressure live steam. If a quantity of steam equivalent to the heat used for re-superheating is added to the above consumption, the total weight of steam used comes to 2.62 kg/PS. ind. (5.85 lb. per L.I.P.). This result seems to mark the highest attainable efficiency of the reciprocating engine. On the other hand the economy of steam turbines, by the means adopted at the test engine can also be considerably improved.

Supposing that the best modern steam turbines using superheated steam take about 2,800 kcal/PS. eff. (11,200 B.T.U. per B.H.P.) at 15 atm. (214 lb. per sq. in.) working pressure and 95 per cent. vacuum, the gain obtained by raising the initial pressures

and temperatures and by re-superheating will be, when the initial pressure is raised:

From 15 atm. (214 lb.) to 30 atm. (427 lb. per sq. in.) 13.2 per cent.
„ 15 atm. (214 lb.) to 60 atm. (854 „ „) 21.5 per cent.
„ 15 atm. (214 lb.) to 100 atm. (1425 „ „) 26.5 per cent.

Taking the total heat of the superheated steam above 0°C. (32 deg. Fahr.) to be 768 kcal/kg. (1,380 B.T.U. per lb.) the best possible re-superheating engines will consume:

At 15 atm. (214 lb. p. sq. in.) init. pressure 2680 kcal/PS eff. (10750 B.T.U. per B.H.P.)
„ 30 „ (427 „ „) „ „ 2430 „ „ (9750 „ „)
„ 60 „ (854 „ „) „ „ 2200 „ „ (8850 „ „)
„ 100 „ (1425 „ „) „ „ 2060 „ „ (8300 „ „)

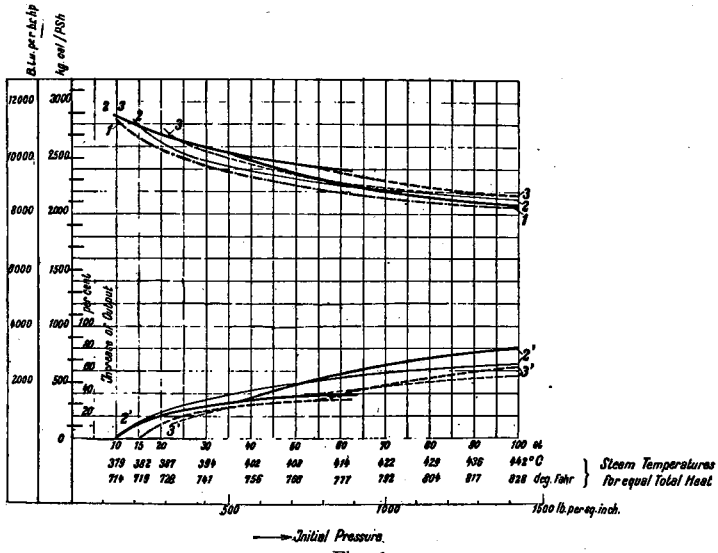

Fig. 1.

Total Heat Consumption above 0° C. (32° Fahr.), in steam (resuperheating included) for 95 per cent. vacuum.

Heat Consumption of best possible high pressure engines and of engines with 10 and 15 at (142 and 214 lb. per sq. in.) steam pressure, when combined with high pressure stages.

Increase of Output obtained by the addition of high pressure stages.

Curve 1 —.—.— 1 Best possible engine.
Curve 2——2, 2'——2' Engine with 10 at (142 lb. per sq. in.) initial pressure, combined with high pressure back pressure engine.
Curve 3——3, 3'——3' Engine with 15 at (214 lb. per sq. in.) initial pressure combined with high pressure back pressure engine.

The thick lines are rated for resuperheating by saturated live steam.
The thin lines are rated for resuperheating to 350° C. (662° Fahr.) by fire gases after the first stage.

In Fig. 1 these values are shown by the dashed and dotted lines 1-1. The advantages connected with high-pressure superheated steam are not confined to entirely new plants but may also be obtained in existing plants by adding to these a high pressure back pressure installation. In many cases this way will even be the most feasible as the operation of existing plants will not be disturbed. In a plant using steam of 10 atm. (142 lb. per sq. in.) with 350°C. (662 deg. Fahr.) steam temperature, the output can be raised 80 per cent by the addition of an engine working with steam of 100 atm. (1,425 lb. per sq. in.) pressure and 442°C. (828 deg. Fahr.) temperature (see line 2' - 2' of Fig. 1). The quantity of heat consumed is shown by the line 2 - 2. In general, by the means adopted, the fuel consumption will be reduced 25 to 30 per cent. with condensing engines.

In Fig. 1 also the influence of different methods of re-superheating is visible. Re-superheating can be effected by saturated high pressure live steam or by the flue gases. As to thermal efficiency, both methods are approximately equal. But the first one has practical advantages, because for instance, the long pipelines from the engine to the boiler and back, are eliminated and thus radiation and friction losses are reduced. Moreover, there will be equal superheat at all loads without the application of any regulating device, and there is no danger of the temperature of steam getting too high, as can easily happen with fire-gas superheaters. A design of a low pressure re-superheater for 100,000 kg/h. (220,000 lb. per hour) is shown in Figs. 2 and 3.

A further improvement can be effected by pre-heating the feed water with extracted steam, which method shows the best advantages with high steam pressures. For it becomes possible now to save 8 to 15 per cent. of heat without getting too much pre-heating. The best value of 2,060 kcal/PS. eff. (8,300 B.T.U. per B.H.P.), given above, can, therefore, be lowered by 310 kcal (1250 B.T.U.), so as to get a total heat consumption of 1,750 kcal (7,050 B.T.U. per B.H.P.) in steam. In such cases, however, by the application of air pre-heaters in the boilers, the gases have to be cooled sufficiently so as to get a boiler efficiency of 85 per cent. The heat consumption in fuel will then be 2,060 kcal/PS. eff. (8, 300 B.T.U. per B.H.P.), being equal to that of a two-cycle Diesel engine.

By the new working method which has become practical only by the use of high steam pressures an unexpected increase of the theoretical gain has been attained.

Interstage Superheater (reheater) heated by saturated high pressure steam for 100,000 kg. (220,000 lb.) per hour of low pressure steam.

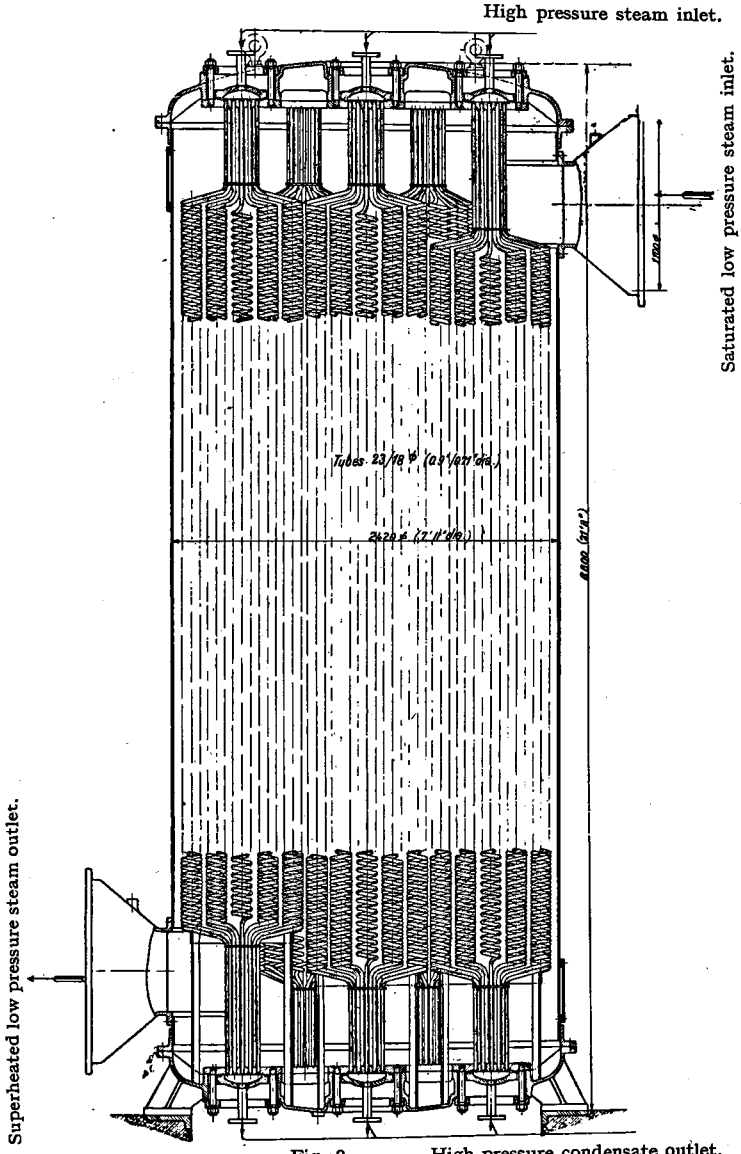

Fig. 2.

HIGH PRESSURE STEAM IN A HIGH PRESSURE BACK PRESSURE PLANT IN COMBINATION WITH THE UTILISATION OF EXHAUST STEAM.

Even more striking are the advantages of high steam pressures when the steam works in back pressure engines and the exhaust is used for heating or other purposes. Up to now, back pressure engines with the usual initial pressures had only a narrow field, as at higher back pressures the greater part of the energy of the steam was absorbed by the back pressure. But if the pressure of steam is raised far above the usual pressure, the energy contained in the low pressure steam used for heating purposes, is but a small portion of the total energy. This is visible in Fig. 4. The area f^3

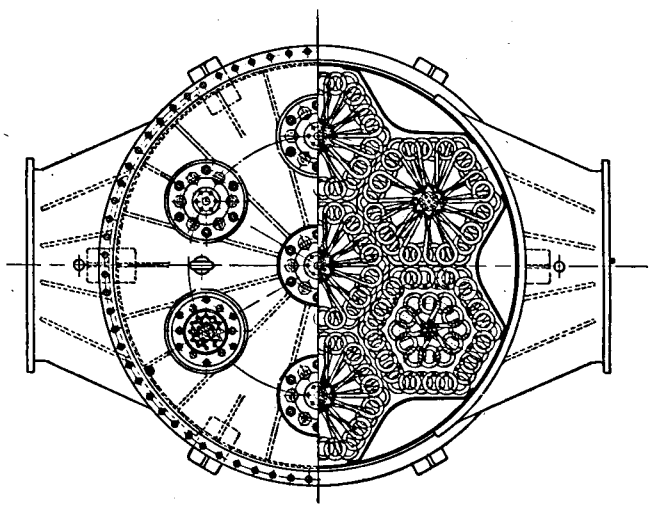

Fig. 3.

shaded to the left gives the increase of work when the pressure is raised from 15 atm. (214 lb. per sq. in.) to 60 atm. (854 lb. per sq. in.). By choosing a suitable initial pressure the drawback of a high back pressure can be thoroughly equalised. It is rather startling to see that with initial pressures of 30 atm. (427 lb. per sq. in.) the steam consumption will not rise considerably with rising back pressures, the increasing consumption following up the rising back pressure in equal or even in diminishing steps. In Fig. 5 this is clearly visible.

In the following Table 1 some examples are given to show the work obtainable from 1,000 kg/h, (2,200 lb. of steam per hour) when the back pressure amounts to 2.6 and 12 atm. (28.5,854 and

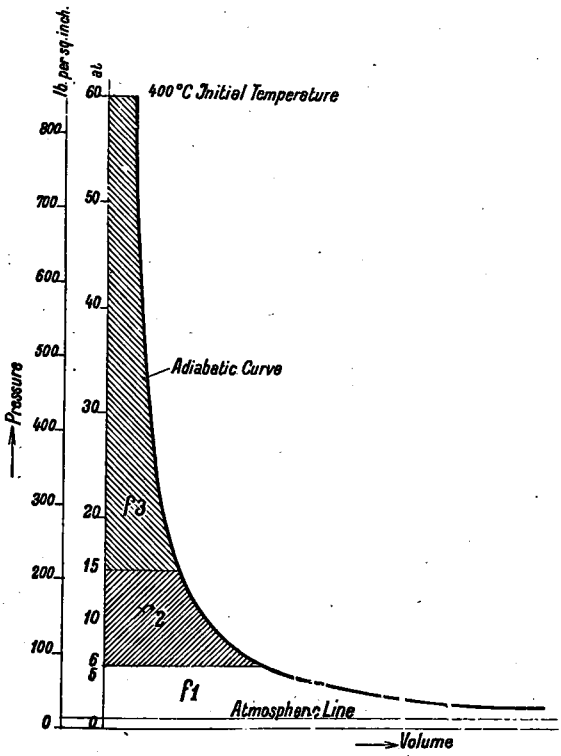

Fig. 4.

Influence of high initial pressures on the output of back pressure engines.

171 lb. per sq. in.). At a back pressure of 2 atm. (28.5 lb. per sq. in.) steam of 15 atm. (214 lb. per sq in.) initial pressure will give 185.5 PS (183 H.P.); steam of 60 atm. (854 lb. per sq. in.) however, will give 268 PS. (264 H.P.), *i.e.*, 45 per cent. more. For 6 atm. (85.4 lb. per sq. in.) and 12 atm. (171 lb. per sq. in.) back pressure the difference will be even more conspicuous. From these figures the great importance of high steam pressures for back pressure

engines is evident, especially in view of the fact that for one kW. hour only 1,400 kcal. (5,550 B.T.U.) in fuel will be consumed, all losses included.

By the use of high steam pressures many new, formerly impracticable ways for the planning of combined power and heating plants can be found. Much process work, hitherto done by direct

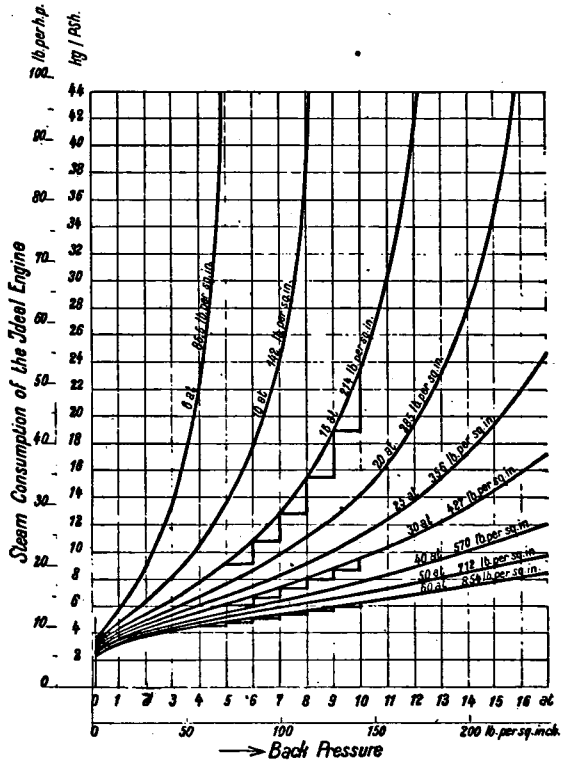

Fig. 5.

Relation between steam consumption and rising back pressures for various initial pressures and 400° C. (752° Fahr.) initial temperature.

heating or by heating with live steam can now be done by exhaust steam. For instance, the work done by a given weight of steam will be only slightly altered, when exhaust steam of widely varying temperature is wanted for heating purposes. Furthermore, the capacity of existing heating plants can be raised or the first cost of a new plant reduced by the application of high steam pressures.

For in many cases evaporating and drying plants can then be operated without vacuum as multi-stage apparatus.

In future, in all plants requiring heat, the whole quantity of steam necessary ought to be generated at pressures over 30 atm. (427 lb. per sq. in.) and expanded in steam engines before being used. A new power plant erected in place of a mere heating plant, will have only 20 to 25 per cent. more grate surface and will have lower first cost and better economy than any other type of plant.

By the use of high steam pressures it becomes possible to generate power and heat simultaneously though they may be required at separate times or at separate places. For instance, exhaust steam

Back Pressure { in atmosph. / in lb. per sq. in.	2 / 28.5	6 / 85.5	12 / 171
Initial Pressure 15 atm. (214 lb. per sq. in.)	185.5 PS / 183 HP	92.5 PS / 91.5 HP	23.7 PS / 23.4 HP
Initial Pressure 30 atm. (427 lb. per sq. in)	228 PS / 225 HP	149 PS / 147 HP	90 PS / 89 HP
Initial Pressure 60 atm. (855 lb. per sq. in.)	268 PS / 264 HP	196 PS / 193 HP	147 PS / 145 HP

Table I.

Theoretical output, H.P. from 1,000 kg/h. (2,200 lb. per hour) of steam, for 400° C. (752° Fahr.) initial temperature.

of 10 atm. (142 lb. per sq. in.) pressure and more can be accumulated in comparatively small reservoirs and, owing to the higher pressure, can be transmitted over long distances. By inserting a compressor into the pipe line after some miles, in order to restore a part or all of the lost pressure, it becomes possible to transmit the exhaust steam over a distance of up to 10 km. (6.2 miles) with an efficiency of 75 per cent.

HIGH PRESSURE BOILER PLANTS ERECTED UP TO NOW IN GERMANY

At first in Germany, an attempt was made to develop the coil boiler for high pressures. But owing to the inherent difficulties these efforts had to be given up. The first practically working high pressure boiler was the narrow tube boiler of W. Schmidt, built in 1910-11, for 60 atm. (854 lb. per sq. in.) working pressure (Fig. 6 to 9). It consists of three parts: evaporator, superheater and economiser. The grate surface is 1.44 m^2 (15.5 sq. ft.). The total heating surface, superheater included, is 72 m^2 (775 sq. ft.). This boiler has given up to 1,350 kg/h (3,000 lb. per hour) of 60 atm. (854 lb. per sq. in.) pressure and 450°C. (842 deg. Fahr.) temperature. Steam and water drums of this boiler are seamless drawn cylinders,

HIGH PRESSURE BOILER OF W. SCHMIDT

for 60 at. (854 lb. per sq. in.) working pressure.

Total heating surface 72 m² (775 sq. ft.).
Grate area, 1·44 m² (15·5 sq. ft.).

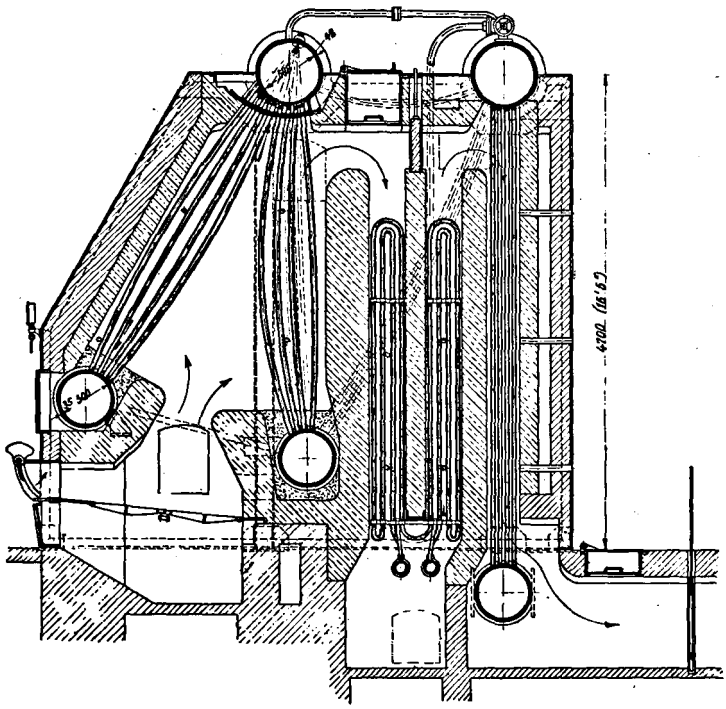

Fig. 6.

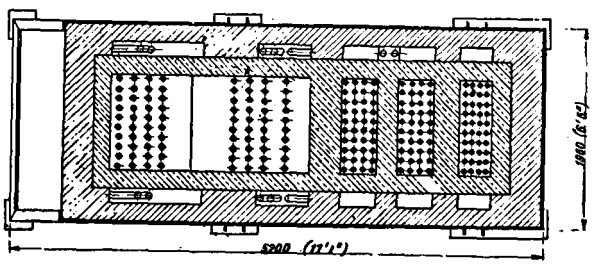

Fig. 7.

the drum heads being welded on by water gas with wedge-shaped seams. The upper drums have a diameter of 600 mm. (1 ft. 11.6 in.), the lower drums of 500 mm. (1 ft. 7.7 in.), the water tubes of 36/28 mm. (1.42 in. to 1.1 in.). Water is fed into the lower rear drum; it ascends through the water tubes of the economiser in the opposite

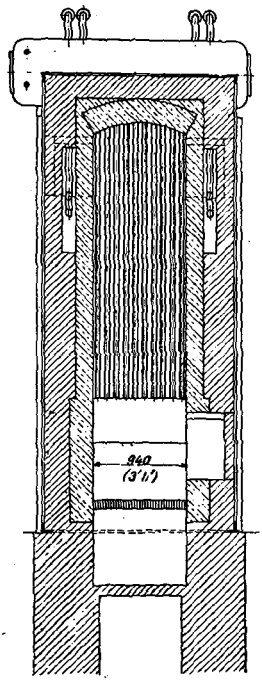

Fig. 8.

direction to the flue gases and being pre-heated to 180°C. (356 deg. Fahr.) is led into the main circulation by lateral downcomers.

The superheater is arranged in two flues and can be short-circuited. The drums of the evaporating part are protected against the direct action of the flue gases in order to avoid too great a difference of the temperature between the inner and outer surface of the drum walls. In this way no additional strain by temperature difference will be put on the material of the drums.

The only difficulty experienced was the frequent bursting of the water gauge glasses; this was overcome by a modification of the design. Then in the economiser tubes there appeared corrosions,

because the feed water had not been de-aerated before entering the economiser. This high pressure boiler has been working 17,500 hours up to now.

On the basis of the experiences made with this boiler, one firm began the construction of a high pressure boiler for their own works under the patents of the Schmidt'sche Heissdampf-Gesellschaft. By the occupation of the Ruhr the delivery of the

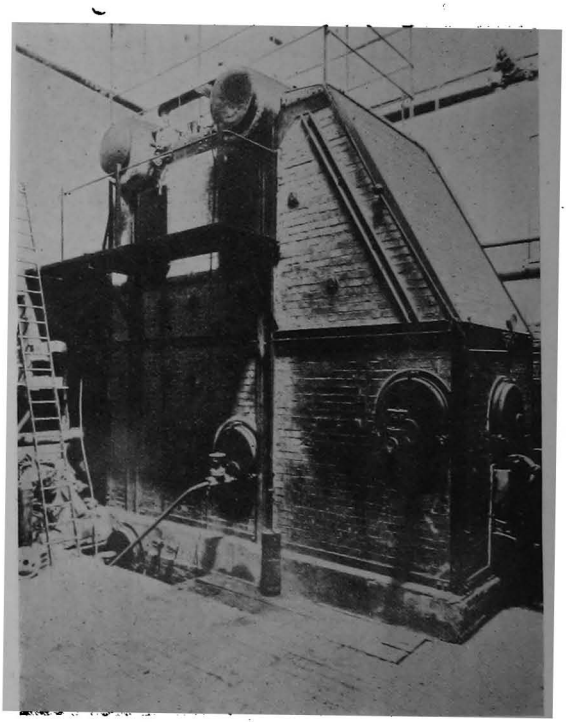

Fig. 9.

boiler material and the starting of the plant was delayed one year. The general disposition of the Schmidt-Borsig boiler is shown in Figs. 10 and 11. Here the drums are not welded, but forged in one piece. With these drums there is no difficulty in raising the working pressure up to 100 atm. (1,425 lb. per sq. in.) as the walls can be made in any thickness. Here also protective screens for the drums are provided in the first flue. By these screens it becomes possible to inspect the connections of the

SCHMIDT - BORSIG HIGH PRESSURE BOILER OF 300 m² (3,230 sq. ft.) HEATING SURFACE.

For 60 at. (854 lb. per sq. in.) working pressure with superheater and with a low pressure boiler for 2 at. (28·5 lb. per sq. in.) working pressure.

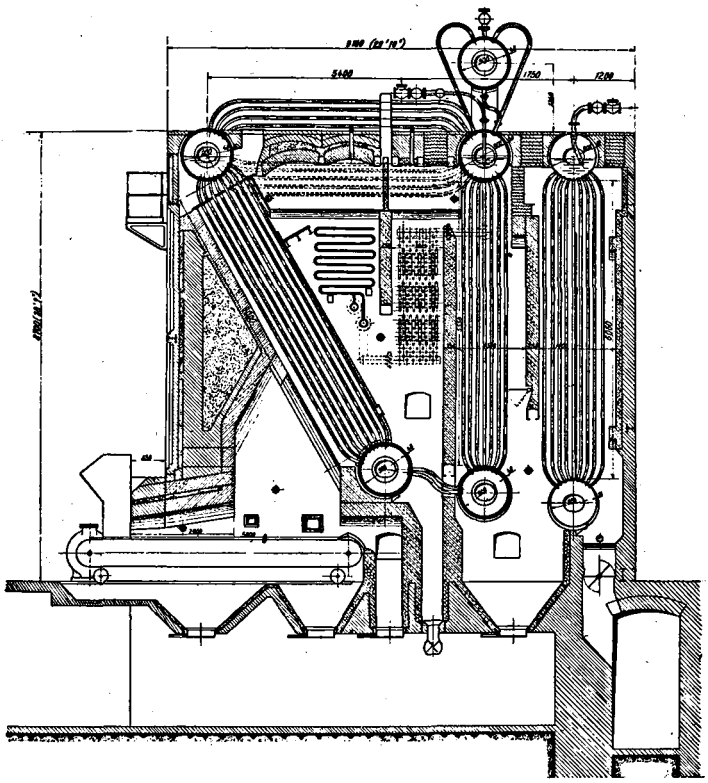

Fig. 10.

water tubes with the drums while the boiler is working. With high pressure boilers it is advisable to employ drums of small diameter in order to save cost, as has also been done with the Schmidt-Borsig boiler. The use of small drums is quite admissible, as the steam bubbles are considerably smaller than at the usual pressures, and as priming will not occur so easily. The superheater is arranged in a similar way as with the Schmidt trial boiler. In order to avoid the drawbacks of the steel economiser, there has been arranged behind the boiler proper a low pressure boiler,

serving as economiser for the high pressure boiler. The normal evaporation of the high pressure boiler is to be 7,000 kg/h (15,400 lb. per hour), though with 300 m² (3,230 sq. ft.) of heating surface at least 50 per cent. more steam would be easily obtainable. In place of the low pressure boiler, a cast iron economiser for low pressure with two-stage feed pumps might have been installed.

One of the chief obstacles to the introduction of high steam pressures was the doubt whether the material of the boiler would stand

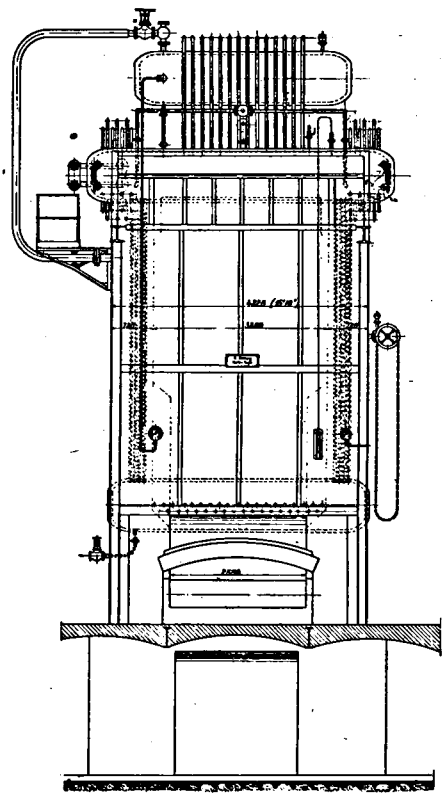

Fig. 11.

the high temperatures. To overcome this doubt the rear upper drum of the Schmidt trial boiler, which had been exposed to high temperatures and had been in service 15,000 hours, was taken out and was tested for its properties by the Staatliche Material-Prüfungsamt at Berlin-Dahlem and by some other institutions. All

tests have concurrently shown that the material behaves in quite the same manner as at normal pressures, if only certain precautions are taken. In recent years in Germany many investigations have been made with boiler material.

Goerens in the Z.d.V.d.I. 1924/No. 3, has shown to what circumstances the eventual deterioration of the material is due. According to Goerens, riveted drums ought not to be used for high pressure boilers as the material gets stressed in its cold state by riveting. Moreover, the use of 5 per cent. Ni.-steel has been recommended for forged drums. This steel at the temperature of 250° to 300°C. (480 to 570 deg. Fahr.), being the temperatures of high pressure steams has very good properties as to strength, elongation and resistance against impact.

Recently, one German company in particular, made much progress in the art of welding. They are able now to weld drums up to 60 mm. (2.35 in.) in thickness by water gas. The seams, by a new process, are tested at 3 to 4 times the working stress, and the over stressed material is afterwards reconstituted by annealing at 900°C. (1,650 deg. Fahr.). Such drums should be very applicable for pressures up to 50 atm. (710 lb. per sq. in.).

In Germany, owing to the bad economic conditions, only few plants with pressures higher than 30 atm. (427 lb. per sq. in.) have been installed. In 1916, Dr. G. Bauer gave a report on a two-pressure boiler of the Vulcan-Werke for 40/15 atm. (570/214 lb. per sq. in.) pressure. This boiler has, however, no practical importance.

The largest German high pressure plant now under construction is destined for the Bayer'sche Farbenfabriken at Leverkusen (Rheinland). Here for the generation of 200 to 240,000 kg/h (440 to 530,000 lb. per hour) at 32 atm. (455 lb. per sq. in.) pressure, 12 boilers of 600 m^2 (6,500 sq. ft.) heating surface each are provided. The boilers are of the Stirling type. Several leading German boiler makers have also designed Stirling type boilers for pressures up to 100 atm. (1,425 lb. per sq. in.) and are able to start building at once.

An attempt is being made by one firm to develop, besides the vertical boiler, a sectional boiler for high pressures. They have an order for 5 sectional boilers of 400 m^2 (4,300 sq. ft.) heating surface each, for 34 atm. (484 lb. per sq. in.) working pressure.

This type of boiler, however, seems to have not so much prospect of wider application, as, when pressures are further increased, only small water spaces will be obtainable. Also, the water circulation is not so reliable and the outer heating surface is more difficult to keep clean.

HIGH PRESSURE RECIPROCATING ENGINES.

In the course of Schmidt's trials a series of reciprocating engines of 100 to 300 I.H.P. have been built and tested. They were designed for high speeds up to 1,500 R.P.M. or for normal speeds. It was the object of the trials to show the influence of high pressure and highly superheated steam on pistons, stuffing boxes and distributing valves under service conditions. Pistons and stuffing boxes worked better than was expected from the very first. The following valve gears have been tried : positive double beat valves, steam governed automatic valves and piston valves. The double beat valves were somewhat leaky at first ; by an improvement in the design this trouble was overcome.

The automatic steam governed valves for high engine speeds gave rise to some difficulties at first. Later on, when grouped valves of very light weight and small lift were used they worked very well.

The piston valves did well from the very first. This type of valves, when built as drop valves, would seem to be the best suited for high pressures.

The last built four-stage 150 H.P. engine which gave the above mentioned unexpectedly high economy, is fitted with piston valves on the high pressure cylinder. This engine, shown in Figs. 12 to

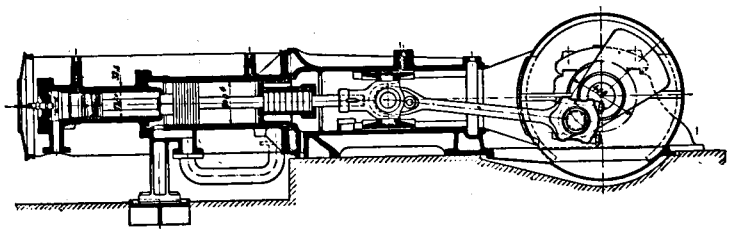

Fig. 12.

Four stage high pressure engine (high pressure side) 135/240 mm. (5·3 in./9·45 in.) dia., 400 mm. (15·75 in.) stroke, 150 r.p.m. for 60 at. (854 lb. per sq. in.) pressure, 400° (752° F.) temperature, exhausting against 3 to 6 at. (44 to 85 lb. per sq. in.) back pressure, fitted with Wilh. Schmidt-System steam governed inlet valves.

Fig. 13.

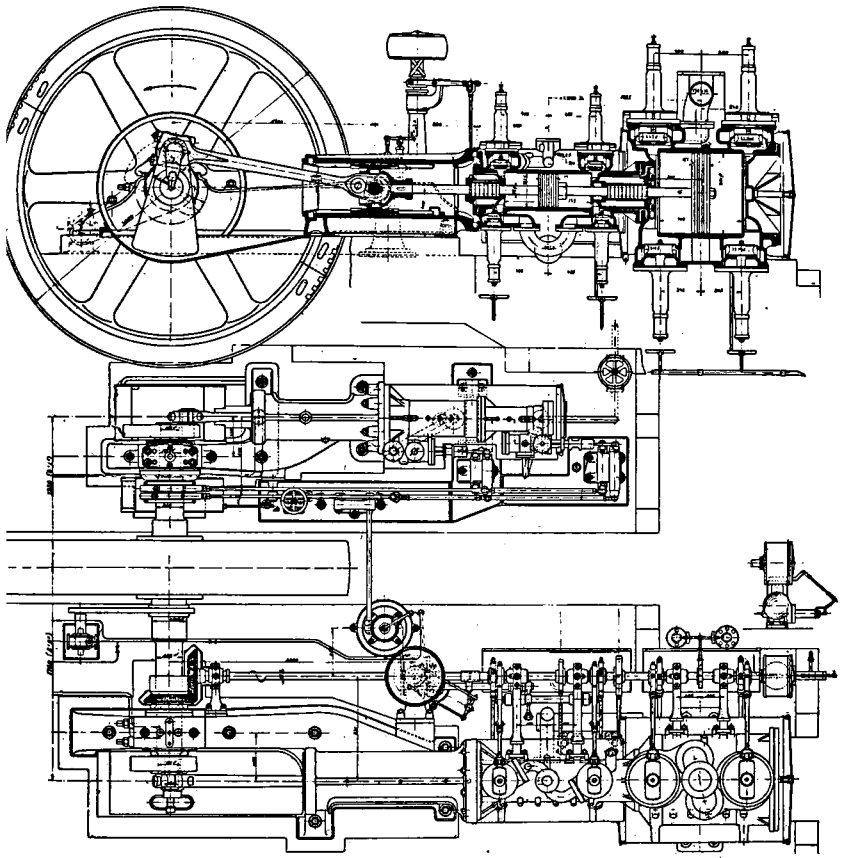

Fig. 14.
Four Stage high pressure engine.

Principal Dimensions.

High Pressure Side.

Cylinder dia. 135/240 mm. (5·3 in./9·45 in.)
Stroke, 400 mm. (15·75 in.).
R.p.m., 150.
Init. pressure 60 at. (854 lb. per sq. in.)

Low Pressure Side.

Cylinder dia. 285/680 mm. (11·2 in./26·8 in.)
Stroke, 600 mm. (23·6 in.)
R.p.m., 150.

14, is not to be regarded as perfect, being partly composed of earlier trial engines.

The most compact type of high pressure engine will be a back pressure engine, the exhaust of which is used for heating purposes. This engine will have very small dimensions even for great powers. A high pressure back pressure engine for 4,000 I.H.P. is shown in Figs. 15 and 16; the cylinders are only 440/700 mm. (17.3 in./ 27.6 in.) in diameter, the stroke is 1,000 mm. (39.4 in.) and the

4,000 H.P. high pressure back pressure engine.

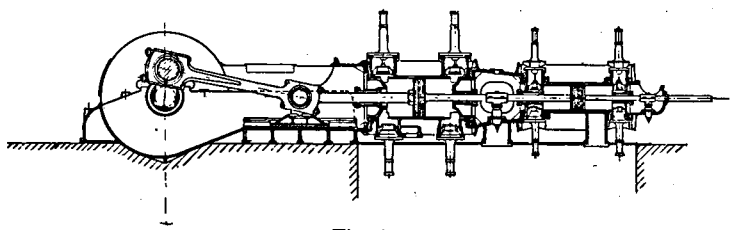

Fig. 15.

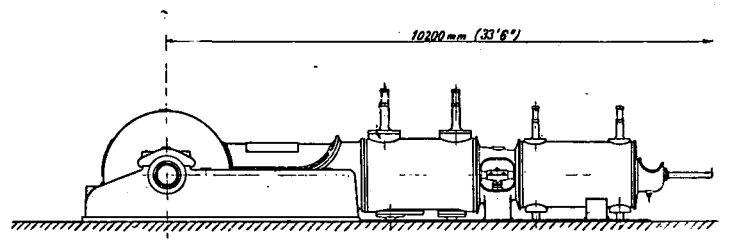

Fig. 16.

speed 125 R.P.M. A condensing engine for 15 atm. (214 lb. per sq. in.) pressure consumes about 3,000 kcal/PS. h (12,000 B.T.U. per I.H.P.) in steam, 2,300 kcal (9,200 B.T.U.) of these going to the condenser. A high pressure back pressure engine exhausting against 6 atm. (85.4 lb. per sq. in.) pressure on the other hand will want only 3,600 kcal/PS_i h (14,500 B.T.U. per I.H.P.), 2,900 kcal (11,650 B.T.U.) of which can be used for heating purposes, for the exhaust steam having a pressure of 6 atm. (85.4 lb. per sq. in.) can easily be transmitted for use at a distance. Already this simple comparison shows the great importance which high steam pressures will have for the combined generation and utilisation of power and heat.

The Schmidt-Borsig high pressure back pressure engine (Fig. 17) is built on the same principles as the high pressure cylinder of the four-stage Schmidt engine. High pressure and low pressure cylinders are single acting, 325 mm. (12.8 in) and 510 mm. (20 in.) in diameter, with a stroke of 900 mm. (35.5 in.). The engine will run at 90 to 120 R.P.M., and will drive an air compressor from the left-hand crank Both cylinders have Hochwald piston valves. At 60 atm. (854 lb. per sq. in.) inital pressure and 10 atm. (142. lb. per sq. in.) back pressure the power developed will be 820 I.H.P.

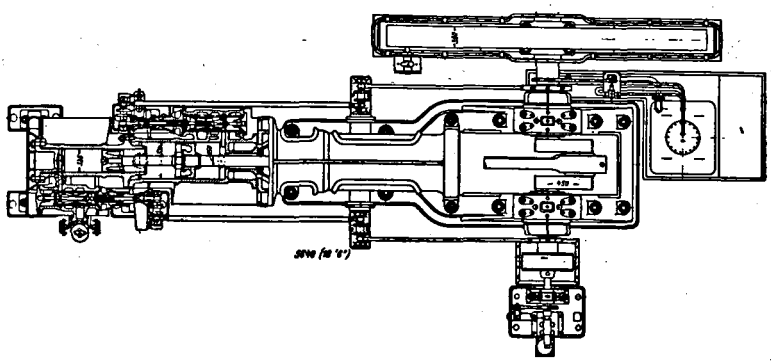

Fig. 17.

Schmidt-Borsig high pressure engine.

Cylinders 325/510 mm. (12·8 in./20 in.) dia.;
900 mm. (35·5 in.) stroke; 90 to 120 r.p.m.
Inlet pressure 60 at. (854 lb. per sq. in.)
Exhaust pressure 10 at. (142 lb. per sq. in.)

The exhaust steam will be led into an accumulator from which steam is drawn by the steam hammers of the Tegel works of this firm.

HIGH PRESSURE TURBINES.

Only after it had been practically demonstrated that the advantages of high pressures are greater than those theoretically expected, did turbine builders begin to develop steam turbines for very high working pressures. As is well known, the high pressure stages of the usual steam turbines have a much lower efficiency than reciprocating engines. But now new solutions, at least for large units, seem to have been found, giving efficiencies not so far off those of the reciprocating engine. Two distinct methods are being followed. In the first, high pressure turbines are to be built for high speeds

with small rotors and only few stages ; the other method, proposed by the Erste Brünner Maschinenfabrik, uses a large number of stages and very low steam velocities of about 100 m/sec. (330 feet per sec.). On the latter system, Borsig is building a turbine for 60 atm. (854 lb. per sq. in.) pressure which is to be supplied with steam from the Schmidt-Borsig boiler already referred to.

THE FIELD FOR HIGH PRESSURE STEAM.

High pressure steam will be applied in stationary plants for condensing engines and for back pressure engines. To existing plants high pressure stages will be added in many cases. The highest possible economy will, however, only be reached when the utilisation of power and heat is combined.

High pressure marine engines will compete with Diesel engines. Furthermore, high steam pressures will gain great importance for locomotives; here under the present working conditions a gain of 25 to 30 per cent. in fuel and a 50 per cent. higher load can be attained, without the addition of complicated auxiliaries such as are necessary in turbine locomotives.

CONCLUSION.

Since the publication at the 1921 meeting of the V.D.I., of Schmidt's research work with high pressure steam, working pressures for new steam power plants have everywhere been raised to a great extent. As tests have shown, the practical advantages are considerably higher than was theoretically expected. By the use of pressures above 30 atm. (427 lb. per sq. in.) and of temperatures above 400° C. (752 deg. Fahr.) and by re-superheating and feed-water heating by extracted steam, the fuel consumption can be lowered to about 2,000 kcal/PS h (8,000 B.T.U. per B.H.P.) in fuel with condensing engines. Still higher economies can be attained by the combined generation and utilisation of power and heat. With high initial pressures it is possible now to get any desirable exhaust pressure and therefore to obtain the high economy of combined power and heating plants in nearly all cases.

The problem of generating high pressure steam and of utilising it in reciprocating engines has been solved by practical experience. For steam turbines practical solutions are being worked out. It is to be expected that before long high steam pressures will be the rule in all steam plants.

RÉSUMÉ.

Depuis la publication des travaux de Wilhelm Schmidt dans le domaine de la vapeur à haute pression en 1921 à l'assemblée du V.D.J. à Cassel, on peut, en général, constater une augmentation par sauts des pressions de travail dans les installations de force motrice à vapeur. Ainsi qu'il a été établi par des essais, les avantages pratiques sont sensiblement plus grands que ceux que l'on pouvait espérer d'après la théorie. Par l'emploi de pressions de plus de 30 Kg. : cm² (427 lbs.) et de températures de vapeur vive de plus de 400°C. (752°F.) et par surchauffe intermédiare et réchauffage de l'eau d'alimentation au moyen de vapeur intermédiare, on peut avec des installations à condensation réduire la consommation de combustible à environ 2,000 Cal. par C.V. (8,000 B.T.H. par B.H.P.). Des économies encore plus grandes peuvent être réalisées par l'emploi de pressions de service plus élevées. Il est à présent possible d'obtenir avec des pressions initiales élevées toute pression d'échappement voulue et en conséquence dans presque tous les cas l'économie élevée d'installations combinées de force motrice et de chauffage.

La production de vapeur à haute pression et son application dans des machines à piston a été sanctionnée par la pratique. Pour des turbines à vapeur des solutions utiles sont à l'étude a présent. La vapeur à haute pression sera sous peu la règle dans toutes les installations à vapeur.

THE INFLUENCE OF HIGH PRESSURE STEAM ON THE DESIGN AND ECONOMY OF LARGE STEAM BOILER PLANT WITH SPECIAL REFERENCE TO BOILER PLANT FOR ELECTRIC POWER STATIONS.

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I. GENERAL.

The interest in all matters relating to very high pressure steam was effectively stimulated in Germany by the paper on the work of Baurat Wilhelm Schmidt, prepared by O. H. Hartmann in 1921 (1)*

Although conditions have not been sufficiently favourable for the construction of more than a few installations of boilers producing steam above 30 Atm. (427 lbs.p.sq.in.) the work done in the meanwhile may be regarded as very valuable.

When the above paper was read I expressed the opinion, that the greatest difficulty in the application of very high steam pressures would be the construction of suitable boilers and that a large amount of hard work would still be required before it would become possible to manufacture boilers for high pressures, which are sufficiently inexpensive, reliable and efficient. Since then, this opinion has spread more and more.(2)

There are 4 important circumstances, which have a decisive influence in Germany on the development of high pressure boiler plant, viz.:

(1) Scientific research of the occurrences in water tube boilers, which has been enlivened during the last 8 years.

(2) Investigations concerning the properties of boiler plates and the influence of the manufacturing process on the durability of boilers. These questions have been taken up to a hitherto unknown extent by the Vereinigung der Grosskesselbesitzer (Association of larger boiler owners) which was founded in 1920.

* The index numbers refer to the list of publishers at the end

(3) Progress in the production of special steel plates and their treatment for the manufacture of boiler drums.

(4) The acquisition and further development of the inventions and designs of Dr. Ruths for the construction of steam accumulators by a few prominent German companies.

II. BOILER PLATES AND THE MANUFACTURE OF BOILER DRUMS.

The most vital part of water tube boilers are the boiler drums. The manufacturing process and thickness are largely controlled by official regulation in Germany.

These refer particularly to:

(a) The properties of boiler plates.

(b) The factor of safety (4 to 4·5) to be used when calculating the thickness.

(c) The formulæ for determining the thickness and the design of riveted joints.

(d) The treatment and riveting of boiler plates.(4)

In recent years serious boiler defects have repeatedly occurred, which, to a certain extent, may have been caused by the rapid increase in heating surface and specific evaporation. Doubts have consequently arisen in the practicability of the regulations and the experience has lead to a careful investigation of the properties of the ordinary plates obtained in the market, the process of manufacture, the methods of testing and the further treatment of the plates. It was found that important points were not sufficiently taken into consideration when selecting test-bars in the customary manner and making the tests for determining the strength. The methods, which had been standardized, are practically the same as those customary abroad.

It was, for instance, found that the strength and composition of plates is different and not so good at the edges as towards the middle. This is an important point in the case of plates for drums intended for vertical tubular boilers, because in these drums the riveted seams are made along the weakest parts of the plate, namely near the edges. This is one of the reasons why test pieces for determining the strength were taken from the plate in a manner different from hitherto.(5)

Furthermore, it could not at first be explained why plates conforming to the official regulations during the test proved

defective later and caused serious damage. The solution was to be found in the fact that the plates, which were originally satisfactory, underwent alterations in the course of the manufacturing process of boiler drums or later under operating conditions, which made them brittle. Careful and tedious research has produced very valuable information on the cause of this surprising behaviour.

Professor Baumann proved that the pressure exerted when riveting was generally far too high, the plates suffered, cracks developed in the structure and the strength was weakened.

The most important discovery was, however, the great influence of ageing and re-crystallisation on boiler plates. By ageing is understood the gradual alteration of the strength of a plate, which is stretched when cold, i.e., beyond its elastic limit. The altered condition of the structure is noticeable by a considerable reduction in the notch bending toughness and the brittleness. A similar effect is produced by re-crystallisation through cold stretching, which, however, occurs at very much higher temperatures than those affecting ageing. What makes both ageing and re-crystallisation so dangerous is that they cannot be proved by the customary static breaking test.(6)

Careless treatment of boiler plates, either when rolling or later when forming the drum may, however, be the cause of alterations similar to ageing and re-crystallisation. This is especially the case when plates are subjected to a considerable amount of bending at low temperatures, for instance, when the plates are shaped or riveted under too high pressures. Alterations similar to ageing or re-crystallisation may, however, also occur later, when the finished boiler is in commission, through temperature stresses due to differences in the temperature at various points of the heating surface. Insufficient water circulation or insufficient elasticity and the prevention of the possibility of expansion are the causes of this trouble. The investigations of the Vereinigung der Grosskesselbesitzer, in particular, have shown that the notch-shock test is an excellent means for determining injurious excessive stresses of this kind, i.e., stresses which cannot be proved by the original breaking test. Fig. 1 shows, for example, the surprisingly rapid decrease of the notch bending toughness of superstressed and aged S.M.mild steel plates obtainable in the market.(4)

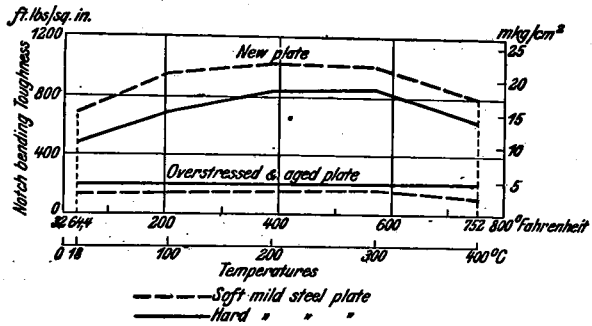


Fig. 1.

Notch bending toughness of two S.M. mild steel plates when new and after overstressing and ageing at different temperatures.

		Soft plate.	Hard plate.
At 18° C. temperature			
Breaking strength	kg./mm.²	31·5	58·6
	lbs. per sq. in.	45,000	83,500
Yield point	kg./mm.²	20·5	36·2
	lbs. per sq. in.	29,160	51,200

NOTE.—The notch bending toughness of S.M. mild steel sinks to a small fraction of the figures for fresh material after overstressing and ageing. Hard S.M. mild steel is in this regard more favourable than the soft quality.

These injurious influences will become more prominent as the boiler pressure and the thickness of the plates increase, because of the greater difficulties of machinery and riveting. Larger heating surfaces and higher evaporation have a similar effect, they offer more favourable conditions for temperature differences and additional stresses in the heating surface. Therefore when employing thicker drums for high pressure boilers it becomes more and more important to avoid all undeterminable additional stresses in the boilers, and to employ material which is less sensitive to careless treatment and posseses a greater strength than S.M.mild steel. (4)

The development will probably take the same course as was the case with combustion engines. The demand for higher power units compelled manufacturers to find special kinds of material. The capacity of machines and the qualities of the materials of which they are made are two of the most prominent questions of modern engineering. One controls and affects the other and it will take some time before their mutual influence is fully manifested in high pressure boiler manufacture also.

The foregoing considerations had the following practical results:

(a) The methods for determining the strength of boiler plates were improved, particularly by introducing and developing the notch shock test.

(b) Riveting pressures were reduced to 7,000 to 8,000 kg/cm.² (100,000 to 113,000 lbs.p.sq.in.) and the pressure and time taken for each rivet were automatically checked.

(c) Special steels were produced with very much more favourable properties than S.M.mild steel.

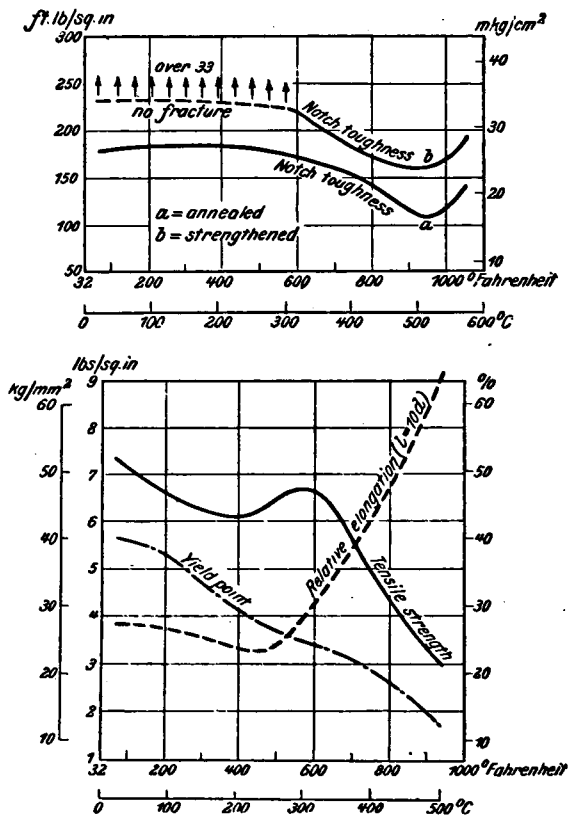


Fig. 2.

Curves showing the strength, yield point, breaking strength, elongation and notch bending toughness of annealed 5 per cent nickel steel in relation to temperature.

(d) New processes were developed for making seamless boiler drums by drawing, pressing or forging.

(e) The design of boilers was improved by making allowances for expansion of individual parts and by protecting all parts of thick plates against contact with hot gases, so as to avoid additional stresses through the temperature drop at this point.

In this connection a very remarkable progress in the design of high pressure boilers was made by the production of two steels of special quality (one with 5 per cent. nickel, the other with 3 per cent. nickel) at the Krupp ironworks. Both the tensile strength and the yield point of nickel steel are considerably higher than for S.M. mild steel at the temperatures

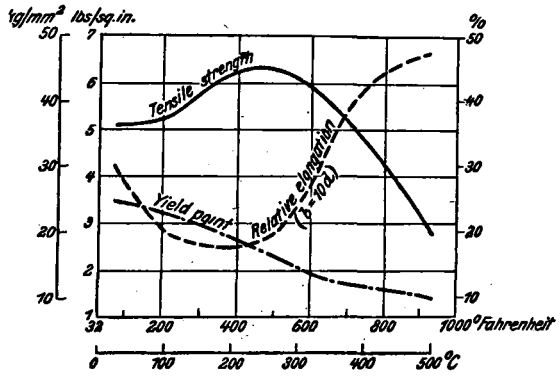


Fig 3.
Curves showing the strength of soft mild steel in relation to temperature.

met with in boilers.(6) In Fig. 2 for instance, the yield point of 5 per cent. nickel steel is shown to drop from 30 kg/mm² (42,600 lbs.p.sq.in.) to 23 kg/mm² (33,000 lbs.p.sq.in.) when the temperature rises from 198°C. to 310°C. The yield point is therefore roughly twice as high as for mild steel, Fig. 3. At temperatures for which modern boiler plant is laid out, the yield point is equal to that of mild steel at room temperature. The principal advantage of nickel steel compared with mild steel is, however, that it is almost entirely free from ageing and re-crystallisation, Fig. 4. Drums made of nickel steel of the above quality and forged with the end plates in one piece without seams are the most suitable for very high steam pressures and correspondingly high temperatures. They will

doubtless attain considerable importance for steam pressures of more than 40 to 50 Atm. (570 to 710 lbs.p.sq.in.).(6)

III. BOILER PRICES AFFECTED BY STEAM PRESSURE.

Drums made of nickel steel plates are very expensive,

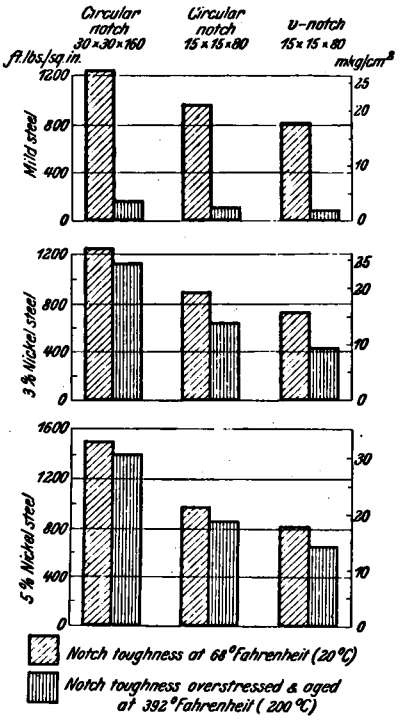


Fig. 4.

Notch bending toughness of S.M. mild steel, 5 per cent nickel steel and 3 per cent. nickel steel in their natural condition and after overstressing and ageing according to tests made at the Krupp Iron Works, in Essen.

NOTE.—The notch bending toughness of ordinary S.M. mild steel is very much reduced after overstressing. The two qualities of nickel steel are, therefore, very much less sensitive against injurious treatment when the plates or drums are made, a treatment which has a similar effect to that of over-stretching. A sufficient breaking strength and elongation of a plate at room temperature alone are no sufficient criterion for its suitability for drums of boilers.

especially when forged from a single block. Fig. 5 shows the relation between boiler price and steam pressure for vertical tubular and inclined tubular boilers. The design and technical details were chosen intentionally with the object of obtaining

a maximum and a minimum limit for the manufacturing costs. The prices of all other boilers made according to similar principles will therefore lie between these two curves. They will be nearer one or the other of the two limits according to with which of the designs and assumptions they coincide best.

The curve for the upper limit refers to vertical tubular boilers for pressures from 15 to 50 Atm. (200 to 700 lbs.p.sq.in.),

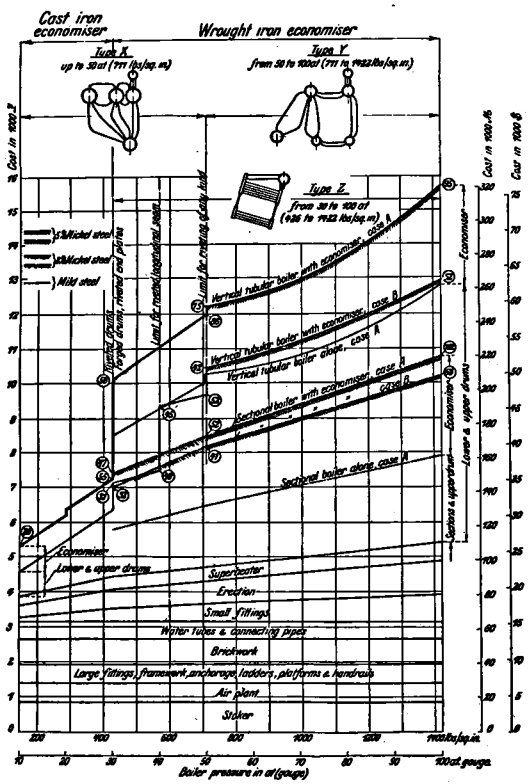


Fig. 5.

Price of the boiler, ready for work, including stoker, blower equipment and brickwork for burning about 2,300 kg. (5,070 lbs.) of coal in one hour for pressures from 10 to 100 atm. (140 to 1,400 lbs. per sq. in.), 400° C. steam temperature at constant efficiency. The figures inside circles give the thickness of the thickest drum plate in mm.

NOTE.—Very high proportion of drum costs in the total for vertical tubular boilers with a large water capacity. The top curve, referring to a vertical tubular boiler with economiser (expensive design), is the upper limit, the cost of a suitable design will probably be below this limit.

type X; for 50 to 100 Atm. (700 to 1,400 lbs.p.sq.in.), type Y in Fig. 5. The lower curve refers to sectional boilers resembling the type of Babcock & Wilcox boilers installed in the Waukegan power station. The water and steam capacities of these boilers are very much smaller, and this, as well as the fact that the sections may be made of mild steel, accounts for their comparatively low costs. The prices are based on conditions that existed in the first half of 1914.

The condition must be enforced, that the factor of safety against breaking and also against a permanent set (when the elastic limit is exceeded), remains approximately unaltered, independent of boiler pressure and its corresponding saturation temperature. In view of the rapid decrease in the elastic limit that accompanies the increase in temperature, one should cease to accept the breaking strength at room temperature for high pressure boilers. The thickness of plates should rather include a certain factor of safety against breaking and a certain factor of safety against overstressing at the running temperature of the boiler. The calculations were based on two fundamentally different cases in order to show the difference in prices for boilers with plates where the influence of the temperature on the strength is taken into consideration and where this is not so.

Case A.—The factor of safety against breaking and against overstressing is the same at all running temperatures; the tensile stress chosen for determining the thickness of the plates is therefore reduced as the boiler pressure increases.

30 to 50 Atm. (430 to 700 lbs.p.sq.in.): Forged drums made of three per cent. nickel steel with riveted end plates of S.M. mild steel.

50 to 100 Atm. (700 to 1,400 lbs.p.sq.in.): Drums and end plates forged out of a single block of 5 per cent. nickel steel.

Case B.—No consideration is given to alterations of tensile strength and yield point with increasing plate temperatures; figures based on room temperatures are adopted throughout.

30 to 40 Atm. (430 to 570 lbs.p.sq.in.): Drums made of S.M. mild steel of a harder quality than for pressures below 30 Atm., riveted or welded longitudinal seams, riveted end plates.

40 to 50 Atm. (570 to 700 lbs.p.sq.in.): Three per cent. nickel

steel, riveted end plates of S.M. mild steel, riveted or welded longitudinal seams.

50 to 100 Atm. (700 to 1,400 lbs.p.sq.in.): Five per cent. nickel steel, drums and end plates forged out of a single block.

A factor of safety of 4·5 at room temperature was used for pressures up to 30 Atm. in both cases. The tensile stress being that for room temperature.

In Case A the factor of safety against rupture is constant, and at least 4·5 for all pressures from 30 to 100 Atm. The factor of safety against overstressing is at least 2·5. In Case B the safety for both stresses is to a certain extent considerably less for higher pressures than for lower pressures.

Fig. 5 shows the following remarkable result:—

(1) The price of a high pressure vertical tubular boiler for 80 to 100 Atm. (1,140 to 1,400 lbs.p.sq.in.), including all accessories calculated according to Case A is roughly 2·4 to 2·8 times as expensive as a "normal" boiler for 15 Atm. (215 lbs.p.sq.in.).

(2) The price of a sectional boiler with one upper drum only, calculated according to Case A, and including all accessories, is 1·75 to 1·9 times as expensive under exactly similar conditions.

(3) For high pressure vertical tubular boilers the cost of the drums absorb the main portion of the total cost.

(4) High pressure boilers which are calculated according to the principles in use at the present moment where the alterations in strength due to increased temperatures are not taken into consideration would, for 40 Atm. (570 lbs.p.sq.in.) cost roughly 70 per cent., and for 50 to 100 Atm. (700 to 1,400 lbs.p.sq.in.) roughly only 80 per cent. of a boiler calculated according to Case A.

(5) In the case of high pressure sectional boilers the cost is not appreciably affected, whether they are designed according to Case A or B, because they have only one drum, which has to be made of expensive material and according to an expensive process.

(6) The price of high pressure boilers is largely affected by its water capacity, the process for making the drum and the adopted stress in the plates.

These calculations show the extraordinary influence which

the cost of boiler drums has on the price of the whole boiler. They explain why sectional boilers for high pressures, with one drum only and consequently a very small water capacity, are so very much cheaper than vertical tubular boilers with four to five drums. It is, however, essential that the interest and amortisation on the extra capital expenditure for high pressure boiler plant is not greater than the saving in coal, because there would be no financial inducement to undergo the risk accompanied by changing over to higher pressures.

The number and diameter of boiler drums will evidently have to be reduced in order to lower the price of high pressure boilers; to what extent, is determined by questions of design and operation. For power stations with a fluctuating load a

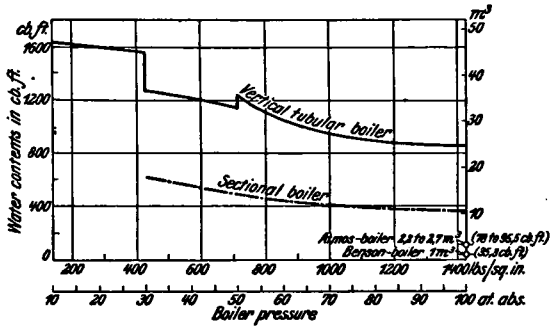


Fig. 6.

Water capacity of vertical tubular boilers and sectional boilers for boiler pressures of 10 to 100 atm. (140 to 1,400 lbs. per sq. in.) and 5,070 lbs per hour of bituminous coal.

certain water capacity is, however, essential, because otherwise the boiler pressure would vary too much and thus seriously affect the economy, and, what may be more important, the reliability.

According to Fig. 6 the water capacity of vertical tubular boilers, type X and Y in Fig. 5, is considerably greater than that of sectional boilers, type Z. From Fig. 7 it will be seen how much the pressure of a boiler, according to Fig. 6, may drop at a peak load such as is experienced in traction power stations, if it requires five minutes until the boiler man has adapted the supply of fuel to the stoker to suit the rush demand for steam. With mechanical stokers it may take quite this time

before the conditions of burning are sufficiently adapted. It is evident that with sectional boilers, type Z for very high pressure the pressure drop reaches values which are not permissible.

IV. MEANS FOR REDUCING THE COST OF BOILERS.

If it should be found that for very high pressures sectional boilers are equal, or even superior to vertical tubular boilers, both from the point of view of efficiency and of operation, the question arises how to benefit by their cheap cost in stations for high steam pressures, always assuming that no difficulties

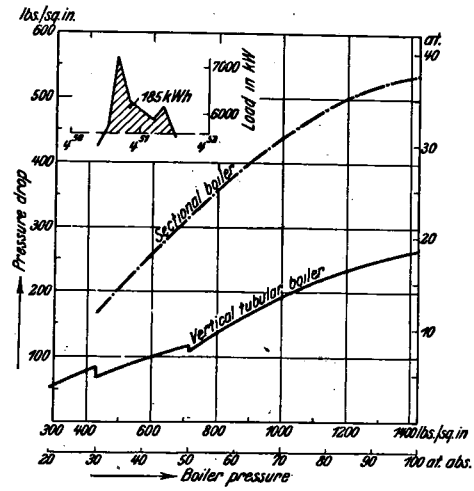
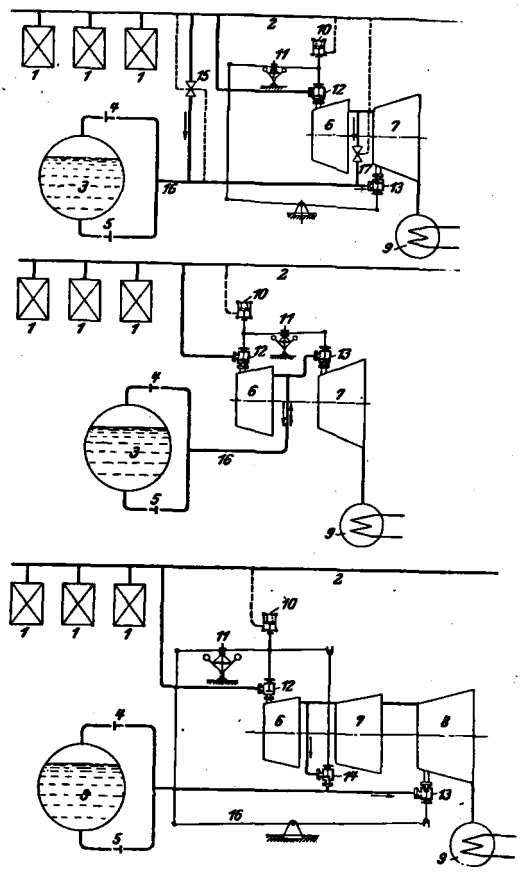


Fig. 7.

Pressure drop at a peak load (peak of a traction station) which exceeds by 3·3 per cent the normal evaporation of the boiler in one hour for an average load lasting 5 minutes.
NOTE.—The storage capacity of the boilers is not sufficient at high pressures. It is, therefore, necessary to insert steam accumulators into the low pressure range.

arise from the numerous joint caps. In this connection the small capacity must be supplemented by some cheap and sufficient means for storage. A very good solution is the provision of a Ruths steam accumulator between the high pressure and low pressure stages of the turbines according to one of the arrangements shown in Fig. 8 to 10. Ruths accumulators for purposes of this kind can be looked upon as supplementary water capacity for drums omitted from the high pressure boilers and placed in a low pressure range for reasons



Figs. 8 to 10.

Different arrangements of steam accumulators in high pressure steam power stations.

Fig. 8.

The accumulator is here charged either with live steam only, which is throttled, or in addition with exhaust steam of the high pressure stage of the turbine. 1 = high pressure boilers, 2 = high pressure live steam pipe, 3 = Ruths accumulator, 4 = non-return valve in the discharge pipe, 5 = non-return valve in the charge pipe, 6 = high pressure stage, 7 = low pressure stage of the turbine, 9 = condenser, 10 = steam regulator (controlled from pressure in 2), 11 = speed governor of the turbine, 12 = inlet valve for the high pressure stage, 13 = inlet valve for special groups of nozzles in the low pressure stage, 15 = relief valve for live steam, 16 = charge and discharge pipe of the Ruths accumulator, 17 = relief valve for exhaust steam from the high pressure stage.

Fig. 9.

The accumulator is charged with the exhaust steam of the high pressure stage only. 13 = inlet valve for the low pressure stage.

Fig. 10.

The accumulator is charged with exhaust steam of the high pressure stage, this steam is passed into the low pressure stage, the middle being omitted. 7 = middle pressure stage, 8 = low pressure stage of the turbine, 14 = charging valve of the accumulator with exhaust steam from the high pressure stage. 13 = inlet valve for a special group of nozzles in the low pressure stage 8.

of design and cost. The economical superiority of Ruths accumulators, when used for this purpose, is due to the fact that they can be made of ordinary S.M. mild steel plates, which are riveted at low cost, as against boiler drums that have to be dimensioned for very high pressures and must be made of expensive special forging. A further reason for the economical superiority of a Ruths accumulator as a substitute for large water capacity in high pressure boilers lies in the fact that the storage capacity of 1 cu.ft. of water at saturation temperature at 15 Atm. (210 lbs.p.sq.in.) is about six times as high as at 100 Atm. (1,400 lbs.p.sq.in). One can say, according to our present knowledge, that in many cases the economical use of high pressure steam in stations with high peaks, can probably only be made possible by the insertion of such accumulators. In order to avoid misconceptions it is, however, expressly pointed out that these accumulators for this purpose are only required to equalise peaks of short (minutes) duration, contrary to what they are expected to do in most other cases.

Fig. 11 shows the price of a Ruths accumulator having twice the storage capacity of boiler drums of vertical tubular boilers under the most favourable conditions. This figure will give a clear idea of the saving that can be effected in high pressure plant by these accumulators. The price is far below the difference between the price of vertical tubular boilers and that of sectional boilers when using Ruths accumulators in the low pressure range. The drums can, therefore, be made as small as is permissible for the production of dry steam; there is no danger of the boilers being affected by high peaks of short duration owing to insufficient water capacity.

The higher the steam pressure the larger must be the economiser, because the amount of heat it has to transmit rises owing to the increase in saturation temperature. For high pressures the comparative price for the economiser is therefore very must higher than for low pressures, Fig. 5. For this reason a considerable saving can be made by substituting air heaters for economisers. They can be made of thin sheets, quite irrespective of the boiler pressure. Being cheap, their financial superiority over economisers becomes more and more apparent as the boiler pressure increases. In the case of pulverised fuel the air for combustion can be pre-heated to 200° C. (392° F.). I have shown elsewhere that the temperature

in the combustion chamber is raised only by about 30 per cent. of the temperature rise of pre-heated air, and even this increase can be avoided without difficulty by suitable dimensions of the combustion chamber.(8)

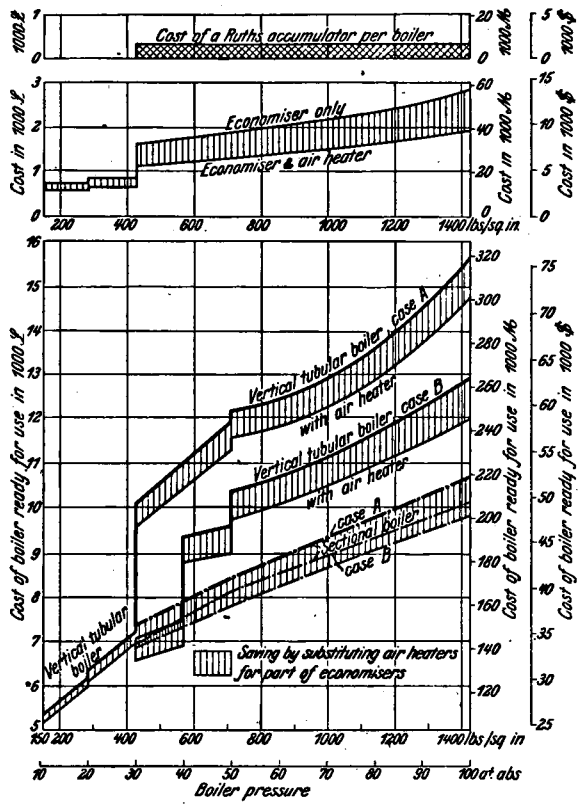


Fig. 11.

Prices of complete boiler units, including superheater, economiser, stoker and air heater for 2,300 kgs. (5,070 lbs.) of coal per hour.

NOTE.—When a portion of the economiser is replaced by an air heater, the saving in capital outlay increases for higher boiler pressures. The possibility of effecting a large saving in expenditure by inserting a Ruths steam accumulator in the low pressure range instead of the expensive and insufficient corresponding water capacity of high pressure boilers.

V. THE PRACTICAL BENEFIT FOR THE CONSTRUCTION OF HIGH PRESSURE BOILERS OF RECENT SCIENTIFIC ENGINEERING RESEARCH.

Several scientists have arrived at the conclusion, that the full benefit of large increase in steam pressure for pure power

station operation can only be realised by means of the regenerative process. Feed water heating up to high temperatures, using steam bled from turbines, must necessarily affect the use of economisers. As, however, the heat absorbed by the air heater should not exceed an equivalent feed water temperature rise of about 70° C. (125° F.), the heating surface of high pressure boilers should be somewhat more liberally designed in order to obtain the same efficiency, as with economisers.

Having shown the great importance of recent progress and insight into questions of reliability and economy of high pressure boilers (Items 2 to 4), a similar brief reference will now be made to what has been done as regards investigating occurrences in water tube boilers, Item 1.

Scientific investigation has been devoted primarily to the following three points:—

(a) The arrangement of the combustion chamber.
(b) The transfer of heat by contact in the flues.
(c) Water circulation.

Hans Thoma has written an interesting book on point (b), opening up the possibility of examining the arrangement of heating surface by means of small, inexpensive models.(9) Quite recently a contribution by Schack has been published giving valuable information on self-radiation of hot gases.(10) With regard to points (a) and (c) two of my own theories may be mentioned, as they are of immediate use to the designer.(11) My theory on water circulation has been confirmed in the meanwhile by tests. It is of interest in the present connection, because it can be used for proving with a high degree of probability that water circulation will present no difficulties in the usual form of boiler up to very high pressures. The cooling of water tubes will even be better at very high steam pressures than at 10 to 20 Atm. (140 to 280 lbs.p.sq.in.), because the water contents of the mixture of steam and water coming out of the most heavily heated water tubes is increased from a volume of about 13 parts at 10 Atm. (140 lbs.) to about 60 parts at 100 Atm. (1,400 lbs). See Fig. 12.

The practical value of the result of research on questions under (a) and (c) is that efforts towards increasing the specific evaporation of the boiler heating surface are of primary importance in view of the high price of high pressure boilers.

Although only a few boilers for high pressures have bee manufactured in Germany, as already stated, the concentrate scientific engineering work produced an indispensable basis fo

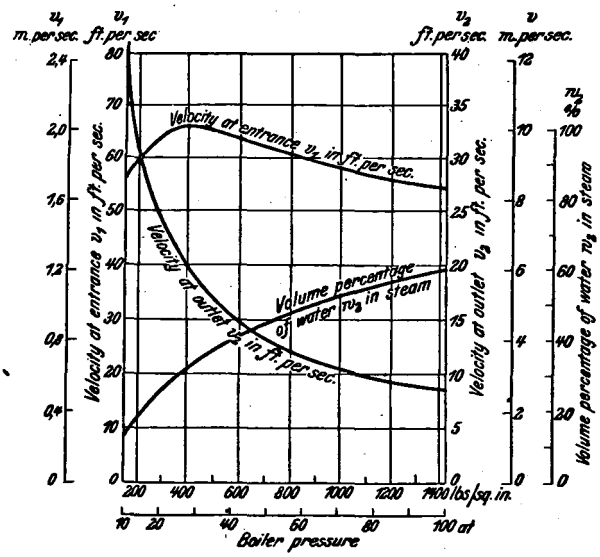


Fig. 12.

Water circulation in a riser of a vertical tubular boiler at pressures of 10 to 1(atm. (140 to 1,400 lbs. per sq. in.), internal diameter of tubes = 50 mm. inches), length of tubes = 6 m., evaporation = 200,000 kcal. per sq. r (74,000 B.Th.U. per sq. ft.) per hour.

NOTE.—The speed v_1 at which the water enters the riser varies but litt between 10 and 100 atm. The water capacity w_2 of the mixture of steam ar water coming out of the top end of the tube rises rapidly with the boil pressure. " Insufficient water circulation " at very high pressure is not to l expected.

further development, which will be free from serious disa pointments. Thus the matter can be advanced more rapidl than would have been the case if the experience had had to b made with actual high pressure boilers.

It may be said to-day that electric power stations in the future will show the following characteristic features:—

The use of steam pressures from 40 to 100 Atm. (570 to 1,400 lbs.

Steam temperatures from 400 to 425°C. (750 to 800°F.).

Boilers with a small water capacity and extensive use of feed water heating by steam bled from turbines.

Ruths steam accumulators in the low pressure range.

Re-superheating of the steam.

Pulverised fuel.

Air heaters.

A station designed along these lines may reach a thermal efficiency which is very near to that of Diesel engines. The calorific saving, even for works for the supply of electrical energy only where there is no possibility of making full use of the surplus heat lost in the cooling water of the condenser, will then considerably exceed in monetary value the interest and amortisation of the extra capital expenditure on plant for high pressure. The total saving in working costs, including coal and capital costs, will amount to about 10 to 20 per cent. for a steam pressure of 100 Atm. (1,400 lbs.) as against 15 Atm. (220 lbs.), provided it becomes possible to make an inexpensive high pressure boiler with a small water capacity. This probable saving also applies to purely electrical power stations with a good load-factor.

VI. LIST OF PUBLICATIONS REFERRED TO.

(1) "Höchstdruckdampf bis zu 60 at. in der Kraft—und Wärmewirtschaft." By O. H. Hartmann, Zeitschrift des Vereines deutscher Ingenieure, 1921, p.663.

(2) Zeitschrift des Vereines deutscher Ingenieure, 1921, p.993.

(3) "Erfahrungen und Forderungen des praktischen Kesselbetriebes." By Dr. Guilleaume, Zeitschrift des Vereines deutscher Ingenieure, 1924, p.185.

(4) "Höchstdruckdampf." By Dr. Münzinger. Publishers: Julius Springer, 1924.

(5) "Die Beanspruchungen der Bleche beim Nieten." By Baumann, Forschungsarbeiten des Vereines deutscher Ingenieure, 1922.

(6) "Die Kesselbaustoffe." By Goerens, Zeitschrift des Vereines deutscher Ingenieure, 1924, p.41.

(7) "Maschinen—und Herstellungsverfahren im Dampfkesselbau." By Loch, Zeitschrift des Vereines deutscher Ingenieure, 1924, p.194.

(8) "Amerikanische und deutsche Grossdampfkessel." By Dr. Münzinger. Publishers: Julius Springer, 1923.

(9) " Hochleistungskessel." By Hans Thoma. Publishers: Julius Springer, 1921.
(10) " Der Wärmeübergang in technischen Feuerungen unter dem Einfluss der Eigenstrahlung der Gase." By Schack. Publishers: Stahleisen, 1923.
(11) " Die Leistungssteigerung von Grossdampfkesseln." By Dr. Münzinger. Publishers: Julius Springer, 1922.
(12) " Hochdruckdampf." Publishers: V. D. J. Verlag, Berlin, 1924.

RÉSUMÉ.

L'introduction traîte des dernières expériences effectuées concernant les propriétés des matériaux employés dans la fabrication des chaudières, surtout de l'importance primordiale des effets de vieillissement et de cristallisation sur les tôles d'acier Siemens-Martin qui constituent les tambours-collecteurs des chaudières. Deux qualités d'un alliage spécial acier-nickel de la maison Krupp semblent bien appropriées pour la construction des chaudières à pression très élevée. On indique ensuite de quelle manière les prix des chaudières dépendent de la pression de la vapeur, du système de la chaudière et de la méthode de fabrication, comment le prix de revient des chaudières à très haute pression pourra être abaissé en employant des réchauffeurs d'air au lieu d'économiseurs, et également comment le contenu d'eau de la chaudière peut être réduit considérablement en employant des accumulateurs de vapeur du système Ruths dans la partie basse pression et par d'autres moyens. Enfin les dernières recherches scientifiques allemandes sur la construction des chaudières sont mentionnées ainsi que leur importance pour la construction des chaudières à pression très élevées qui doivent réunir les conditions de sécurité, prix modérés et économie de service.

STEAM GENERATION

SIR JAMES KEMNAL, F.R.S.E., M.I.M.E., M.I.N.A., M.I.E.E.

The first attempt at the idea of utilising steam power was made in the steam generator attributed to Hero of Alexandria, in 130 B.C.

As is well known, this steam generator was merely a globe, with a fire under it. This globe had nozzles issuing in opposite directions, and as the globe was mounted on trunnions, the force of the issuing steam turned the globe round, and thus produced power.

It is curious to contemplate that reaction employed in steam turbines at the present time is, to a certain extent, similar, steam being caused to pass through nozzles and impinge on the blades, producing a rotative effect.

There is a long stretch between the two, for whilst in the first engines it was utilised in a crude and primitive manner,—for instance, in Savery's engine of 1698, Newcomen's of 1712 and Watt's of 1784—in the steam turbine it is utilised in the most efficient manner possible, and all that has become known in the interval of the qualities of steam is utilised in that most efficient prime mover.

It was not until the properties of steam were experimentally det rmined by Regnault in 1847 that prime movers began to be designed in which these data, as applicable to steam—which is, of course, a gas produced from water—were fully recognised and utilised, and since that time much inventiveness has occurred, both in the generation and the utilisation of steam.

In the early steam prime movers the cylinder of the engine served at the same time as steam generator and condenser, the steam passing through a complete heat cycle, from water put into the cylinder to water returned to the cylinder.

The first development was undertaken in single cylinder engine, with which the steam was produced in egg-ended or Cornish boilers, at low pressure. The steam pressure was then increased to about 30 lbs., in conjunction with the simple expansion engine and the box boiler.

Thereafter, the construction of boilers was improved, so that 60 lbs. per sq. inch above the atmosphere was utilised in the cylinder of an engine. The use of steam expansively in two stages

followed and forecasted the line of development that would be followed in the quest for greater efficiency of operation.

Steam pressures rose and gave occasion for the construction of triple and quadruple expansion engines which, in the multiplicity of cylinders, utilised the expansive force of the steam which, of course, was increased as the pressure increased and this, with various refinements is, to a considerable extent, used at the present day; but the prime mover that is now most largely used for the production of electric power and propulsion at the present time is the steam turbine—the perfection of which is due to the inventiveness, persistence and scientific attainment of Sir Charles Parsons.

I have been asked to say something as to future developments in the production of power, and, as far as my judgment goes, the future lies in the utilisation of very high pressure and superheat in the steam turbine. The modern steam turbine, being a high speed engine, occupies a comparatively small space and is relatively cheap to construct for the power generated. Its thermal rival—the Diesel engine—is limited to low speeds of revolution, on account of limiting reciprocating stresses; also, the cost of electrical generators working in conjunction with Diesel engines is relatively high for the power developed.

The type of steam generator that has been used in this development of the steam turbine is the water-tube, which is the type that has made headway as being most suitable; in fact, the only one suitable for producing high pressure steam, and the most prominent of steam generators, utilising the water-tube principle of construction, is the Babcock & Wilcox.

The reason that I anticipate generating steam at pressures of from 500—1,500 lbs. superheated to 750° F., or higher, is that experience with the lower pressure of 500 lbs. is already sufficient to warrant incurring the extra capital cost involved in higher pressures, in view of the increased thermal efficiency to be expected.

I have Sir Charles Parsons' authority for stating that the increases in thermal efficiency over that at 250 lbs. due to increased working pressure, would be estimated to be as follows:—

500 lbs. per sq. in. working pressure, 6 per cent.
1,000 lbs. per sq. in. working pressure, 11 per cent.
1,500 lbs. per sq. in. working pressure, 15 per cent.

To put the matter in another way, assuming a boiler efficiency of 84 per cent., the thermal efficiency, coal to electricity, of the complete unit of turbine and boiler at 1,500 lbs. per sq. in. W.P. would

be in the neighbourhood of 30·8 per cent., which approaches very closely to the thermal efficiency realisable in large Diesel engines.

The boiler installation would include re-heater, water economiser

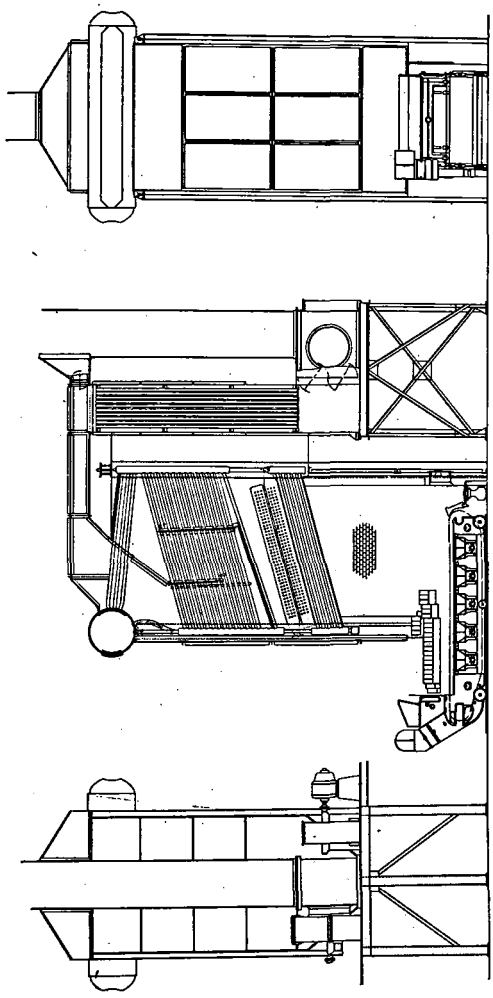


Fig. 1.

and air heater and it is assumed that the following would be the operating cnoditions.

Final temperature throughout 750° F. total; exhaust vacuum

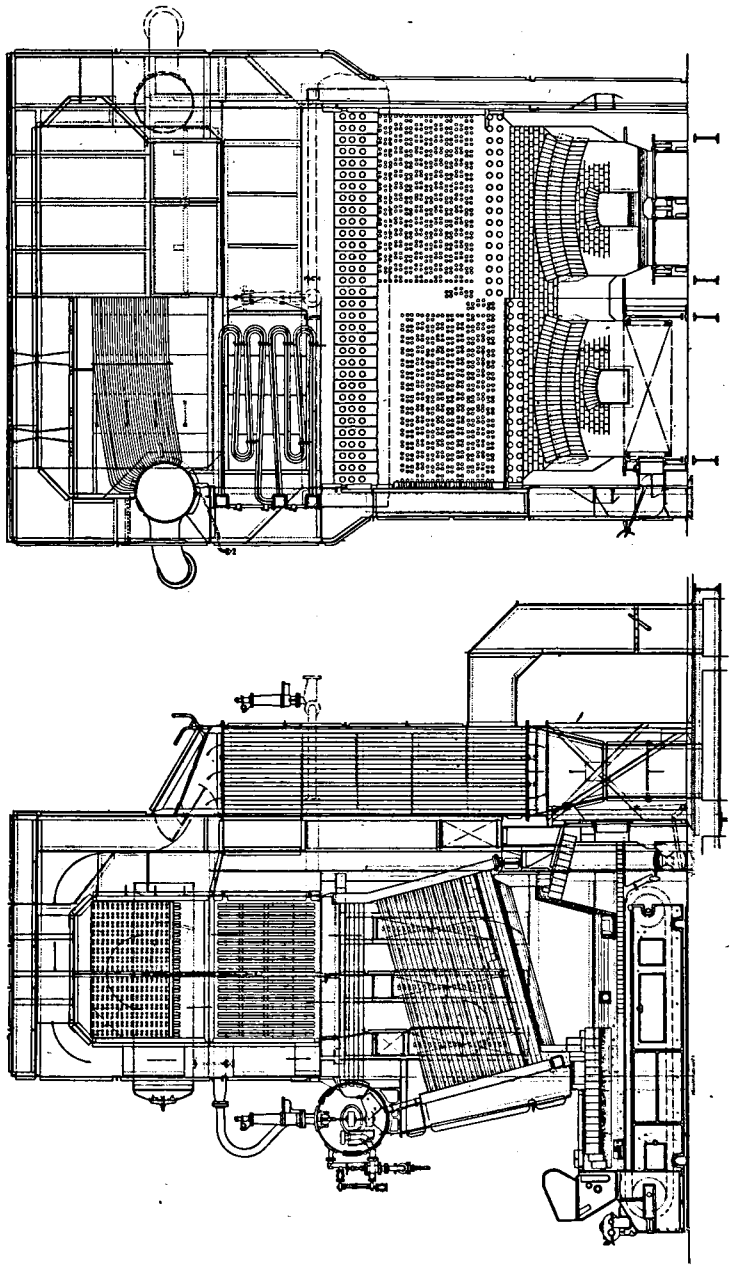


Fig. 2.

at the turbine 29·25 in. (barometer 30·00 in.); re-heating to 700° F.; feed-water heating to within 50° F. of boiler temperature, and under the assumption that the flue gas final temperature would be

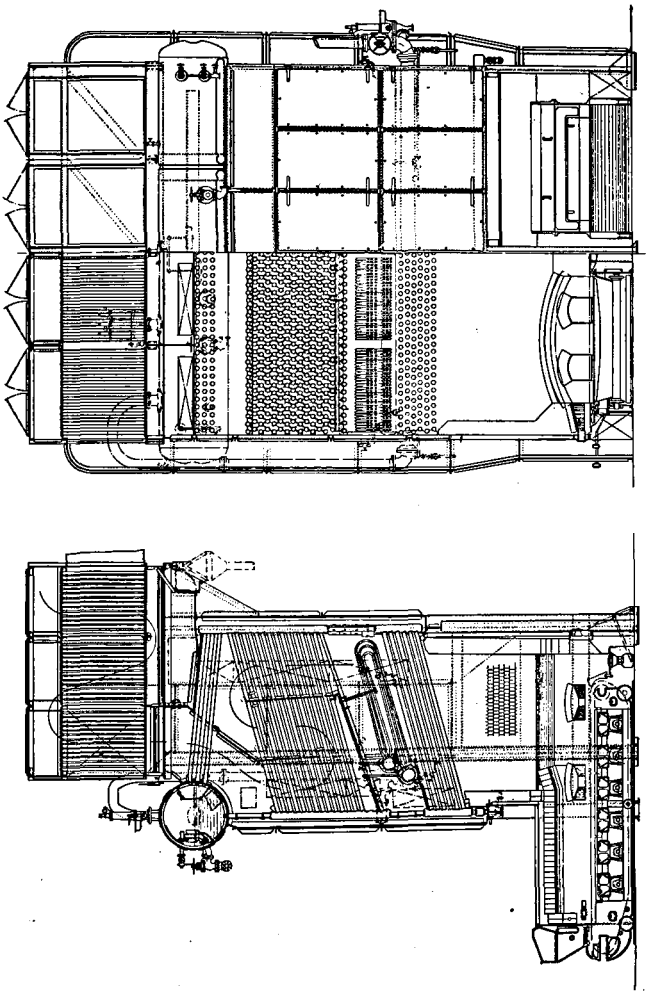


Fig. 3.

prevented from increasing appreciably by the use of air pre-heating.

Naturally, the construction of steam generators that are safe for these working pressures requires full knowledge of the art and great

care in the material and workmanship. The steam generators that have so far been constructed or are under construction for these pressures are mostly the Babcock & Wilcox.

I do not propose to weary my readers with particulars of constructional details that have led up to this development, but to confine myself to illustrating merely a set of boilers which are to be made to supply steam at 50 atmospheres (710 lbs.), the boilers carrying 800 lbs. pressure, for an installation that is being carried out by the Electricity Works of Flanders, at Langerbrugge, in which the steam, after passing through turbines at this pressure, will be exhausted into turbines that exist already for the service of the station at 300 lbs. pressure. (Fig. 1.)

There has also been an installation of such boilers at work for the last three years, at 500 lbs. pressure, in the north of England, supplying current regularly, and no trouble has been experienced with the constructional details of the boilers, superheaters, re-heaters or pipe lines.

With the turbines a notable economy has been obtained, so that the engineers who constructed this Station have recently ordered another installation for the same pressure and of the same size, and yet another installation, working nearly at the same pressure, so that working at 500 lbs. pressure is shown to be in every way practicable.

Fig. 2 is an illustration of boilers with superheaters and re-heaters, the boilers and superheaters working at 500 lbs. pressure, and the re-heaters at 65 lbs. pressure ; Fig. 3 is an illustration of the most modern design, showing the boilers and superheaters for one of the other installations mentioned. Fig. 4 shows similar boilers with the addition of re-heaters.

Up to pressure of about 60 atmospheres this general design will not be altered, but for pressures beyond that, whilst the sections of tubes will not be altered, the steam and water drums will, instead of being riveted up, be made seamless and probably a number of small ones on each boiler substituted for the large one.

As the pressure increases and the volume decreases or, in other words, the density of the steam becomes higher, the same necessity for an ample steam space does not arise and, within reasonable limits, the volume of steam drum can be reduced.

A necessity for high pressure working is the freeing of the feed water from air and carbonic acid and a de-aerator will be introduced into the feed water system. An example of this is shown in the

illustration (Fig. 5), with a diagram (Fig. 6) illustrating its application.

The kind of feed pump to be used in these high pressure installations

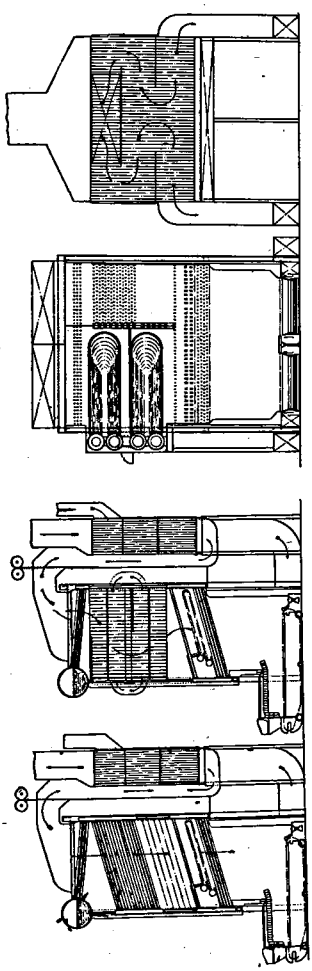


Fig. 4.

is the rotary, but it is quite practicable to construct plunger pumps that will do the service.

The steam and feed pipes, of course, require corresponding care in

construction. In the installations referred to they are seamless throughout.

Up to 6 in. diameter the pipes are screwed into very heavy flanges and after being made a fit they are expanded. Above 6 in. diameter the pipes are expanded into heavy steel flanges and, thereafter, radially drilled for rivets.

On the straight runs of pipe, the pipes are riveted together permanently.

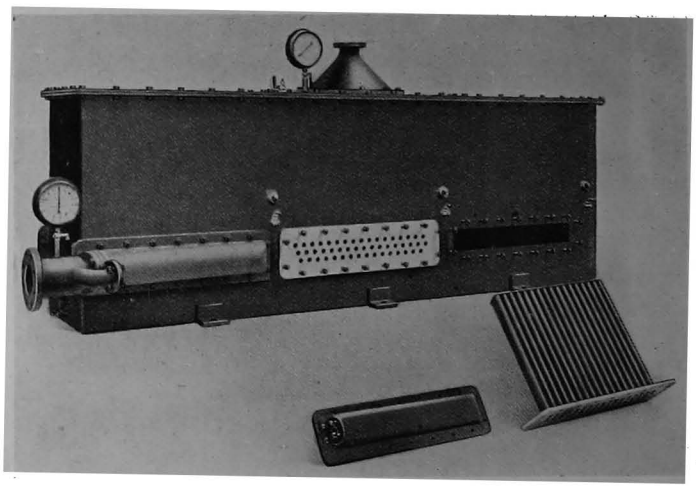


Fig. 5.

Where a valve is inserted, this is done without any jointing material.

Care in workmanship and correct proportions of details of flanges and joints must be observed.

A modern installation for the production of electric power requires not only the observance of these considerations, but also the lowest possible cost of maintenance and this is achieved not only by correctness in the selection of the plant, but by the skill that can be brought to bear on its construction and erection. It also requires the saving of labour to the utmost extent, so that the total cost of production of this electric energy—which is of universal application—may be within the reach of all at the lowest possible figure, and the saving of labour is achieved by getting the fuel into the boilers and ashes removed at the lowest possible cost.

The fuel with which the labour costs can be brought down to the

lowest limit is liquid fuel and the use of this depends upon its initial cost in relation to any other fuel, such as coal or wood; in making a comparison it should be borne in mind that its heating

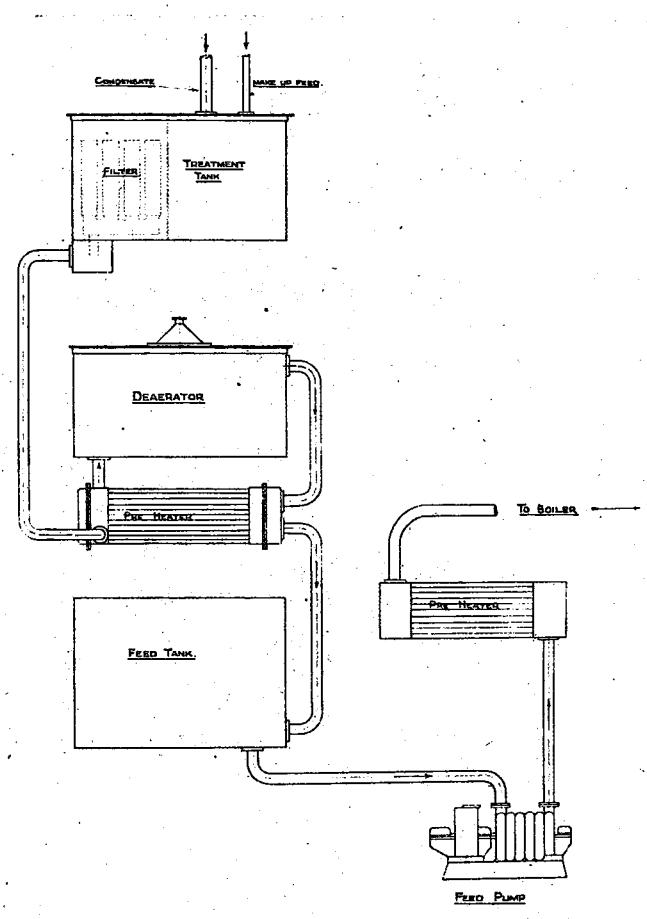


Fig. 6.

value is practically 50 per cent. to 100 per cent. more than that of coal; but within the British Empire the fuel most generally used is coal and in the burning of coal, mechanical stokers are the most

economical method of labour saving. The fuel should be conveyed to the mechanical stokers mechanically and the ashes removed mechanically also.

It would make this paper too long to discuss the various types of appliances that may be best employed for this purpose, depending upon the situation of the installation, but the goal of the designers of installations should be that the fuel should not be touched by hand after it is delivered into the installation.

With the sizes of units of power in use, artificial draught is essential; induced and forced draught are generally combined for this purpose.

In the foregoing I have dealt with the production of steam and the use of steam of suitable properties as a source of economy in the production of energy.

The efficiency of the steam generator has already increased to so great a degree with the growing knowledge of the art, that there is no great margin for further improvement but with the use of correct and well arranged heating surfaces, the heating of the feed water by economisers to better utilise the temperature differences, the heating of the air for combustion by the heat in the gases after they leave the economiser or water heater, the use of mechanical stokers with balanced draught, the use of the superheater and possibly re-heaters—the efficiency of the steam generating plant can be brought up to nearly 90 per cent.; that is to say, nearly 90 per cent. of the heat units in the fuel are utilised and this result has been mainly reached during the last quarter of a century.

Beyond this little can be done in regard to economy in generating steam and it is to the use of the steam in the prime mover that we must look for reductions in cost of energy; it is also the design of the steam generator for producing steam of such properties (pressure and temperature) that enables the machine to obtain a much higher efficiency than obtains at present.

RÉSUMÉ.

L'auteur remonte à l'origine du développement de la production de la vapeur et de son utilisation, depuis son adaptation, la plus anciennement connue à un générateur, attribuée à Héron d'Alexandrie, en l'an 130 av. J.C.

Les premières machines à vapeur sont mentionnées, telles que celles de Savery, Newcomen et Watt, ainsi que l'influence des recherches de Regnault sur la construction des machines motrices à vapeur.

L'auteur examine l'augmentation des pressions de vapeur depuis les premières chaudières à fonds hémisphériques et l'emploi de ces pressions dans les machines à multiple expansion.

KEMNAL: STEAM GENERATION

L'auteur compare le moteur Diesel avec la chaudière multitubulaire et la turbine à vapeur au point de vue de l'espace occupé, et prédit l'emploi dans un avenir prochain de pressions de vapeur variant entre 500 et 1,500 lbs. par pouce carré (35 à 225 kg. : cm^2). Les rendements que l'on obtient actuellement sont comparés avec ceux que l'on compte obtenir à ces pressions supérieures.

Des illustrations sont données représentant plusieurs installations de chaudières en service, et en construction, variant entre 500 et 800 lbs. par pouce carré (35 à 56 kg. : cm^2).

L'influence de la densité de la vapeur sur la construction des chaudières à haute pression est mentionnée et l'auteur insiste sur la nécessité d'utiliser pour de telles conditions de travail, de l'eau d'alimentation pure et désaérée.

En discutant le désaérage, l'auteur donne une illustration d'un simple désaérateur et indique son application.

STEAM GENERATION AT EXTRA HIGH PRESSURES

By VIKTOR BLOMQUIST
M.E. Stockholm.

The serious increase in fuel prices which took place a few years ago, created all over the industrial world a demand for improved economy in heat power plants and especially in steam power plants. Whereas the thermal efficiency of the internal combustion engine amounts to about 35%, a modern steam power plant working at 20 kgs. pressure and condensing cannot utilise more than 18-20% of the energy contained in the fuel. It is certainly possible to imagine that the combustion process may be carried out on other lines than those now employed, by which the conversion of the fuel into mechanical energy may be effected in a more economical way, but at the present state of development of thermodynamics this is not possible.

The improvements realised in the design of the steam turbine have been carried so far that further improvements in its economical efficiency are hardly to be expected with the steam pressures generally employed up to date.

The readiest means of improving the economy is, then, to increase the steam pressure as far as possible. By the application of water-tube boilers the steam pressure has been increased considerably during the last two decades from 10 kg. to 18 or 20 kg., and recently, in a few installations, even more.

THEORETICAL CONSIDERATIONS.

The higher the initial steam pressure, the higher will be the percentage of the heat energy in the steam transformed into mechanical energy, when the steam is allowed to expand down to a certain back pressure.

By increasing the steam pressure from 20 kg. per sq. cm. to 30 kg. per sq. cm., with a calorific value of 750 cal. per kg. of steam in either case, the amount of heat transformed into mechanical energy would be increased by almost 5%, when the steam is expanded down to 0.04 kg. abs. pressure. If the initial steam pressure be raised to 100 kg. per sq. cm., the efficiency would increase

by 20% under the same conditions as before, and the higher the back pressure the higher will be the saving derived from the use of extra high pressure steam.

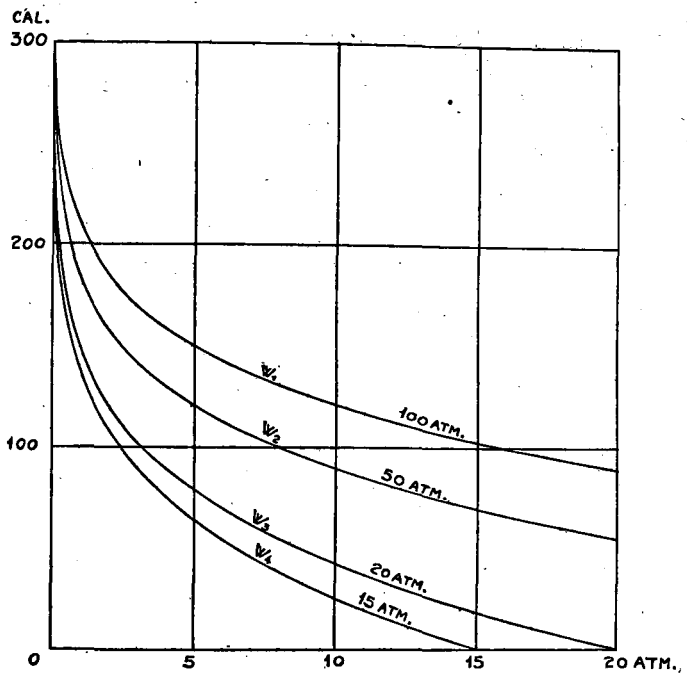


Fig. 1.

The diagram in Fig. 1 indicates the effective drop of heat per kg. of steam expanding from 100, 50, 20 and 15 kg. per sq. cm. absolute pressure down to different back pressures. The calorific value of the high pressure steam is assumed to be equal to 750 calories per kg. of steam for each of the four curves W1, W2, W3, W4.

It will be seen from this diagram that the advantages of employing extra high pressure steam in comparison with steam of ordinary pressures increase considerably as the back pressure increases. Consequently the extra high pressure steam is especially advantageous in all industrial plants which use steam for heating and boiling as well as for power generation, such as chemical works, sugar refineries, breweries, alkali works, etc.

The diagram in Fig. 1 is calculated according to tables and

diagrams by Prof. A. Stodola, Zürich 1922. Researches upon the heat-properties of steam at different temperatures and pressures up to 110 atm., carried out by the author on an " Atmos " Boiler, have shown that the calorific values of the saturated steam differ rather much from those according to the diagrams by Stodola and Schüle, but coincide at lower pressures with the diagram by Knoblauch, as shown in the diagram in Fig. 2. At higher temperatures (about 400° C.) the accordance between the diagram by Stodola and the trials is quite satisfactory.

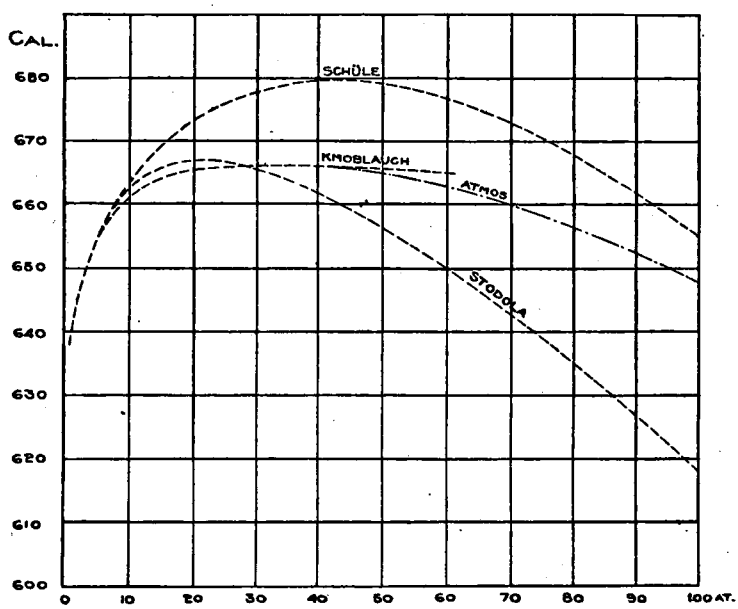


FIG. 2

HEAT-PROPERTIES OF SATURATED STEAM

The power generated by a back pressure turbine is *less expensive* than power generated in any other conceivable way, provided that all the exhaust steam be utilised for heating purposes. If the thermal efficiency of the boiler plant amounts to 82% and the loss of energy from radiation and bearing friction be 5%, the consumption of fuel, when using steam coal with a calorific value of 7,000 cal. per kg. would be:

$$\frac{632}{0{\cdot}82 \times 0{\cdot}95 \times 7{,}000} = 0.116 \text{ kg. of coal per h.p. hour.}$$

It is also evident that the economy of every existing steam power plant may be considerably increased by using an additional steam turbine working at extra high pressure, the exhaust steam from which, when passed into the existing main piping, can be utilised in the existing turbines. If the exhaust steam from the additional turbine has the same calorific value as the high pressure steam in the existing plant, it is evident that the capacity must have been increased by the amount of power developed in the additional turbine, reduced, of course, by the energy required for its auxiliary machinery. This increase in energy will thus have been obtained with the smallest possible fuel consumption, that

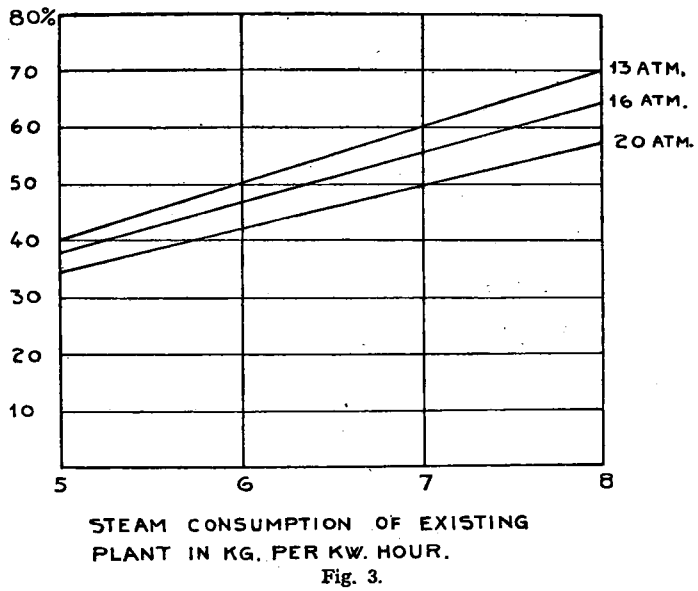


Fig. 3.

is, with the theoretical amount corresponding to the energy developed.

As a matter of fact the efficiency may even be considerably higher, as it obviously depends upon the overall economy of the existing plant. The lower this is, the higher will be the steam or fuel consumption. And the higher the thermal efficiency of the extra high pressure plant is, as compared with that of existing plant, the greater will be the increase of power *for the same fuel consumption.*

The diagram in Fig. 3 indicates the increase of energy per cent.

that may be obtained from the same fuel consumption as before by the application of an additional turbine working at 100 atm. pressure and different back pressures (13, 16 and 20 atm.) The energy consumed by the extra high pressure feed pump is included. As to the temperature of 475° centigrade the objection might be made that it is impossible to generate extra high pressure steam of such a temperature, as the tubes of the superheater would be too hot and would burst. On further consideration, however, it appears that these apprehensions are unnecessary, as the higher the pressure is, the greater will be the co-efficient of heat transmission from the tube to the steam. Consequently the temperature of the tubes in the extra high pressure superheater will be lower than would be the case in a superheater for normal pressures at the same temperature of the steam in both cases. The temperature of the tubes in the extra high pressure superheater will in reality be only a few degrees higher than the steam temperature, and at a temperature of 500° centigrade of the tube the factor of safety against fracture is quite sufficient. This has, in fact, been proved in practice by experiments with boilers for extra high steam pressures up to 200 atmospheres carried out by Dr. de Laval in the last decade of the 19th century, and in the first " Atmos " boiler for 100 atmospheres pressure, now working, a steam temperature of 475° C. was obtained without any trouble.

Another arrangement for improving the thermal efficiency consists in providing the extra high pressure turbine with by-passes for the steam which goes to heat the feed water. By this means it is possible to attain a thermal efficiency of even more than 30 per cent. Thus it is possible to obtain in a steam power plant almost the same thermal efficiencies as in the internal combustion engines.

PRINCIPLES GOVERNING THE DESIGN ON HIGH PRESSURE BOILERS.

From the preceding statement it will be seen that very important economical advantages may be gained with steam of extra high pressures, and a great many inventors have of later years attempted to solve the problem of generating steam of such pressures for industrial purposes, amongst whom de Laval, Serpollet, Hereshoff and White are the most well known, but with very little success. In most of these cases spiral tubes of a small diameter were used, with the object of precluding the risk of explosion, on account of the small water content in the tube. But on the

other hand it is evident that the removal of sediments and incrustations from the inside walls of the small tube is very difficult, if not impossible.

There is another factor which, although it has not received much attention, plays an exceedingly important part in the proper service of a boiler, particularly an extra high pressure boiler. It is a fact that the heat transmitted through the tube walls is far more effectively carried away by water than by steam. Consequently the tube-shell will be far more cooled when in contact with water than would be the case if the tube were filled up with foam composed of steam and water. The more steam in the tube in proportion to the water, the higher will be the temperature of the tube. Now, it is quite evident that the generation of steam will become most violent in those tubes which are nearest to the furnace. Thus an ordinary water-tube boiler with tubes of greater cross-section will be in this respect better than one with slender tubes. But it is also evident that it will be much more difficult to obtain a sufficient fastening of the tubes the higher the steam pressure is and the greater the cross-section of the tube. Moreover, when scale has accumulated in the tubes, the temperature of the tubes will be increased, thus causing additional strains in the material, which cannot be controlled and might cause pipe fractures.

As a consequence of what has been set forth above, the conditions to be complied with when designing an extra high-pressure steam generator affording a satisfactory margin of safety may be summed up as follows :—

1. *The steam given off from the direct heating surface must be removed immediately as it is generated and replaced by water. Thus the most efficient cooling of the tube-shell will be obtained.*

2. *Allowance must be made for the free expansion of all tubes exposed to the heat from the fire-grate, in order to preclude any extra uncontrolled stresses in the material due to changes in temperature.*

These two conditions are effectively and efficiently fulfilled in the operation of the " Atmos " steam generator.

The principal feature of this boiler is that the steam is generated on rapidly revolving tubes of 12 in. diam. so arranged that they may expand freely without strain. This rotation results in the inside circumference of the tubes being entirely covered with a solid layer of water, which is pressed against the walls by centrifugal force,

thus forcing the steam bubbles rapidly from the wall into the open central space. By this means a very efficient cooling of the tube is attained. Moreover, owing to the rotation, the stresses in the material are uniform all over the tube and may be exactly computed.

RÉSUMÉ.

Dans l'état actuel de la thermodynamique une amélioration effective de l'économie des centrales à vapeur ne peut être réalisée que par l'élevation de la pression de vapeur jusqu'à 100 at. Le gain théorique obtenu par une telle augmentation est indiqué par un diagramme.

Après avoir passé en revue les tentatives de construction de chaudières à vapeur pour des pressions exceptionellement hautes l'auteur attire l'attention spéciale sur deux conditions que doivent remplir une telle chaudière:

1—La surface de chauffe doit être effectivement refroidie par l'eau, et par conséquent les bulles de vapeur formées, doivent être évacuées aussi vite que possible.

2—Les tubes de la chaudière doivent se dilater librement afin d'éviter les tensions dangereuses dues aux variations de température.

HIGH PRESSURE WATER TUBE BOILERS

O. A. WIBERG. Finspong, Sweden.

The demand for high economy in steam generating plants has been a very predominant feature of the industrial development during the last two decades. This tendency leads to the utilisation of still higher steam temperatures and pressures. Especially has the necessity of high pressure been an important question in paper mills and other works, where exhaust steam of relatively high pressure is used for digesters and similar purposes. In central stations and power plants also, the demand for higher economy has led to the adoption of higher temperatures and pressures. The designer's attention has been drawn to these facts and considerable progress has been made in building high pressure boilers during recent years.

It is evident that, when the working pressure is increased, the boiler must be designed with the utmost care as regards elasticity of its elements. The free circulation of the water is another factor which must be carefully considered. Due attention must be paid to these requirements when designing a boiler for high pressures and temperatures. The experience shows that the same durability and factor of safety as commonly used can be easily obtained also in the case of high pressure boilers, without going to impractical dimensions.

As regards the elasticity of boilers with straight tubes, the sectionalised water tube boiler has appreciable advantages. In comparison with other boiler types this boiler retains a predominating position owing to its safety, facility of standardising, transporting, etc. It cannot be denied, however, that the sectional boiler, in comparison with other well-known types, suffers from a serious defect, *viz.*: the restrained circulation, as the tube area between the headers and the main steam and water drum is very narrow.

As it is hardly possible to arrange more than one return tube for the sinking water column between the main drum and the header, the area of this tube will be inversely proportional to the number of tubes in the section. This arrangement means a very small water connection in cases where the number of boiler tubes per section is comparatively large.

In addition, it may be mentioned that the headers themselves of many boiler types tend to restrain the water circulation

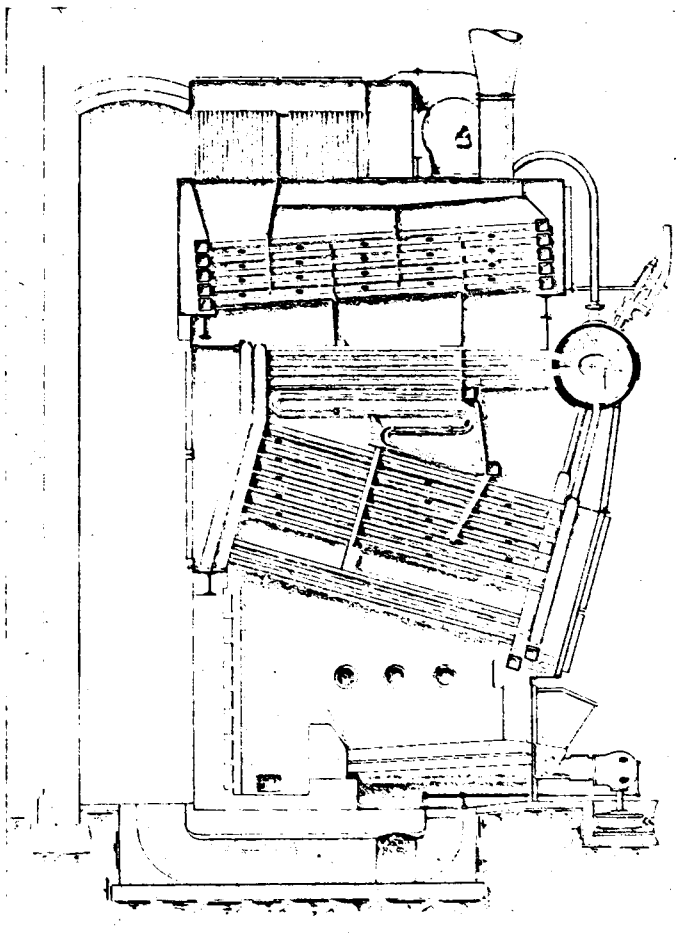


Fig. 1.

on account of their form. In order to get the tubes in the characteristic staggered position, the headers are usually given a sinuous curvature so that each tube end requires a very sharp bend in the header.

In the design of a new sectional type high pressure boiler of Swedish manufacture described below, due attention seems to have been paid to these points of view,

As indicated on the sketch, Figure 1, the headers are applied in two separate rows in a staggered position. In this way the sections

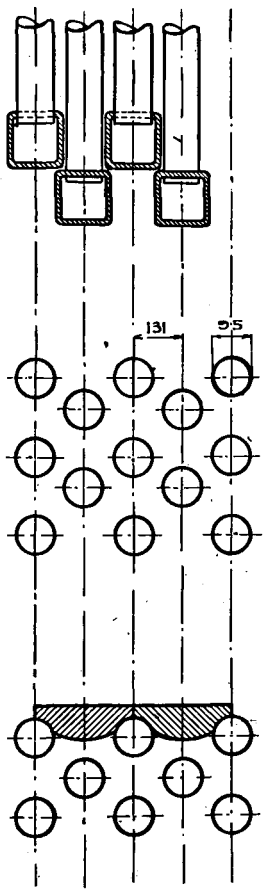


Fig. 2.

can be kept closer; the distance between the sections can be considerably diminished, so that the number of sections and also the number of connections for the water circulation will be increased for a certain width of the boiler.

Owing to this arrangement, the area of the connections between

the boiler drum and the sections will be 40 to 50 per cent. more ample than in a corresponding sectional boiler of the usual type, provided that the tube diameter and the floor space required are the same in both cases.

The double row headers also allow for a staggered spacing of the boiler tubes, the mutual position of which is selected so as to afford a constant velocity of the gases as far as possible. This velocity has been determined to obtain the highest possible heat transmission and a comparatively low loss in head of draught.

As the distance between the tube rows is decreased, the tubes could easily be so arranged that the gases come into contact with practically the whole circumference of the tubes. This will be clearly seen from the cross section in Figure 2.

The area of the circulating tubes being increased, and thus the resistance decreased, it follows that the circulation will be more free and rapid, and consequently the evaporative capacity and efficiency of the boiler will be increased. The risk of local overheating also will be minimised.

The boiler is in all other respects identical with other well-known makes of steam generators.

Both air and water heater are arranged above the boiler as shown on the sketch, Figure 1. In most cases, however, it would prove less expensive to utilise either an air heater or an economiser of correspondingly larger dimensions, to take the whole heat available in the flue gases from the boiler. The air heater is very suitable in case the feed water has a very high temperature, making it unfit to absorb the great amount of heat from the gases. The combustion air is taken from the top of the boiler room and thus the heat in the boiler room will be utilised.

This boiler type is built in all usual sizes and for pressures up to 800 lb. per square inch.

A boiler designed for 600 lb. per sq. inch and 750°F. temperature has been in use in the Stal Company's works since 1920. This boiler was designed at the beginning of 1917, but was not put into service before 1920 owing to war conditions. The following is an extract from a report on tests made with this boiler on November 13th and 14th, 1923. The tests were carried out by the Swedish Boiler Owners Association (Mellersta och Norra Sveriges Ångpann förening).

Heating surface of the boiler	..	..	..	154 m²
„ „ „ superheater	..	..	..	70 m²
„ „ „ economiser	..	..	..	89 m²

There is also provided an air-preheater for combustion air. Grate: automatic Dano-stoker.

Test I. Before this test the boiler was swept, and the furnace was cleaned of ashes and slag before it was fired up. The boiler was under fire for about 4½ hours before the test, during the last hour of this time at the same load as when testing.

Test II. Commenced 46 minutes after the first test had been terminated and without any previous cleaning or sweeping.

Test III. Commenced 6 hours after firing up. The furnaces were cleaned from slag before firing up, but no sweeping had taken place.

RESULTS OF TESTS.

	I.	II.	III.
Number of test			
Duration of test, hours	6·02	2·11	4·5
Coal, effective cal. value	7130	7,080	7,080 cal.
Steam pressure (abs.)	20·25	21·3	38·6 kg/cm.²
Temperature of superheated steam	349	367	390 deg. C.
Kg. steam per hour and m² boiler surface	30·45	49·3	28·73
Kg. steam per m² boiler heating surface (reduced 0—100°)	35·5	58·2	33·2
Temperature of water at economiser inlet	5·1	4·7	4·8 deg. C.
Do. at economiser outlet	67·5	60·7	72·3 ,,
Temperature of flue gases at boiler outlet	253	292	313 ,,
Do. at economiser outlet	132	157	181 ,,
Air temperature at air heater inlet	40	40	47 ,,
Do. at air heater outlet	70	75	86 ,,
Efficiency of boiler including superheater	78·9%	79%	77·1%
Do. including economiser	86·1%	85·3%	84·6%
Do. including air heater	87·5%	86·8%	86·6%

For Test I. the boiler was overloaded, so that the rate of evaporation reached 58·2 kg./m², though the boiler had been running for 11 hours without cleaning grate or tubes. A considerably greater evaporation would certainly have been reached, if time had permitted soot blowing and cleaning of grate before the start.

In addition to the preceding notes, which are all extracted from the report, it might be mentioned that the boiler in question is a comparatively small one and that the surface of the casing is very large in comparison with the heating surface, a comparatively great quantity of heat thus being lost by radiation and air leakage.

RÉSUMÉ.

Les efforts qui ont été faits durant ces dix dernières années pour améliorer l'économie de vapeur et réduire la consommation de charbon, ont eu pour résultat des rendements supérieurs des machines motrices à vapeur ainsi que l'emploi de températures et de pressions de vapeur de plus en plus élevées.

En construisant la chaudière décrite ci-dèssus on s'est efforcé principalement d'obtenir la plus grande élasticité possible, la circulation d'eau la meilleure et le rendement le plus élevé. La chaudière est du type à sections, mais construite de telle manière que la circulation devient plus libre que dans

les chaudières ordinaires de ce type. Le réchauffeur d'air ainsi que l'économiseur sont placés au-dessus de la chaudière. La chaudière est construite en toutes grandeurs habituelles et pour des pressions allant jusqu'à environ 60 kg./cm.^{2}.

Des essais officiels ont été effectués récemment sur une chaudière de cette construction en service depuis 1919 dans les ateliers de Stal à Finspong. La pression est de 40 kg./cm.^{2} et la température de surchauffe de 400° C. La surface de chauffe en est de 154m.^{2}, celle du surchauffeur de 70 m.^{2} et celle de l'économiseur de 89 m.^{2} La chaudière est aussi munie d'un réchauffeur d'air ; foyer : Danostoker automatique. Les essais officiels faits avec cette chaudière par Mellersta och Norra Sveriges Ångpannefören ing (l'Association de Surveillance des Chaudières à vapeur en Suède) donnent les résultats suivants :

A une évaporation de 35·5 kgs. de vapeur par m.^{2} de surface de chauffe, le rendement était de 87·5 pour cent et à 58·2 kgs. de 86·8 pour cent.

La chaudière étant assez petite, la surface de son enveloppe est très grande par rapport à la surface de chauffe, en conséquence, les fuites d'air sont relativement importantes ; certainement avec une chaudière ayant une surface de chauffe pus grande on peut s'attendre à des résultats meilleurs encore.

POWER FROM MERCURY VAPOUR

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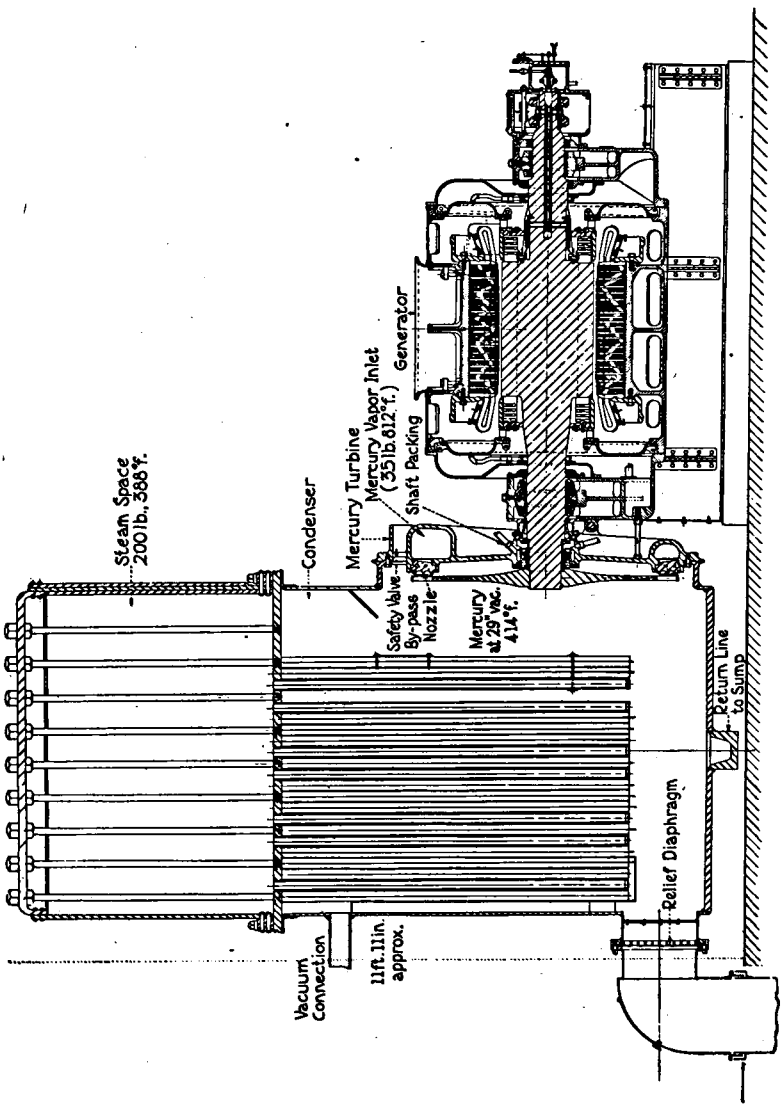
The writer has very recently presented a paper to the American Society of Mechanical Engineers on the subject of the process here referred to. This paper gives information concerning the origin and experimental development of the process, and details concerning the application of it which has for some time past been in operation at a plant of the Hartford Electric Light Company. This paper also gives tables and curves which give the thermodynamic properties of mercury. The intention of the present paper is to supplement that which has already been published and to state some of the uses to which the process should be applicable and suggest the methods of application which should be desirable.

After a long period of experimentation and construction of boilers and apparatus of various types, the above mentioned equipment was built and put into operation in the fall of 1923. This installation is in the Dutch Point Station of the Hartford Electric Light Company and was designed for 1,800 kW. from the mercury turbine with 35 lb. gauge pressure in mercury and 200 lb. in steam.

In order that an idea may be formed of the nature of this process and the work that has been done, it will be best to quote here some parts of the paper above mentioned. Cross-section drawings of the Hartford installation are also given.

" In this process mercury is vaporized in a boiler at temperatures which can be much higher than those which are practicable with steam. It is then carried through a turbine and does useful work, exhausting into a surface condenser where its latent heat is used to make steam at pressure desirable for use. The condensed liquid is carried back to the boiler preferably by gravity. The characteristics of mercury are such that high temperature can be used without excessive pressure, and the heat of condensation can be delivered at a convenient degree of vacuum and at a temperature suited to making steam at pressures desirable for power uses. The process thus affords means by which the temperature ranges practicable


Steam Space
200lb., 388°f.
Condenser
Mercury Turbine
Mercury Vapor Inlet
(351lb. 812°f.)
Shaft Packing
Generator
Safety Valve
By-pass
Nozzle
Mercury
at 29" vac.
414°f.
Return Line
to Sump
Relief Diaphragm
Vacuum
Connection
11ft. 11in.
approx.

with steam are greatly increased under conditions which afford large gains in efficiency of conversion of the heat energy of fuel into work.

THE HARTFORD INSTALLATION.

"The equipment at Hartford was designed to operate with 35 lb. gauge pressure on the mercury boiler, to deliver about 1,800 kW. from the mercury turbine, and to make steam at 200 lb. pressure with about 100 degrees of superheat. The furnace gases pass in order through the mercury boiler, a mercury-liquid heater, a steam superheater, and a feed-water heater. It would be more economical to substitute for the last-named device an air heater, since it would put this residuum of heat into the mercury instead of into the steam. The feed heat would then be accomplished by bleeding the steam turbine. The approximate temperatures in the gases at different points, and the temperatures and pressures of fluids, are given on cross-section drawings.

"Referring to Fig. 1, the mercury vapour formed in the boiler passes through a governing and emergency valve to the turbine, the single wheel of which is overhung on the end of the generator shaft and operates in the condenser space. Two safety valves are arranged to by-pass the vapour into the condenser if the governor causes its valve to close, so that the mercury vapour continues to be condensed and to make steam whether it is passing through the m rcury turbine or not. The shaft passes through a packing between the generator and the turbine wheel and this is sealed by mercury vapour above atmospheric pressure. The outward leakage from this packing is sucked into a cooler where it is all condensed and returned to the system.

"The discharge from the turbine wheel is delivered directly against the condensing surface, which consists of dead-ended tubes hanging vertically from a cylindrical steam and water drum, to which they are attached by rolling and also arc welding.

"The condenser shell and all the pipes and containers which carry mercury are put together by welding. From the condenser the liquefied mercury runs through a sump to the mercury heater and boiler by gravity.

"On the side of the condenser shell a large blowout diaphragm is provided which communicates to the stack and will give way if, through escape of steam or water or other cause, the pressure in the condenser should begin to rise unduly.

"The mercury boiler at Hartford is made up of fire tubes the lower

two-thirds of which are hexagonal with slightly convex faces. These are nested together like a honeycomb and for each 7 tubes a space is left for a duct which returns the circulating liquid. This liquid rises and the vapour forms in clearances between the tubes at the corners. The use of such tubes in a mercury boiler was proposed by Mr. B. P. Coulson, the author's assistant. The upper

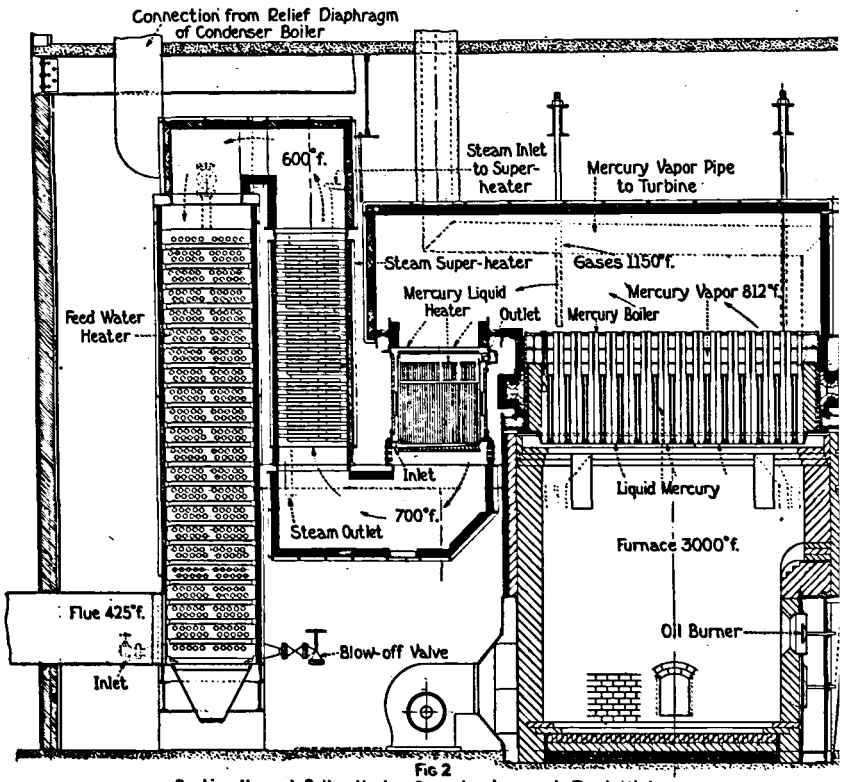


FIG 2
Section through Boiler, Heater, Superheater and Feed Water

round part of the tubes acts as superheating surface and the vapour is delivered with a little superheat, which is desirable for the reason that it probably tends to prevent cutting of the turbine blades—of which there has been none at Hartford, although a slight amount was observed in former turbines.

" This equipment has been run experimentally for several months.

Few troubles have been experienced and nothing of a serious nature. It has delivered power to the circuits for about 800 hours. The highest load carried has been 1,500 kW. and the load carried most of the time has been 1,200 kW. There has been some uncertainty as to the safe capacity of the boiler and, since experience with continued operation has been the most important need, it has been thought best to avoid risk of any possible serious trouble. The conditions of running cannot be considered commercial, but the results secured give a very good indication that commercial results are not difficult of attainment.

"In Hartford, where oil is burned and measured, and where steam flow and feed are both measured, it has been estimated that, if the steam produced were used effectively, the fuel rate would be about 12,000 B.Th.U. per kWh. This is with only 1,200 kW. load, a single-wheel turbine of only about 60 per cent. efficiency, and with only 22 lb. mercury pressure.

MERCURY SUPPLY.

"The demand for mercury has always been strictly limited and it is probably not safe to predict positively the consequences of a greatly increased demand. The cost is governed largely by the richness of ore. Ore of various grades exists in many places and it only now pays to work the best of it. A well-informed mercury mine operator has estimated that a maintained price of $2 per lb. would call forth from known sources in the United States enough mercury, if used as we expect, to correspond in plant capacity to the largest yearly output of General Electric turbines. Several other experienced persons have expressed opinions generally agreeing with such a view. Unworked deposits are known in Alaska, South America, New Zealand, and elsewhere, and a rise of price will undoubtedly bring much more to light. It is thought, therefore, that we need not slack our efforts for the present through fear of a shortage of mercury.

POISONING.

"In ten years of experimentation with many kinds of mercury apparatus we have experienced no case of poisoning but nevertheless realise that the utmost care is necessary. On several occasions men have been in contact with much mercury vapour in hot places, and in one or two cases men have been temporarily quite sick as an apparent result. There has been no case of salivation or continued symptoms of mercury poisoning, although most of these men have

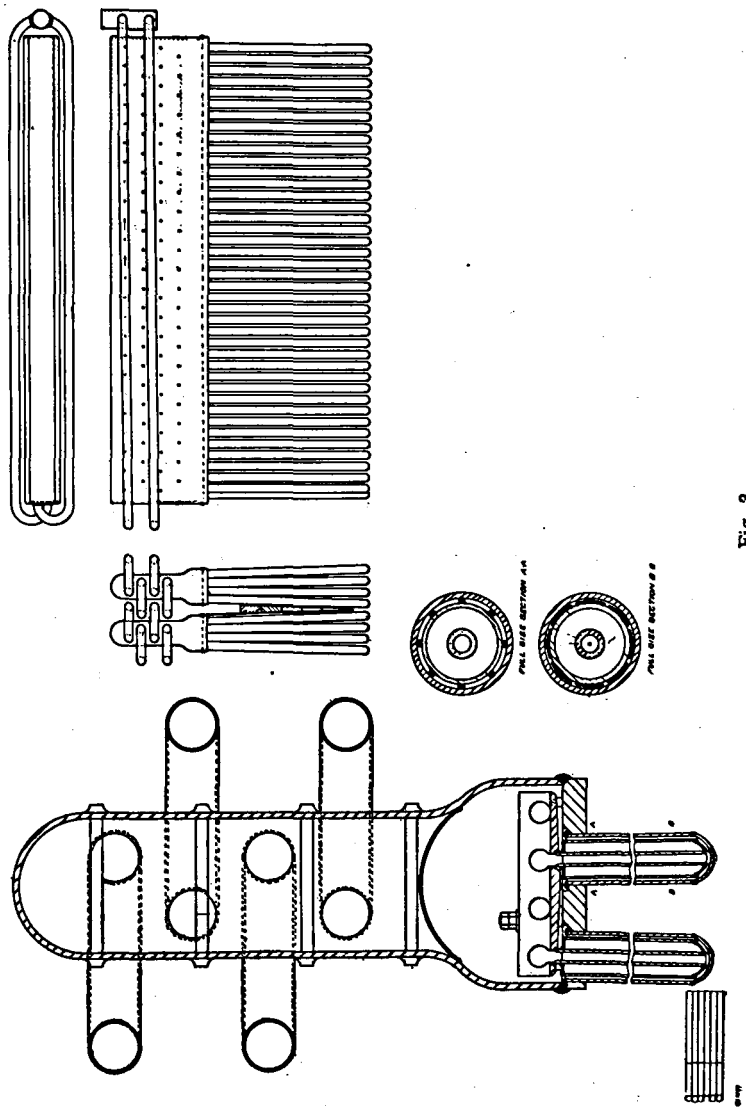


Fig. 3.

been on the job for long periods. The experience of mercury production and its use in other arts would indicate that, with reasonable precautions, danger of poisoning should not be appreciable."

This Hartford equipment was designed more than two years ago, and since that time much experimentation and study has been given to various features of this process. A type of boiler quite different from that at Hartford has been designed and experimented with. This boiler is built in sections which are individually removable, and which could be rather easily taken apart for cleaning or replacement of parts if desirable. The accompanying drawing, Fig. 3, shows the construction of this boiler. It is so arranged that all the tubes receive nearly equal heat, both from radiation and convection, and each tube has its own circulation; the arrangement being such that the discharge of vapour cannot interfere with the run back of the liquid in any tube.

An experimental boiler of this type, having twenty-four (24) tubes and containing about 700 lb. of mercury, has been run at 70 lb. gauge pressure and on output of 7,000 lb. of mercury vapour per hour. Oil firing was used with the highest temperatures attainable and no oxide scale was produced on any part of the surface. The design admits of no expansion strains and the test indicates that this is a safe load condition for operation even without the use of calorizing, a process which protects iron to high temperatures which is easily applicable to the tubes of a boiler of this design.

A type of liquid heater, different from that used at Hartford, has also been developed. This will also be built in sections. One of these sections is shown by Fig. 4. This heater is made up of small, slightly curved tubes welded into headers. Each tube is filled by a loosely fitting steel core and a channel in the core provides space for the circulating mercury. Means are provided by which each section can be very effectively blown out with air in case passages tend to become obstructed as is possible with unclean mercury. The headers are also so arranged that they can be easily opened by cutting certain welds in case the blowing process should in any case not be effective.

A process for cleaning mercury has been experimented with at Hartford, which seems to promise entire freedom from dirt trouble in such apparatus. The mercury returning from the condenser is run downwards through several compartments in parallel. These chambers are filled with steel balls. The solid matter, if there is

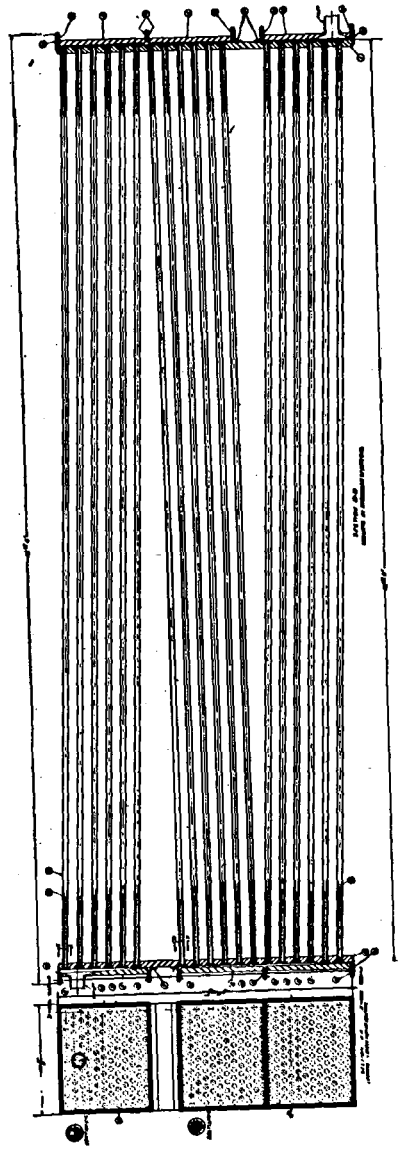


Fig. 4.

any, lodges among the balls and can easily at intervals be blown out with air without opening the apparatus or stopping operation.

It is proposed to install such a boiler and heater in place of those now used at Hartford, and if these prove to be thoroughly

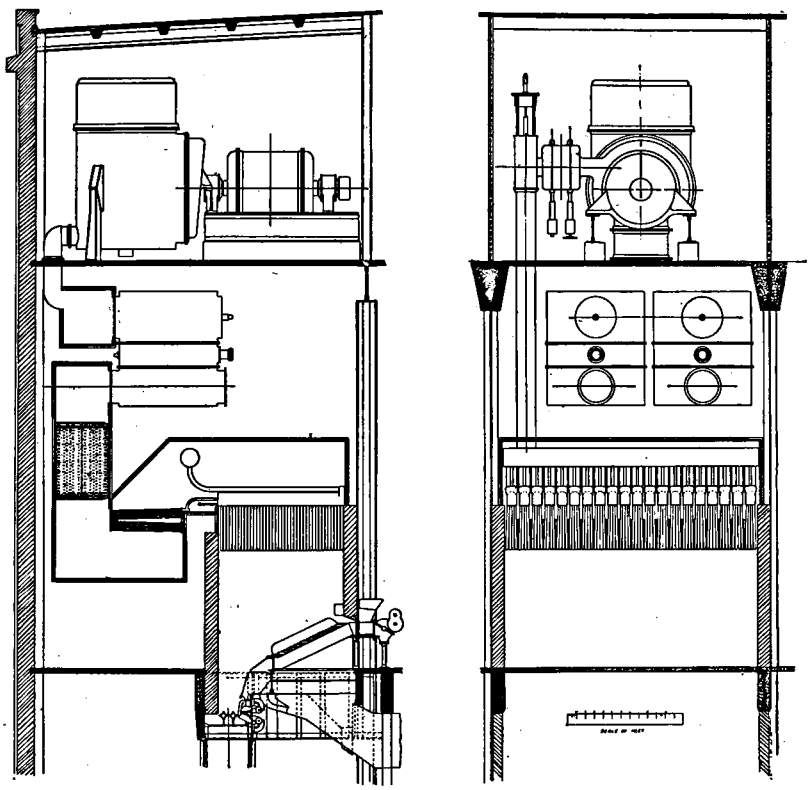


Fig. 5.

serviceable, applications on any scale can be undertaken without introducing any new or problematical features.

The boiler and heater at Hartford have both developed several small leaks through expansion effects at welds, and for other reasons

are not well adapted to large scale manufacture. It is thought that these new types are excellently suited to such purpose.

All other parts of the Hartford equipment have given very good service, and, while they involve many new features, they seem to be well adapted to commercial use.

At an early date we also expect to install, at Hartford, a three-stage mercury turbine instead of the single-wheel turbine now used. Calculations from the throat areas and measured pressures, and from the measured steam flow, indicate that the present turbine with generator is only about 60 per cent. efficient. It was at first thought that this low efficiency might be due to some action of the mercury different from steam, possible in the matter of supersaturation, but reaction tests of steam nozzles, under similar expansion conditions, have indicated that the action of the mercury is about equivalent to that of steam. Calculations indicate that with a three-stage turbine we ought to get something over 70 per cent. efficiency.

Fig. 5 shows an application of the new designs above mentioned to a large furnace such as those which are commonly used in modern power stations. The furnace space is 28 ft. wide and 14 ft. deep. Operating from such a furnace, with economical firing conditions and good fuel, tests of an experimental boiler indicate that we could produce from the mercury turbine about 7,500 kW. and about 10,000 kW. from the steam produced if it were used in the most efficient manner in large turbines.

To illustrate the economic possibilities of this process the following table has been prepared, which is based upon the expected results in one of the most advanced steam applications which is now being made. In such a case the figures bear a positive relation to each other, and the comparison does not admit of appreciable error unless it be in the assumption of efficiency of the mercury turbine.

HEAT DISTRIBUTION PER kW. OUTPUT 50,000 kW. PARSONS TURBINE.

Expected Normal Monthly Operation.

Steam Press. 550 lb. G., Temp. 750 deg. F., Reheat Press. 115 lb. abs. Reheat Temp. 700 deg. F., Exhaust at 0·75 in. abs.

COMPARED WITH MERCURY STEAM COMBINATION.

Mercury generating unit having an efficiency of 70 per cent. and operating at 70 lb. G. press.; steam turbine being the same with same conditions but without reheating.

	Steam Alone.		Mercury & Steam.
Heat from Fuel :	B.Th.U.	Per cent.	B.Th.U.
Heat to Normal Boilers	14,004	93·4	
Heat to Reheater	996	6·6	
	15,000	100·0	11,000
Heat from Turbine returned to boilers by heaters	2,320	—	—
Heat Distribution			
Banked fire and standby losses ...	1,800	12·0	1,305
Stack loss	1,443	9·6	1,046
Other boiler losses	812	5·4	585
Auxiliary power	670	4·5	487
Net Heat to steam jets, etc.	35	0·2	21
Heat to circulating water	6,649	44·4	3,983
Generator losses	178	1·2	103
Electrical energy from steam generator	3,413	22·7	1,992
		100·0	
Mercury generator losses	—	—	57
Electrical energy from mercury generator	—	—	1,421
Total electrical energy 1 kW. hour ...	3,413	—	3,413

In these figures the auxiliary load has been taken as proportionate to the fuel burned, which assumption is unfavourable to the mercury process since the load of circulating air feed and hot well pumps are all proportionate to the steam load and not to the fuel burned. The mercury apparatus adds no auxiliary but an air pump which takes very little power.

The following table, quoted from the paper above mentioned, shows the results which were produced in the month of January, 1924, in three among the best of the American power stations, and the results which might have been accomplished if the same fuel had burned under mercury boilers instead of under steam boilers :

	Plant 1.	Plant 2.	Plant 3.
kW. capacity	180,000	50,000	100,000
Economisers	No.	No.	Yes.
Steam pressure	219	286	235
Superheat	217	245	200
Load Factor	57%	50%	50%
B.Th.U. in fuel per kilowatt hour ...	19,850	19,700	18,250
Results obtainable with mercury ...	12,000	12,350	12,300
Gain in output	65%	58%	51%

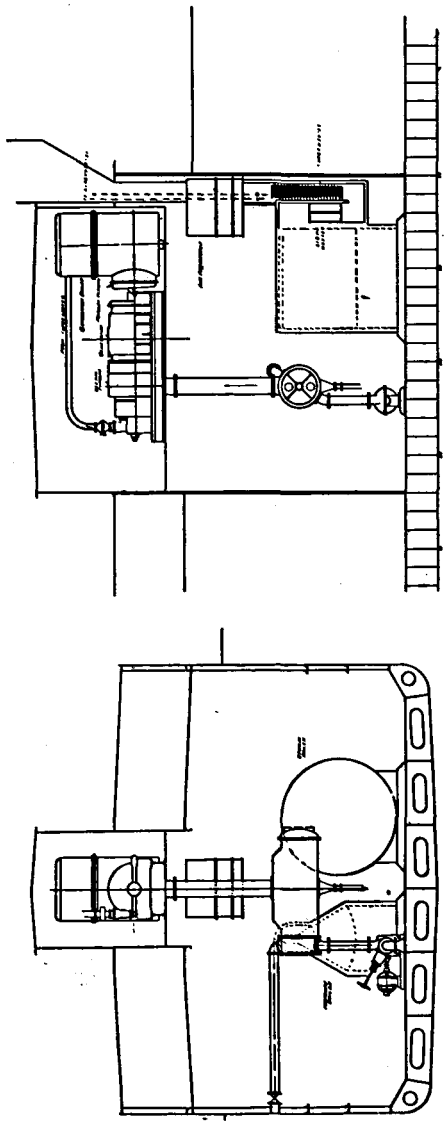


Fig. 6

The writer's activities for some years past have been largely devoted to the task of designing and experimentation necessary to make this process available for power station uses, and little time has been devoted to other possible uses. There are, however, many interesting applications which should be possible.

Since the gain of the mercury process is all in the higher temperature ranges it will give relatively large gains in cases where lack of condensing water, or water shortage, limits the use of vacuum. In a locomotive its use should involve no great practical difficulty, and it should be possible to carry some steam vacuum by air cooling without any appreciable loss of water. Such a locomotive should run for less than half the fuel used in an ordinary steam locomotive and with much less cooling effect than is required by some of the recent turbine driven locomotives.

Another possible application in which the writer feels a great interest, but to which it has not been possible to devote much study, is the propulsion of ships. The only new problem involved in the design of a mercury boiler for ship use is to so arrange it that the rolling of the ship will not defeat its action. A plan has been considered for this purpose and, although it has not been developed or experimented with, the action of experimental boilers for other purposes has indicated that it would be successful.

Fig. 6 shows the important parts of a possible equipment for a 3,000 H.P. cargo boat. In this the propelling motor is not shown, being supposed to be in an after compartment near the propeller. In such an installation it is thought that it would be desirable to use one mercury generating unit, arranged for gravity feed and having a generator which is also connected to a steam turbine. In addition to the mercury boiler it might be desirable to have one steam boiler in reserve so that the ship could run at reduced speed as a steamer in case of any trouble with the mercury apparatus. It might also be desirable to install a small auxiliary steam turbine unit which could be run in port and could also be used for low speed propulsion in case of need.

To illustrate the possibilities of such an installation a study has been based upon the performance of the S.S. "Archer," of which the operations have been very carefully studied and recorded on many long voyages. The steam consumption of the main turbine and of all auxiliaries has been carefully measured under different conditions and the corresponding fuel oil consumptions have been recorded.

The "Archer" is an electrically propelled steam freighter; length—440 ft.; beam—56 ft.; mean draught loaded—28 ft. 7½ in.; displacement light—4,060 tons and loaded 15,942 tons. She was designed for about 3,000 shaft horse-power with a propeller speed of 100 R.P.M. This ship has made four voyages around the world and records have been kept over a long period.

While operating at 3,150 shaft horse-power she consumes, for all purposes, 1·02 lb. of oil per shaft horse-power. 31,360 lb. of steam per hour are used in her main turbines and 10,682 for auxiliary uses.

If the equipment of this ship were changed to a mercury steam equipment, as described above, using the same generator and motor and similar auxiliaries and stack temperature, the fuel consumption would be ·52 lb. of oil per shaft horse-power. With electrically driven auxiliaries and air heating arrangements, it would be materially less. This figure assumes an efficiency of 70 per cent. for the mercury turbine and such reduction of the efficiency of the steam turbine and auxiliaries as would be incident to their reduced size.

Calculations indicate that in a large liner, using highly efficient steam conditions, with the best auxiliary arrangement, a fuel consumption as low as ·42 lb. of oil per shaft horse-power could be accomplished by the use of this process.

RÉSUMÉ.

Ce rapport décrit la nature du procédé à la vapeur de mercure, couvrant les caractéristiques du mercure à haute température, ses sources d'approvisionnement, le coût probable et le danger d'empoisonnement. Il refère particulièrement à l'installation, au fonctionnement et aux résultats obtenus à la station Centrale de "Dutch Point" de la Hartford Electric Light Company où une chaudière à mercure a été installée en 1923. La Station a été en service depuis cette date. Le rapport décrit les expériences qui sont effectuées actuellement et signale les modifications et les améliorations de l'installation de "Dutch point" qu'il est désirable d'obtenir. Quoique les recherches décrites aient été surtout faites en vue de la construction de ces machines pour les Stations centrales, d'autres applications possibles du procédé à vapeur de mercure sont décrites. A ce sujet l'auteur insiste sur le fait que, comme le développement qui a été essayé se classe dans les hautes températures, on peut espérer réaliser de grandes économies où l'eau de condensation disponible est limitée. Les possibilités économiques du procédé au mercure sont clairement illustrées par des chiffres donnés sous forme de tableau. Les caractéristiques de construction décrites dans le rapport sont illustrées à l'aide de dessins.

PRESENT PRACTICE IN STEAM GENERATION IN THE UNITED STATES

D. S. JACOBUS

The paper outlines the practice of the Babcock & Wilcox Company, with which the writer is associated, and is generally representative of that in the United States. The company has had to do with the majority of recent important installations and much of what follows is the result of its experience and research work. The subject of high steam pressures is stressed because of the great interest in it in connection with the problem of securing higher efficiencies in power plants, and the great amount of study which the Company has given this subject. It deals with stationary boilers and their superheaters, economisers and air heaters and includes some data on marine boilers, to enable certain features of stationary and marine installations to be compared.

There is a wide difference of opinion among engineers in regard to the best pressure and temperature at which to operate a steam power plant. The question is an involved one and cannot be answered in a general way because all the conditions existing in each particular case must be considered in deciding the best pressure and temperature to adopt.

In a base load plant it pays to employ a higher pressure and temperature than in one having a low load factor. In order to employ high-pressure steam to good advantage it is necessary to re-superheat the steam between the turbine stages, which adds complication so that in many cases it is better to use a lower pressure and not re-superheat the steam.

There are a number of factors to be considered in determining the economy of a plant. The economy obtained through heating the feed water by means of steam bled from the steam turbine is one of these. Where economisers are used, heating the feed water by steam extracted from the turbine reduces the heat absorbed by the economisers and there is a certain feed temperature above which it will not pay to install economisers to further heat the feed water. Air heaters for heating the air for combustion may be used to advantage where the feed water is heated by abstracting steam from the turbine to a temperature that will handicap the economisers.

The cost of fuel is a governing factor, and it pays to install a more expensive and complicated plant for a high-priced fuel and to shoulder such extra expense as may be required for operating the more complicated plant. The problem is a complex one and the Babcock & Wilcox Company has taken pride in always standing ready to furnish boilers for any pressures or temperatures of steam that may be called for.

The great majority of the boilers built for higher pressures and temperatures have been for supplying steam at a gauge pressure of 350 lb. per square inch or thereabouts, at the turbine throttle, where the steam is not re-superheated between the stages of the steam turbine. Boilers having a total heating surface of about 2,560,000 square feet were sold prior to 1924 for 54 stations for working pressures of 350 lb. or more. Of these, boilers having 400,000 square feet were for 650 lb. working pressure. In the latter plants the steam is re-superheated.

The highest pressure for which the Babcock & Wilcox Company is building boilers is somewhat over 1,200 lb. per square inch, one such boiler being for the Edison Electric Illuminating Company of Boston, and one for the Consolidated Safety Valve Company. The Commonwealth Edison Company of Chicago was the first to order a 1,200 lb. boiler, but the manufacture of it has been temporarily held up awaiting results of its 650 lb. development. The boiler for the Edison Electric Illuminating Company of Boston is arranged to evaporate about 150,000 lb. of steam per hour as a maximum. Few appreciate what it means to design and build such high pressure boilers. A small boiler can readily be constructed for operating at any desired working pressure, but it is a far different proposition to design one to meet the exacting demands of central power plant work.

In marine work, space and weight limitations impose conditions which necessitate a different design from that for stationary boilers. Notwithstanding these limitations marine boilers must be capable of being operated at high capacities with good efficiencies. The modern tendency is to operate stationary boilers at higher and higher capacities and it is interesting to compare the results with those secured in marine practice.

FEATURES BEARING ON CAPACITY OF BOILERS.

The limit of capacity ordinarily depends on the maximum amount of fuel that can be burned and the draft available for overcoming the resistance of the gases flowing through the boiler. It was

considered good practice not very long ago to operate stationary boilers at capacities not exceeding an evaporation of about 5 lb. of water per square foot of heating surface. The maximum capacity called for has gradually crept up until to-day boilers are regularly installed to evaporate from 8 to 10 lb. of water per hour per square foot of heating surface and in some instances for a still higher rate of evaporation. These capacities are obtained with both coal and oil fuels and are sometimes considerably exceeded in actual operation.

FEATURES BEARING ON EFFICIENCY.

Increase in fuel cost and a growing tendency toward base load operation has led to a steady improvement in the economy of power plants. It does not follow that a plant designed to give the highest thermal efficiency will have the highest commercial efficiency. Economisers will add to the thermal efficiency and the same applies to air heaters, whereas on considering all features it may be that the character of the load, class of operation and fuel conditions, will make it advisable to install boilers without either economisers or air heaters. Each case must be considered by itself and a careful analysis made to determine what it will be best to use.

The most economical capacity at which to run a given boiler plant depends on the load conditions and the class of fuel. The economical rating is naturally influenced by the presence or absence of economisers or air heaters. Where there are short peak-load periods the greatest economy is usually secured by operating at as high a capacity as possible during the periods of peak loads. The maximum capacity obtainable is an important factor and the tendency is upward rather than downward.

Additional efficiency may be secured by causing the gases which flow through a boiler to pass over a greater number of rows of tubes, and in some cases by changing the arrangement of the tubes. In the case of a boiler with horizontally extending tubes, adding to the height so as to increase the number of rows of tubes from, say, 14 to 20 will result in a considerable increase in efficiency with but little increase in draft loss. In certain instances the ability to operate the boilers with natural draft makes it desirable to use a high boiler without an economiser or air heater.

Increasing the number of passes of the gases over the tubes increases the draft loss, much of the loss being due to the change in direction of the gases in passing over the ends of the baffles. This has led to an endeavour to minimise the number of passes and we have

built a number of two-pass boilers. It may be asked why not use a single pass. The answer is that a single pass boiler for a given capacity and efficiency would cost more than a two-pass boiler. The two-pass boilers also lend themselves more readily to separating the soot and cinder from the gases, and fit in well with most plant layouts when used in connection with economisers and air heaters. A two-pass boiler costs more than a three-pass boiler for a given capacity and efficiency and most boilers are three-pass. In the case of Stirling boilers, the gases are made to pass three or four times lengthwise of the tubes, including the pass over the tubes next the furnace, and in some cases five times.

The arrangement of the furnace influences the draft loss measured between the bottom of the furnace and the breeching, because the stack effect of a high furnace assists materially in overcoming the draft loss of the boiler. Where the first pass of a boiler is directly above the furnace, the greater stack effect of the first pass over the others, on account of its higher temperature, results in less draft loss through the boiler than should the first pass of the gases be downward. In some cases the draft at the bottom of a furnace may be greater than at the point where the gases leave the setting with the boiler steaming at fair capacity.

USE OF ECONOMISERS AND AIR HEATERS.

In determining whether it will pay to install economizers, the economy of boilers of the size best suited for the particular service without economisers should be compared with the results to be expected from boilers of the best size to use with economisers.

It will sometimes be found that a boiler properly designed and baffled will give better results when all features are considered than a boiler and economiser unit. In some instances it is well to arrange a portion of the plant to be run continuously for carrying the base load, with boilers, economisers or air heaters to give a high efficiency, and the remainder of the plant so that the boilers can be run at a maximum capacity with a lower efficiency, for peak load service.

Wrought steel economisers are used to a much greater extent than formerly. Cast iron economisers held the field for a long time on account of being less subject to interior corrosion than wrought steel economisers. Interior corrosion of wrought steel economisers is now overcome by reducing the free oxygen in the feed water to the point where it will not give trouble. In early efforts to remove the air the feed water was heated in an open heater to about the boiling point at atmospheric pressure. An extensive series of tests

at a plant where the feed water was handled in this way showed that it reduced the oxygen to about 0·2 c.c. per litre, which was only a small fraction of the quantity contained in the feed water for an average plant, which at the time ran from 2 to 4 c.c. per litre. At first it was thought that removing the free oxygen to this point would prevent interior corrosion. Heating the water to 210 to 212 degrees instead of feeding it to the economisers at the temperature, otherwise available, of 160 degrees, led to a reduction of about one per cent. in the quantity of heat absorbed by the economisers, and at first it seemed that such conditions did not warrant the first cost and additional operating complications of an air removal apparatus. It was found later that there was an additional loss on account of vapor escaping through the vent pipe of the feed water heater which might be as great as, or greater than, the loss due to the reduced absorption of heat by the economiser. Some corrosion was also observed with the oxygen component as low as 0·2 c.c. per litre, and this led to installing an Elliott apparatus for removing the free gases from the feed water at its temperature when leaving the hot well. In this apparatus the water is heated to a temperature somewhat higher than that at which it is discharged freed from air. It is then sprayed into a separating chamber, which is maintained under a partial vacuum, and the boiling of the small particles of water, on being suddenly subjected to a pressure less than that of steam corresponding to their temperature, liberates the gases. No heat is lost from the system other than through radiation. The water treated by this apparatus was found to contain practically no free oxygen and there was no appreciable corrosion of the economisers after it was put in use.

Individual economisers are ordinarily used for each boiler without by-pass connections for short-circuiting the gases around the economiser, thereby preventing any loss of efficiency from leakage of hot gases through the by-pass and simplifying the flue connections.

The greater part of the economisers now installed by the Babcock & Wilcox Company have tubes inclined slightly upward from the horizontal in the direction of the flow of the water through them. Two-inch seamless steel tubes are used. They are expanded into forged steel boxes which are spaced apart to allow the removal and replacement of the tubes from between the boxes. The tubes, when not attached to the headers, can be introduced at an angle between the boxes which makes it possible to remove and replace the tubes with a relatively narrow aisle width and enables the economiser to be installed in positions where it would be impossible to remove

the tubes through hand holes placed in the boxes. There is a counterflow of the water and the gases. The water enters at the bottom and flows back and forth from a box on one side to one on the other side, until it reaches the top of the economiser. The hot gases flow downward.

In some small plants steel tube economisers have been operated by eliminating a considerable part of the free gases from the feed water by heating it in an open heater to about the boiling point at atmospheric pressure before feeding it to the economisers. Corrosion in the economisers has been found when they are operated in this way, but with the counter-flow type of economiser described the lower rows of tubes have corroded and there has been little or no corrosion above the sixth and eighth rows from the bottom. This is, of course, an important advantage, as in case of corrosion it is necessary to replace only the lowermost tubes. As already stated, the free gases are removed from the feed water in power plant work to a point where there will be no appreciable corrosion of the economiser, and corrosion is now becoming more and more limited to the smaller plants where the owners would rather replace economiser tubes from time to time than go to the expense of installing an air-removal apparatus.

The economies now demanded have stimulated the use of air heaters and the Babcock & Wilcox Company has supplied a number in connection with its boilers. Most of the air heaters made by this Company are made up of tubes, because it has been found necessary in the case of plate heaters to weld all of the joints in order to prevent leakage, and for equally tight and efficient heaters of the types the Company has manufactured, tubular heaters cost less than the plate heaters and are easier to repair.

The gain in the efficiency due to the use of air heaters may be greater than that corresponding to the heat absorbed by the air heaters, on account of the effect of the heated air in increasing the heat absorbed by the boiler and improving the efficiency of combustion. This is in line with what has been predicted and was borne out in experiments made by Mr. C. W. E. Clarke on a Babcock & Wilcox boiler fitted with another make of air heater, which he reported to the American Society of Mechanical Engineers last December. These were the first tests on a large boiler fitted with an air heater in the United States, which shows the newness of air heater practice in America. In certain cases air heaters have the added advantage of increasing the available boiler capacity 10 to 15 per cent. by making it possible to burn a greater amount

of coal. They are also advantageous, as already stated, where extraction feed water heaters are used which heat the feed water to a point that reduces the amount of heat available for absorption by economisers, in which case they are used either with or without economisers.

FURNACE DESIGN.

Furnace design must be co-ordinated with that of the boiler to secure the best results. From time to time ways are suggested for measuring the efficiency of a boiler apart from that of the furnace, all of which have been approximate. The line of division between the stoker-and-furnace efficiency and the boiler efficiency is influenced by delayed or secondary combustion between the boiler tubes, which is an element that cannot be included in any analysis. The effect of excess air is another element which cannot be correctly divided between the boiler and furnace. The combined unit should, therefore, be considered in any study of efficiency or capacity.

The furnace should have sufficient effective volume to consume the fuel properly and there should be a suitable length of travel for the hot gases in passing through the furnace before they strike the boiler tubes, as well as an adequate mingling action of the gases within the furnace. With an incorrectly designed furnace it may be possible for a lane of gases containing excess air to pass through the furnace and boiler to the uptake. The effect of the eddying action within the furnace in mingling unconsumed combustible matter with the excess air must be carefully studied. An irregular mingling of the fuel and air may lead to pulsations within the setting. The velocity at which the air is admitted in the case of gaseous, liquid and powdered fuel is an important element in securing proper combustion.

Furnaces are made considerably larger than in former practice. For coal-fired boilers with forced blast chain grate stokers the latest installations have about 4 cubic feet of furnace volume per 10 square feet of boiler heating surface. In the case of the latest powdered fuel furnaces the volume is about 6 cubic feet per 10 square feet of boiler heating surface. In the latest installations for blast furnace gas, the furnaces have a volume of at least 2 cubic feet per 10 square feet of boiler heating surface. These figures are for the larger furnaces used in stationary practice. With smaller furnaces a considerably higher capacity is often developed than these rules would call for. As has already been stated, most coal and oil fired boilers used in power plants are called on to evaporate from 8 to 10 lb. of water per hour per square foot of heating surface as a

maximum, and at peak loads 60 lbs. of water or more may be evaporated per hour per cubic foot of furnace volume. In marine practice as high as 150 to 180 lb. of water may be evaporated per hour as a maximum per cubic foot of furnace volume in both coal and oil fired boilers. It is necessary to operate with the cleanest of feed water and with the highest class of attendance in order to secure such high capacities.

The question may be raised as to why furnaces are made, say, two or three times as large for stationary practice as for marine practice. The reason is that increasing the size of the furnace makes it possible to burn the fuel more completely within the furnace before the gases strike the boiler tubes. One cannot select fuels as carefully for stationary as for marine work, and where a fuel is of such a nature that it gives trouble through the accumulation of slag on the outside of the boiler tubes the larger furnaces minimise the difficulty. Again, with a larger furnace there is less danger of tube troubles, especially where there is a chance of the flames and heat being localised on certain parts of the tubes; there is also a less amount of ash or fine cinder thrown from the stacks.

A high efficiency of combustion involves a high furnace temperature, because the effect of increasing the amount of CO_2 in the gases leaving the furnace is to increase the furnace temperature.

The brickwork employed to-day will fail in most cases if brought to the full heat of the furnace, and to maintain the brickwork there must be some cooling. In most instances enough heat may be dissipated through radiation from the sides of the furnaces, combined with the radiation from the brickwork to the boiler tubes, without employing any special means for cooling the furnace walls. Where furnaces are operated under a suction the cooler air from the outside percolates inward through the brickwork and serves to prevent overheating, whereas if operated under a pressure, the hot gases percolate outward and increase the temperature of the brickwork. The difference in the temperature of the brickwork when running with a slight suction, say, 0·1 in. water column, and when running with a pressure within the furnace may cause all the difference between the success or failure of a furnace. The greater the load carried by the brickwork, the more likely it is to fail by plastic deformation. Fire bricks of the best quality ordinarily used in boiler settings, which have a fusing point somewhat higher than 3,100 degrees F., may show plastic deformation under a load of 20 lbs. per square inch at 2,000 to 2,200 degrees F. A reduction of the load to 10 lbs. per square inch will increase the temperature at which the

bricks begin to deform about 200 degrees F. As furnace temperatures of from 2,700 to 3,000 degrees F. exist with certain grades of fuel, it is apparent that care must be taken to cool the brickwork.

In order to keep the brickwork of the furnace at a somewhat lower temperature than the maximum existing in the furnace, the walls and arches should be heated on one side only. It is sometimes necessary to use double arches, one above the other, with a space for air ventilating and cooling between the arches. Battery walls which are built solid and which are heated on both sides must be thick enough to conduct the heat from the hotter to the cooler parts of the walls.

The absorption of radiant heat by the boiler tubes has a considerable effect on the maintenance of the furnace brickwork. In large coal and oil fired boilers for power plant service, the company ordinarily exposes at least two lines of tubes for their full length to the furnace in order to reduce the upkeep of the brickwork. For low grade fuel, such as wet wood or bagasse, the furnaces are arranged to build up the heat within the furnace to as high a temperature as possible in order to maintain good combustion. With other fuels, such as blast furnace gas, the brickwork near the burner is maintained at a high temperature to assist in igniting the gas in its initial burning, and the furnace is so arranged as to maintain the temperature high enough to burn all remaining gases so far as possible before the products of combustion strike the boiler tubes. In burning blast furnace gas, it is highly essential to obtain an intimate mixture of the gas and air at the burners. Burners where the air is admitted under a blast pressure are becoming more generally used, as well as automatic means for regulating the supply of air in a suitable proportion to the gas burned.

The larger furnaces in use to-day require special care in the design and the laying up of the brickwork. The Babcock & Wilcox Company usually builds the furnace walls entirely of fire brick, without red brick on the outside. A large wall tends to bulge inward toward the fire. Horizontal rows of bonding tile are held in place by cast iron pieces which engage the sides of the tiles and also engage buckstays outside the walls in such a way that the wall can expand in any direction in a generally vertical plane, whereas it is held in alignment and prevented from bulging either inward or outward. Another effective way is to incline the walls outward, making them rest against a steel framework.

In many instances air cooling of the walls is resorted to. Where the heated air is conveyed to the furnace, there is a double benefit

because in addition to assisting in the maintenance of the walls the heated air improves the combustion.

In many cases boiler tubes are placed on the furnace or fire side of the walls for cooling the walls, these tubes being connected so that there is a circulation to and from the steam and water drum of the boiler. The use of furnace wall cooling tubes has been growing and they give advantageous results in protecting the brickwork where the cooling effect on the furnace does not interfere with the combustion. The hotter the furnace, the better, as a rule, will be the combustion, although certain coals when fired on stokers may give trouble with an excessively hot furnace through the fusing of the ash and the matting down of the fuel bed. In the designs so far tested exposing more or less of the boiler surface to the direct radiant heat of the fire, with the stronger fuels, has a comparatively small influence on the efficiency. In general, the hotter the furnace can be carried with any particular arrangement, the higher will be the efficiency. Even where the combustion of the fuel is within a furnace shielded from direct radiation to the boiler tubes, a great proportion of heat is absorbed by the boiler in the form of radiant heat, because the walls of the setting, where the hot gases are conducted to the boiler, will radiate heat to the boiler. In a case where radiant heat is emitted from the hotter part of a fuel bed and there are colder parts of the fuel bed where excess air is admitted, or where excess air may be admitted at points where it does not pass through the fuel bed, a greater efficiency may be obtained by the use of a large amount of boiler heating surface exposed to the direct action of the radiant heat than is obtainable where the gases are mingled within the furnace and afterwards passed to the boiler. This is because the absorption of radiant heat varies as the fourth power of the absolute temperature, which makes it advantageous to absorb the radiant heat from the hot part of the fire before mingling the gases and reducing their general temperature.

The problem of employing furnace wall cooling tubes is a highly complex one, and the best arrangement can be obtained only by painstaking investigations and tests.

The way in which cooling tubes are connected to the boiler pressure parts must be carefully considered so as to provide proper circulation and avoid a water hammer on starting up, as well as to allow for the expansion of the tubes and the connections on being heated. Such cooling tubes should be used only with the cleanest of feed water, as they are usually the first to give trouble should a deposit collect on the inside.

The problem of overcoming difficulties with furnace brickwork has been a long and involved one. That progress has been made in this direction may be appreciated by considering the large furnaces in use to-day, which, should they have been proposed a comparatively few years ago, would have been regarded as impossible. After a problem is solved it may look to be an easy one, even though there may have been many failures on the road to success. Such is the case in the design of large furnaces, where the plant engineers and those responsible for installing the boilers deserve every credit for the part they have taken in solving the problem.

OPERATION OF BOILERS.

Higher class men are now employed in the boiler rooms of our large power plants. It is becoming appreciated more and more that, irrespective of how well a plant may be designed, the best results can be secured only when it is properly operated. There are still, however, glaring examples of inefficiency in this direction and often the simplest requirements of good practice are disregarded. Happily such cases are becoming less frequent and are ordinarily limited to the smaller plants. The trouble is seldom with the fireman, but is due to the fireman lacking the proper means to guide him in his work. In some cases it would seem that the fireman is expected to work by intuition rather than in accordance with any method or system. The importance of this feature is well appreciated in the best operated power plants, where the firemen are well instructed and the highest grade instruments are provided. Instruments for indicating and recording the amount of CO as well as the amount of CO_2 in the flue gases are now available, and these, combined with draft gauges thermometers, pyrometers and steam flow meters, are all necessary for obtaining the best results.

The fireman is human and cannot be blamed if he lacks interest when given a lot of arbitary instructions which he is supposed to follow like an automaton without knowing the results. Where he can see the results of his work and knows that his efforts are appreciated he will take an active interest. High-class instruments and apparatus alone will not insure success, if placed in the hands of an incapable man or one prejudiced against them. The engineer in charge of a boiler room can make or lose more for his employer than anyone else in the plant, and this is being more fully recognised and higher grade men are being employed for this position than formerly.

Automatic systems for controlling the combustion are often used

to advantage. Such systems regulate the air and draft and, in some cases, the quantity of fuel to meet changing load conditions.

In striving for higher and still higher capacities, trouble has been experienced with some grades of coal through slag adhering to the exterior of the boiler tubes to a degree that restricts or completely closes up portions of the passage-ways for the flow of the gases between the tubes. This is primarily a trouble due to combustion and occurs in its most severe form where unburned or partially burned fuel is carried over the outside of the tubes by the hot gases. The difficulty can be minimised by providing a large flow area for the gases on entering the spaces between the tubes which come nearest the furnace and employing a more open spacing for these tubes than for those in the rest of the boiler, the open spacing being secured by increasing either the horizontal or vertical spaces between the tubes. Placing the tubes in the two rows which come next the furnace, one directly over the other, often leads to a good arrangement. Access doors are also provided through which steam or air lances can be passed for removing the slag from the tubes. Steam soot blowers installed within the setting are sometimes used for minimising this difficulty. Where there is trouble from slag, much may sometimes be accomplished by changing the method of operating the stoker. In some instances a great deal of the trouble may come from the fire of a forced blast stoker breaking through at spots and projecting the slag upward. In the case of powdered coal, delayed combustion from insufficient drying of the coal or any cause that will allow flames to pass over the boiler tubes, will usually lead to slag troubles.

Where coal is burned on stokers, there is often trouble with clinker adhering to the walls of the furnace at the sides of the fuel bed. A remedy often applied is to introduce air through a number of openings in the wall, so as to cause the air to flow in a layer against the inner face of the wall. In the Babcock & Wilcox forced blast chain grate stokers, there are water boxes in the side walls, connected to the boiler circulation, as well as a water box at the rear of the stoker, which effectively overcome any troubles through clinker.

In burning powdered coal, the handling of the ash is important. In some earlier installations, there was trouble with ash and clinker fusing and solidifying at the bottom of the furnace into a mass which had to be broken out at intervals in a cold state, necessitating putting the boiler out of service. In the latest furnaces, this is overcome by cooling the ash before it strikes the furnace floor to a point where it will not form a fused mass.

More attention is being given to securing clean feed water. In many cases, the make-up water is distilled, this being done in such a way that the heat of condensation of the distilled water is returned to the system. The point has not yet been reached, however, where absolutely clean feed water is always available. Even with pure feed water there is always a chance for leakage at the condensers. Were it possible to obtain clean feed water at all times it would be unnecessary to provide for cleaning the interior of the boiler tubes, and with a closed water system there would be no trouble from the presence of air in the feed water and the problem of designing and operating boilers and economisers for power plant service would be greatly simplified. Again, with the present methods of fuel burning it is necessary to clean the outside of tubes, all of which leads to a construction different from what might be used were cleaning unnecessary. Steam is often used for process work and the like, and raw water fed to the boilers, and it is sometimes necessary to operate the boilers with the water at a high degree of concentration. This, however, rarely applies to a power plant built along modern lines.

BOILERS FOR HIGH PRESSURES AND HIGH TEMPERATURES.

When Mr. Frederick Sargent, who did so much in the development of power plants, was alive, he talked with the writer a number of times about boilers for high pressures. Mr. Sargent firmly believed that pressures considerably higher than those with which he was dealing would shortly be used. The Babcock & Wilcox Company decided that it would be advantageous to make experiments on a boiler provided with a forced circulation. The first boiler of the sort, which was constructed and tested about eight years ago, was purposely made in a form which it was believed would develop certain difficulties, in order to determine the principles involved. In this boiler the steam passed to a separating tank before entering the superheater, and the water was maintained at a given height in the tank by regulating the supply of feed water and at the same time allowing a small amount of water to be blown continuously from the tank and returned to the feed water. The name " Series Boiler " was applied to the apparatus. The second form of series boiler tested is shown in Fig. 1, where it was used in combination with a relatively small boiler having a steam-and-water drum. The combined unit consisted of a boiler having a natural circulation, with steam-and-water drum and 2-in. tubes, and a series boiler having 1-in. tubes. The surface of the series boiler was 3·7 times

that of the heating surface of the boiler with 2-in. tubes. The unit was a comparatively small one, having 187 square feet of tube surface in the boiler with the steam-and-water drum exposed to the hot gases, 51 square feet of superheater surface and 685 square feet of boiler and economiser surface in the section made of 1-in. tubes or 923 square feet of heating surface in all. The boiler was fired with oil fuel with a mechanical atomising burner and operated at 600 lb. gauge pressure, and was run at times to evaporate over 15 lb. of water per hour per square foot of total boiler and economiser surface. All parts were found to operate in an entirely satisfactory

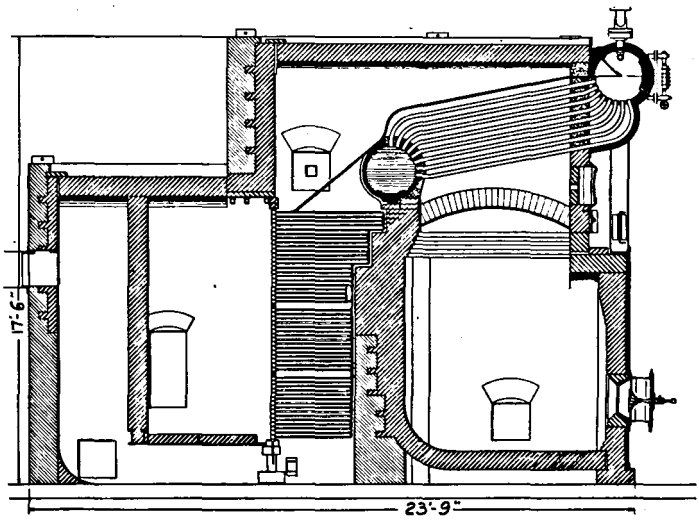


Fig. 1. One of the series boilers tested.

way. The boiler with 2-in. tubes having a natural circulation evaporated about 45 lb. of water per hour per square foot of heating surface in the high capacity tests.

It was originally intended to operate the series boiler shown in Fig. 1 without the element having the steam-and-water drum. The Babcock & Wilcox Company is now making tests with the series boiler proper without a steam-and-water drum, and intends to exhaust the possibilities of using an arrangement of the sort.

The boilers the Company is building for 1,200 lb. working pressure are of the Babcock & Wilcox type. In developing a boiler for this pressure for power plant service the Company had before it the results secured in the tests of the series boiler, as well as its experiments with the use of 1-in. tubes in a great number of marine boilers.

It was finally decided to use tubes 2-in. in diameter which is a convenient size for internal cleaning, and to employ a steam-and-water drum to provide a reserve water capacity, which is highly desirable in starting up a boiler and in operating a boiler under variable loads. The possibilities of operating without a steam-and-water drum were carefully considered. This would, of course, make it necessary to provide feed pumps having 100 per cent. reliability. The relative merits and cost of the single steam-and-water-drum for providing reserve water capacity as compared to

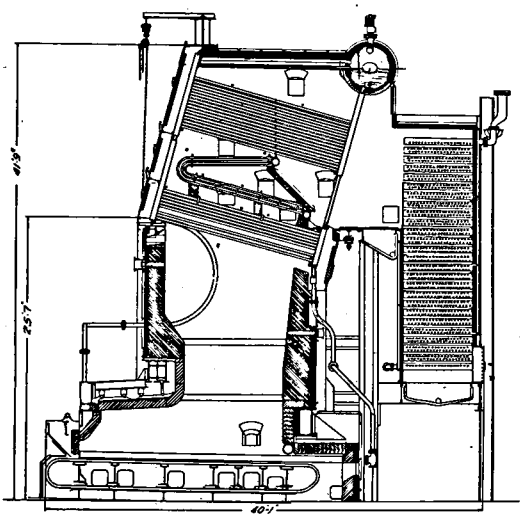


Fig. 2. B. & W. boiler, for 650 lb. working pressure, fired with B. & W. forced draft blast chain grate stoker, with interdeck superheater and economiser, Crawford Ave. Station, Commonwealth Edison Co., Chicago, Ill.

a multiplicity of drums or tubes was also considered, and it was finally agreed that a boiler with 2-in. tubes and with a single steam-and-water drum was the best. This boiler will be described later on.

The maximum temperature of superheated steam for operating steam turbines in power plant practice is 700 to 750 degrees F. In either case some excess above the average operating temperature is permissible. Unless means are provided for regulating the superheat, there is bound to be some variation with a superheater placed within the setting, due to changes in the conditions of firing or irregularities in the feeding of the water to the boilers, aside from any

variations that may come through a change in the capacity at which the boiler is operated,

In some cases means of varying the flow of the hot gases over the superheaters are provided in order to regulate the superheat. A long time ago the company developed an apparatus for automatically regulating the superheat by spraying water into the superheated steam, and was able to hold the superheat within a few degrees of a set figure. There has been little demand for an automatic apparatus of the sort and it has been used in only a few cases. De-superheaters, in which the admission of water is hand adjusted, have been successfully used for a number of years for reducing the superheat in steam used for large piston engines that are run only for short periods of time in peak load service, these readily handling 400,000 lb. of steam per hour and reducing the superheat from about 125 degrees F. to 5 degrees F. A modification of the device has also been successfully used for automatically limiting the superheat under emergency conditions in an independently fired superheater.

TYPICAL RECENT INSTALLATIONS OF STATIONARY BOILERS.

Fig. 2 is a side view of boilers at the Crawford Avenue Station of the Commonwealth Edison Company of Chicago. The boilers are designed for a working pressure of 650 lb. gauge and will be operated to give a pressure at the turbine throttle of 550 lb. gauge and a temperature of superheated steam of 725 degrees F. There is a lower bank of eight rows of 3 ¼-in. tubes 15 ft. long exposed for their full length above the furnace and an upper bank of seventeen rows of 2-in. tubes over which the gases make two passes. The superheater is placed between the two banks of tubes. The gases pass between nipples connecting the upper and lower parts of the downtake headers and flow downward over an economiser. The headers are of wrought steel and the tubes are so spaced that there are diagonal lanes between all of the tubes through which the exterior of the tubes may be thoroughly cleaned. The economisers are of the counter-flow type already described. The feed water enters the economisers at about 210 degrees F. The heating surface of the boiler 16,615 square feet and of the economiser 11,054 square feet or 66·6 per cent. of the boiler heating surface. The boiler is fired with a Babcock & Wilcox forced blast chain grate stoker 24 ft. wide and 20 ft. 6-in. long. It is proposed to evaporate 150,000 lb. of water per hour as a maximum, corresponding to 9 lb. per hour per square foot of boiler heating surface. The steam is

re-superheated by passing it from the steam turbine at 135 lb. per square inch absolute pressure to a re-superheater boiler unit of special design, where its temperature is raised to 725 degrees F. This re-superheater is described by Mr. Wm. S. Monroe, of

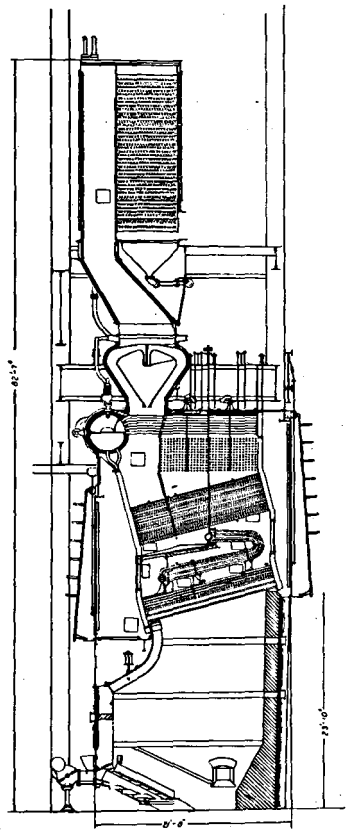


Fig. 3. B. & W. boiler for 1,200 lb. working pressure, fired with underfeed stoker with interdeck superheater, reheater, economiser, and Carty cinder catcher; Edison Electric Illuminating Co., Weymouth Station, Boston, Mass.

Sargent & Lundy, in his paper for this Conference entitled "The Use of Steam at High Pressures and High Temperatures in Central Stations."*

Fig. 3 is a side view of the boiler for 1,200 lb. working pressure

*See page 1441.

at the Weymouth Station of the Edison Electric Illuminating Company of Boston. The steam-and-water drum is of seamless forged steel 48-in. int. dia. and 4-in. thick. The headers are of wrought steel with a lower bank of seven rows of 2-in. tubes and an upper bank having fifteen rows of 2-in. tubes, the tubes being 15 ft. long and staggered in the same way as in the boilers for 650 lb. working pressure. A primary superheater is placed between the two banks of boiler tubes to superheat the steam to a temperature of 700 degrees F. The steam at 700 degrees F. will operate a high pressure steam turbine, the exhaust from which will pass at 360 lb. per square inch gauge pressure to a reheater superheater placed above the boiler tubes, as shown in the figure. The steam will be reheated to 700 degrees F. in the reheater superheater and afterwards discharged into the piping leading to the main steam turbine. A damper is provided, as shown, which is raised and lowered so as to cause more or less of the hot gases to flow over the reheater superheater to regulate the amount of superheat.

The ends of the horizontal circulating tubes which run from the uptake headers to the steam-and-water drum are bent so as to make them enter the drum in circumferential lines which are twice as far apart as the distance between the headers. This greatly increases the efficiency of the ligaments between the tube holes. The steel in the drum conforms closely to that specified in the American Society of Mechanical Engineers Boiler Code, but has a somewhat high minimum tensile strength. The maximum allowable stress employed in computing the strength of the shell is taken at 11,000 lb. per square inch, based on the Barlow formula, where the outer diameter of the shell is used, thereby corresponding to the figure specified in the A.S.M.E. Code for a steel of a lower tensile strength and giving a correspondingly higher factor of safety. In other respects the boiler conforms to the rules of the A.S.M.E. Code.

The counterflow economiser is made up of 2-in. seamless steel tubes; it is built so as to be subjected to the full working pressure of the boiler plus the pressure required for passing the water through the feed valve which comes between the economiser and the boiler. The heating surface of the boiler is 15,732 square feet and of the economiser 11,110 square feet, or 70·6 per cent. of the boiler heating surface. It is proposed to evaporate 143,000 lb. of water per hour as a maximum corresponding to 9·1 lb. per hour per square foot of boiler heating surface. A Carty cinder catcher is placed between the boiler and the economiser; this consists of a number of V-shaped

gas passages between the elements. The separator elements have open ends and open bottoms and the cinders are thrown out through being projected downwardly from the narrow ends of the separator elements and through turning the gases under the sides of the

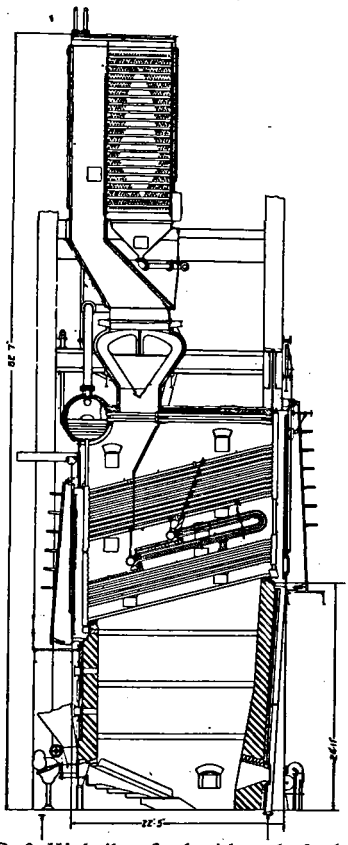


Fig. 4. B. & W. boiler, fired with underfeed stoker with interdeck superheater economiser and Carty cinder catcher; Edison Electric Illuminating Co., Weymouth Station, Boston, Mass.

separator elements into the upwardly flowing streams of gas which come between the elements.

Fig. 4 shows a Babcock & Wilcox boiler with 17 rows of 4-in. tubes, provided with an interdeck superheater, counterflow economiser and Carty cinder catcher installed at the Weymouth Station of the Edison Electric Illuminating Company of Boston. The boilers are

built for a working pressure of 385 lb. per square inch and will be operated at a pressure to give 360 lb. gauge pressure at the turbine throttle. The heating surface of the boiler is 19,743 square feet, and of the ecomoniser 11,110 square feet, or 56·2 per cent. of the boiler heating surface. It is proposed to evaporate 193,000 lb. of

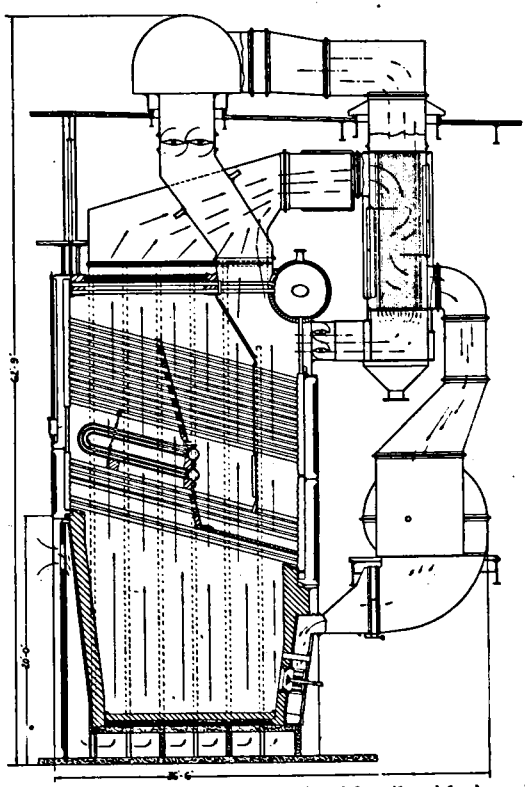


Fig. 5. B. & W. boiler, fired with oil with interdeck superheater, air cooled walls and air heater; Houston Lighting and Pr. Co., Houston, Texas.

water per hour as a maximum, corresponding to 9·8 lb. per hour per square foot of boiler heating surface.

Fig. 5 shows an oil fired Babcock & Wilcox boiler with 20 rows of 4-in. tubes with an interdeck superheater fitted with an air heater which was installed by the Houston Lighting & Power Company, Houston, Texas. The air for combustion first flows through ducts outside the furnace walls, thence through the air heater to the oil

burners. The boiler has 19,884 square feet of heating surface and the air heater has 11,660 square feet of heating surface, which is 59 per cent. of the surface of the boiler. It is proposed to evaporate 150,000 lb. of steam per hour as a maximum, corresponding to an

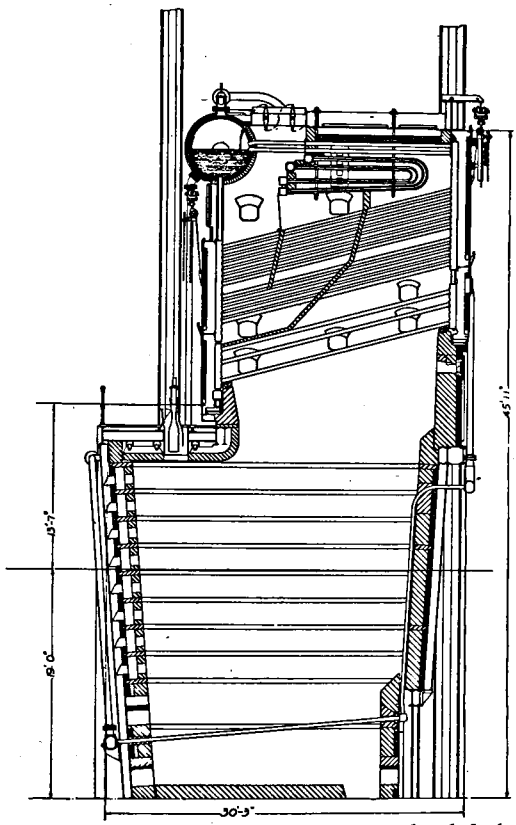


Fig. 6. B. & W. boiler, fired with powdered fuel with interposed type superheater, air cooled walls, water screen and furnace wall cooling tubes; West Penn Power Co., Springdale, Pa.

evaporation of a little over 7½-lb. of water per hour per square foot of heating surface.

Fig. 6 shows a Babcock & Wilcox boiler fired with powdered fuel at the plant of the West Penn Power Company, Springdale, Pa. The boiler is fitted with the Combustion Engineering Corporation's powdered fuel burning equipment. The air for combustion passes

through ducts in the side walls as well as beneath the furnace. A so-called water screen made up of inclined tubes is provided near the bottom of the furnace for cooling the ash and slag which falls between the tubes to a temperature at which they will not fuse

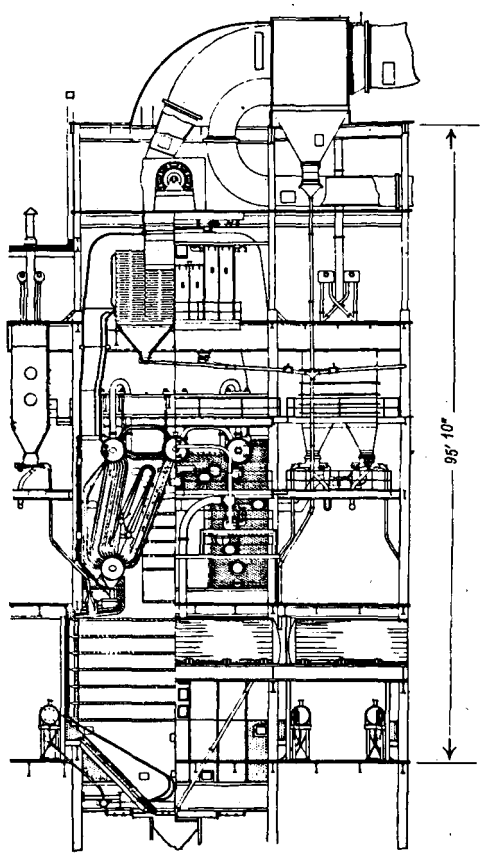


Fig. 7. Class W Stirling boiler, fired with powdered coal, with superheater, economiser and Cottrell dust precipitator; Detroit Edison Co.

together at the bottom of the furnace. The water screen tubes are connected at their ends to horizontal headers, the lowermost header being connected to the water space of the steam and water drum and the uppermost header to vertically extending tubes placed against the rear wall of the furnace. The vertically extending tubes

increase the circulation through the water screen tubes and assist in cooling the furnace to a point that will minimise trouble with the brickwork. The steam-and-water discharged from the water screen and furnace wall cooling tubes pass through a connection outside of the setting to the steam-and-water drum. The surface of the boiler is 15,326 square feet, the surface of that part of the

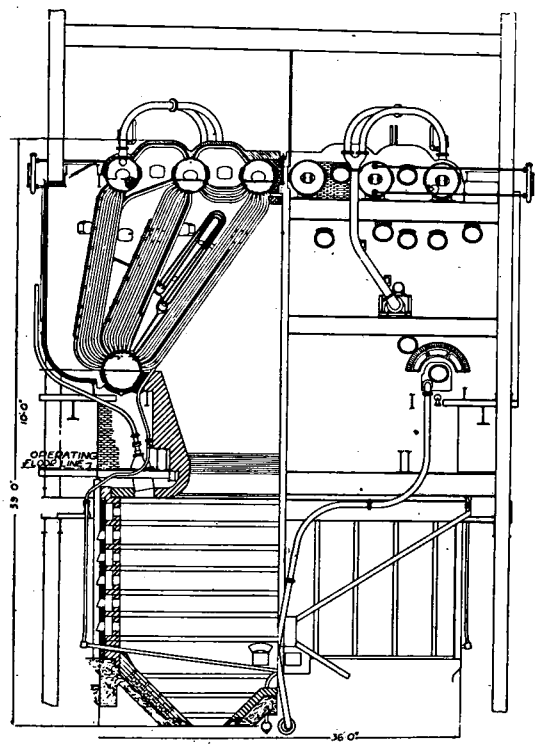


Fig. 8. Class XIII. Stirling boilers, with superheaters in twin setting, fired with powdered fuel. Cleveland Elec. Illuminating Co., Lakeshore Station, Cleveland, Ohio.

water screen tubes and rear wall cooling tubes exposed to the furnace gases 500 square feet. The boiler has been operated to evaporate about 190,000 lb. of water per hour as a maximum corresponding to over 12 lb. per hour per square foot of heating surface.

Fig. 7 shows a side view of a Class W Stirling boiler, with economisers installed at the Trenton Channel plant of the Detroit

Edison Company, for firing with powdered fuel. Instead of connecting the water screen tubes into the circulation of the main boiler they are made to form two separate small boilers. The boiler is built for a working pressure of 416 lb. per square inch and has a heating surface of 29,000 square feet. The combined heating surface of the two water screen boilers exposed to the direct heat of the furnace is 1,190 square feet. There are two economisers, each having

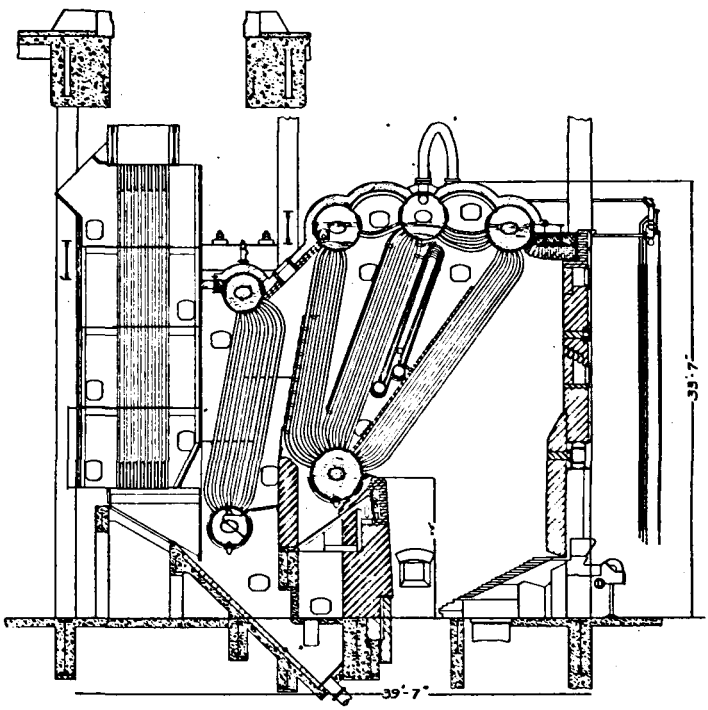


Fig. 9. Stirling boiler, fired with underfeed stoker with superheater, economiser and air heater; Philadelphia Electric Co., Chester Station, Philadelphia, Pa.

9,492 square feet of heating surface, the total surface corresponding to 65·5 per cent. of the boiler heating surface. The economisers are of the counterflow type divided to provide for both an upward and downward flow of the gases over the tubes. It is proposed to evaporate about 300,000 lb. of water per hour as a maximum, which corresponds to an evaporation of 10·3 lb. per hour per square foot of heating surface.

Fig. 8 is a side view of two Stirling boilers in a twin setting to form a single unit fired with powdered fuel at the Lake Shore Station of the Cleveland Electric Illuminating Company, Cleveland, Ohio. Each of the two boilers is fed independently, there being no cross-connection below the water line. The water screen tubes are connected into the boiler circulation as shown in the figure. The combined heating surface of the two boilers is 30,592 square feet and it is proposed to operate each unit at an evaporation of some

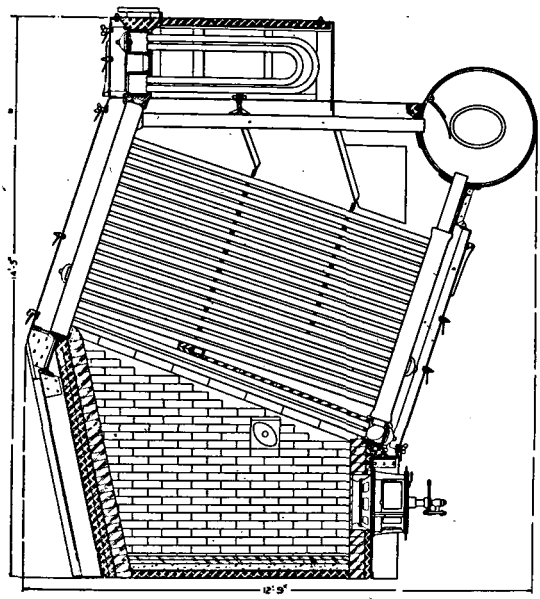


Fig. 10. Babcock & Wilcox marine boiler of battleship type, with superheater and B. & W. oil burners, used by U.S. Navy.

what over 280,000 lb. of steam per hour, corresponding to 9·1 lb. per hour per square foot of heating surface.

Fig. 9 shows a Stirling boiler with economiser and air heater fired with an underfeed stoker at the Chester Station of the Philadelphia Electric Company, Philadelphia, Pa. The heating surface of the boiler is 14,217 square feet that of the economiser 5,250 square feet, or 37 per cent. of the boiler, and that of the air heater 22,076 square feet, or 155 per cent. of the boiler. It is proposed to evaporate 145,000 lb. of water per hour as a maximum, corresponding to 10·21b. per hour per square foot of heating surface. One of the new boilers

will have no economiser and will be fitted with an air heater having 50,276 square feet of heating surface, corresponding to 354 per cent. of the boiler heating surface in order to determine the possibilities of such an arrangement.

TYPICAL INSTALLATIONS OF MARINE BOILERS.

Fig. 10 shows a marine boiler of the battleship type, of which a great number have been installed by the United States Navy. The boiler has 2-in. tubes throughout, the lower tubes being given a

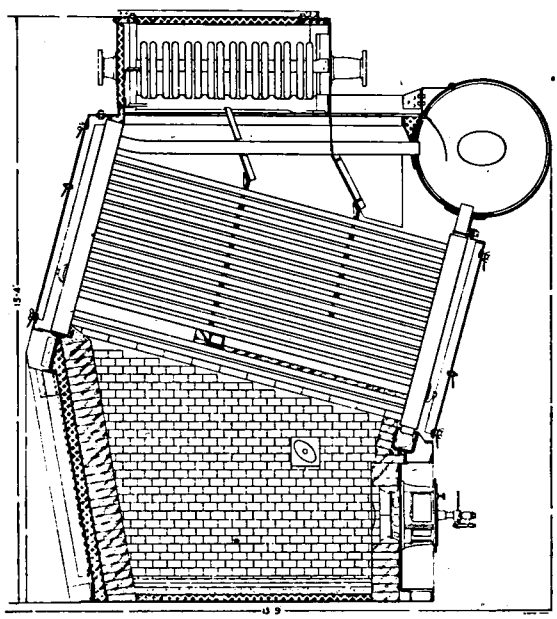


Fig. 11. Babcock & Wilcox marine boiler, with superheater and B. & W. oil burners; used by U.S. Merchant Marine.

slightly greater inclination to the horizontal than the upper tubes as shown. These boilers have tubes 8 or 9 ft. long and the largest units contain about 6,200 square feet of heating surface. With mechanical atomising oil fired boilers as shown in the figure, about 1·25 lb. of oil can be burned per square foot of heating surface per hour, which results in a maximum evaporation in the largest units of 100,000 lb. per hour.

The marine boiler shown in Fig. 11 is that used by the U.S.

Merchant Marine and is in general similar to the boiler of the battleship type shown in Fig. 10, except for the arrangement of the superheater and of the furnace roof tubes, which are made 4-in. in diameter instead of 2-in. diameter. This can be operated at the same rate of capacity per square foot of surface as those of the battleship type.

Fig. 12 shows an Express type boiler, a great number of which are used by the U.S. Government in torpedo boat destroyers. The

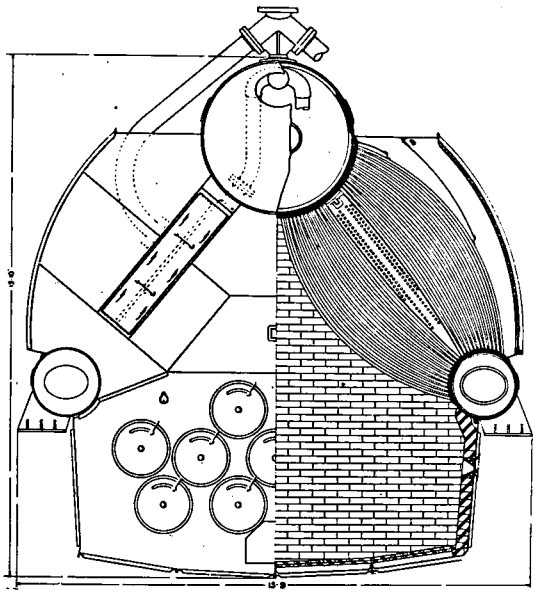


Fig. 12. Babcock & Wilcox express type marine boiler, with superheater and B. & W. oil burners; used by U.S. Navy.

particular boiler shown is at the U.S. Navy Fuel Oil Testing Plant at Philadelphia, Pa., and is fitted with superheaters. There are no superheaters in the boilers of the type so far installed in the vessels of the U.S. Navy, although boilers were actually built during the war with superheaters for the contemplated battleship " IOWA " and the projected battle cruisers, work on which was discontinued after the armistice, and these same boilers will be used in the aeroplane carriers now building. In the test boiler at the U.S. Navy Fuel Oil Testing Plant, which had 7,565 square feet of heating surface, over 1½ lb. of oil were burned per square foot of heating surface per hour

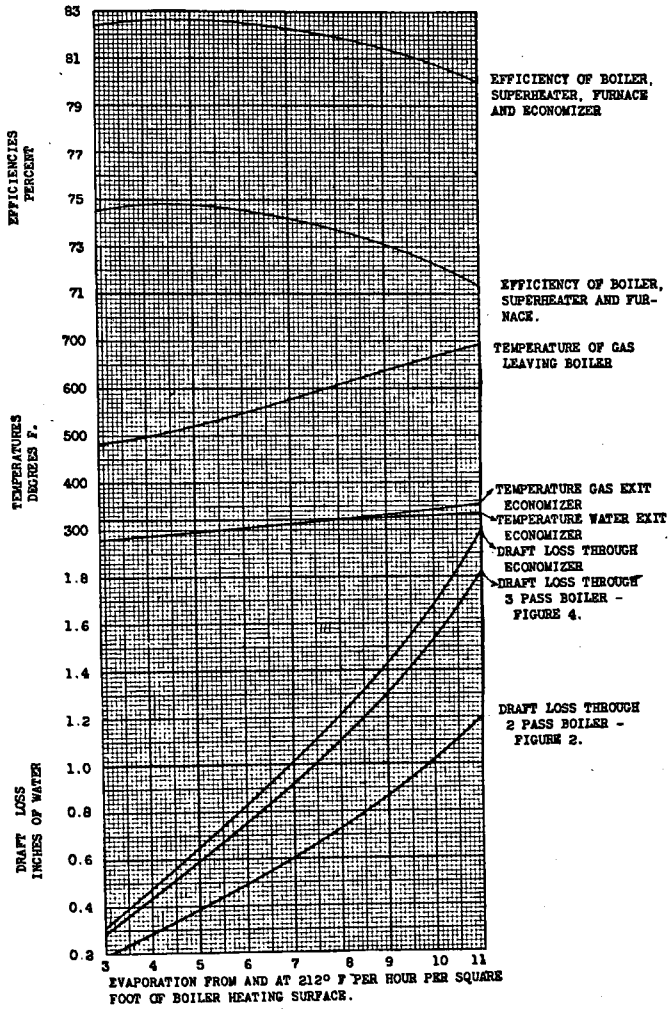


Fig. 13.

Performances of boilers shown in Fig. 2 and Fig. 4 with a Western bituminous coal fired on a Babcock & Wilcox forced blast chain grate stoker. Also performances with economisers having heating surfaces equal to 66.6 per cent. that of the boiler.

and over 153,000 lb. of water were evaporated per hour, corresponding to 20·3 lb. per hour per square foot of heating surface. By comparing the maximum rates of evaporation for the marine boilers with those given for stationary boilers, and by also comparing

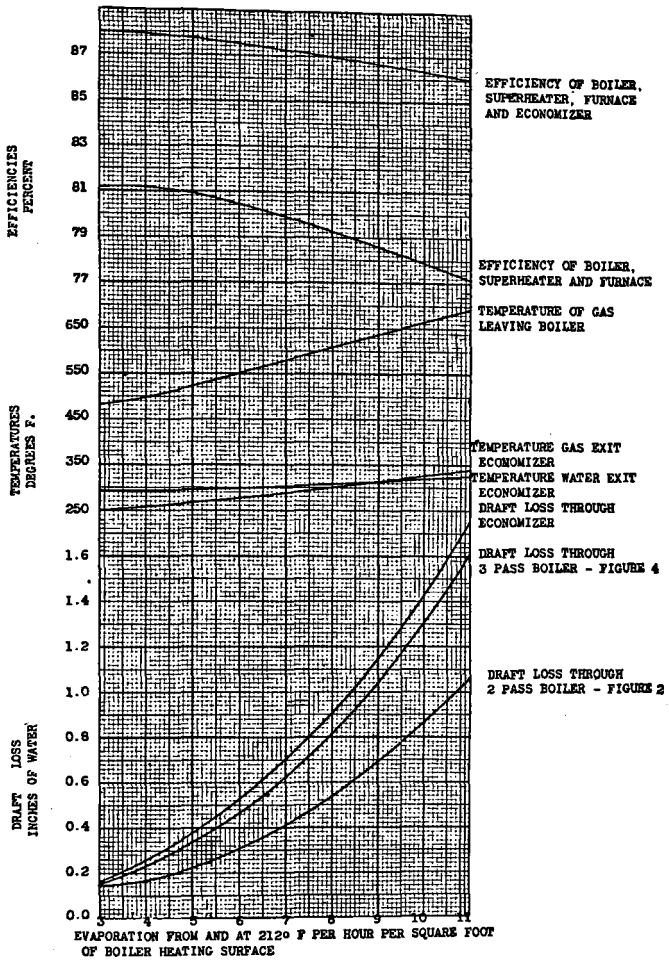


Fig. 14.

Performances of boilers shown in Fig. 2 and Fig. 4 with an Eastern semi-bituminous coal fired on an underfeed stoker. Also performances with economisers having heating surfaces equal to 66.6 per cent. that of the boilers.

the sizes of the boilers, the difference between marine and stationary practice can be appreciated. The efficiencies obtained in stationary and marine practice are given in the curves which follow.

EFFICIENCIES SECURED IN MODERN INSTALLATIONS.

It is difficult to give figures which convey a correct idea of the relative efficiency of different boilers. Coals vary so much in their characteristics that one grade may require an entirely different method of firing than another and it may be possible to obtain a much higher efficiency in one case than in the other. There are still wider variations when it comes to fuels other than coal. Even with coals of approximately the same analyses there may be considerable difference in the efficiency due to the way in which the coal burns on the grate. In comparing the efficiencies of different arrangements a better idea can be obtained by working out the results to be expected from the same coal than by comparing tests made on different coals.

The curves given in Figs. 13 to 16, which are based on the results secured in a great number of tests of stationary boilers, are therefore presented.

The two-pass Babcock & Wilcox boiler shown in Fig. 2, and the three-pass Babcock & Wilcox boiler shown in Fig. 4, will give about the same flue gas temperatures at a given rating when fired in the same way with the same fuel. Curves are given in Figs. 13 to 15 which apply to either of the boilers for a working pressure of 375 lb. per square inch. Curves are also given which apply to either boiler fitted with an economiser of the same proportions as the one shown in Fig. 2, namely, one that is 50 rows of tubes in height and in which the heating surface is 66·6 per cent. that of the boiler with the feed water entering the economiser at 210 degrees F. If the two-pass boiler shown in Fig. 2 is operated at 600 lb. per square inch., the boiler efficiency, with Eastern semi-bituminous coal fired on an underfeed stoker, when evaporating 9 lb. per hour per square foot of heating surface, would be 77·4 per cent as compared with 78·6 per cent. with a steam pressure of 375 lb. per square inch, and the combined efficiency of the boiler and economiser would be 86·2 per cent. as compared with 86·6 per cent.

Fig. 13 shows the results to be expected with a Western bituminous coal fired on a Babcock & Wilcox forced blast chain grate stoker, the results applying to each boiler except for the draft loss, which is about 40 per cent. higher for the three-pass boiler than for the two-pass boiler. The results shown in Fig. 14 are for an Eastern semi-bituminous coal fired on an underfeed stoker. Fig. 15 shows the efficiencies to be expected for the Western bituminous coal taken from Fig. 13 and for the Eastern semi-bituminous coal taken from

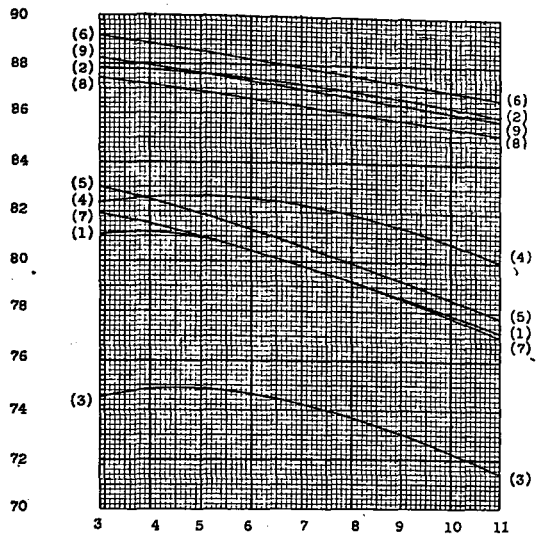


Fig. 15.

Evaporation from and at 212°F. per square foot of boiler heating surface.

Comparison of efficiencies of boilers shown in Fig. 2 and Fig. 4. for Western bituminous and Eastern semi-bituminous coal fired on stokers and for oil fuel and powdered coal. Also efficiencies with economisers having heating surfaces equal to 66.6 per cent. that of the boilers.

(1) Efficiency of boiler, superheater and furnace fired with Eastern semi-bituminous coal on an underfeed stoker.

(2) Efficiency of boiler, superheater, furnace and economiser fired as for Curve 1.

(3) Efficiency of boiler, superheater and furnace fired with Western bituminous coal on chain grate stoker.

(4) Efficiency of boiler, superheater, furnace and economiser fired as for Curve 3.

(5) Efficiency of boiler, superheater and furnace fired with powdered fuel—Eastern semi-bituminous.

(6) Efficiency of boiler, superheater, furnace and economiser fired as for Curve 5.

(7) Efficiency of boiler, superheater and furnace fired with oil and powdered coal—Western bituminous.

(8) Efficiency of boiler, superheater, furnace and economiser fired with oil.

(9) Efficiency of boiler, superheater, furnace and economiser with powdered coal—Western bituminous.

Fig. 14 and the efficiencies to be expected when burning oil and powdered Eastern semi-bituminous coal.

Fig. 16 shows the efficiencies to be expected for the 20-high Babcock & Wilcox boiler shown in Fig. 5 when run without an air heater for the various fuels and the draft losses, for the Western

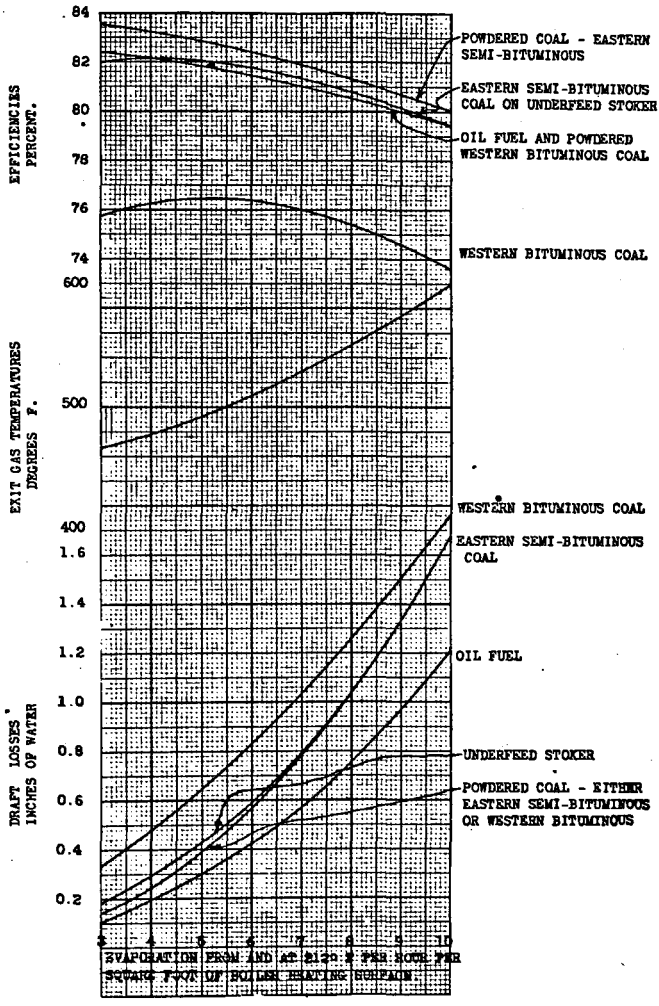


Fig. 16. Performances of boiler shown in Fig. 5 for Western bituminous and Eastern semi-bituminous coal fired on stokers and for oil fuel and powdered coal.

bituminous coal fired on a Babcock & Wilcox forced blast chain grate stoker and an Eastern semi-bituminous coal fired on an underfeed stoker, for the same conditions as in Fig. 15. When run with the air heater the efficiencies would be about 3 per cent. higher on the scale shown in the figure.

The curves in Figs. 15 and 16 for the efficiencies of the boiler, superheater and furnace with oil fuel and with powdered Western bituminous coal came so close together that they were combined.

The efficiencies for powdered Eastern semi-bituminous coal shown by the curves are about 1 per cent. higher than for the same coal fired on an underfeed stoker. The percentage of CO_2 in the flue gases for the underfeed stoker was taken at 12½ per cent. at the lowest load and 14½ per cent. at the most favourable loads. With the underfeed stoker the percentage of combustible in the ash was taken at 6 per cent. at the lowest load and 11 per cent. at the highest load.

The efficiency shown for powdered Western bituminous coal is about 5 per cent. higher than for the same coal fired on a forced blast chain grate stoker. No deduction was made for the fuel required to dry the coal to a point where it would contain 4 per cent. of moisture, which if included would reduce the difference in the efficiencies to about 3½ per cent. The CO_2 in the flue gases for the forced blast chain grate stoker, was taken at about 10 per cent. at the lowest load and somewhat over 14 per cent. at the highest load. The combustible in the ash was taken at 6 per cent. at the lowest load and 20 per cent. at the highest load.

For the powdered fuel the CO_2 was taken at the uniform figure of 14½ per cent. The radiation and unaccounted-for losses were taken at 3½ per cent. in all cases.

The analyses of the Western bituminous coal, of the Eastern semi-bituminous coal, and of the oil, used in working up the curves, are as follows :—

	Western Bituminous Coal. per cent.	Eastern Semi-bituminous Coal. per cent.	Oil. per cent.
Carbon ...	58·53	81·32	83·15
Hydrogen ...	4·99	4·37	10·54
Sulphur ...	2·87	·53	4·14
Nitrogen ...	1·24	1·54	·73
Oxygen ...	5·49	2·91	1·20
Moisture ...	15·91	3·33	·24
Ash ...	10·97	6·00	—
B.T.U. as fired	10765	14210	18000

The heat values given for the coals are the high values where no deduction is made for the latent heat of the water vapor formed in

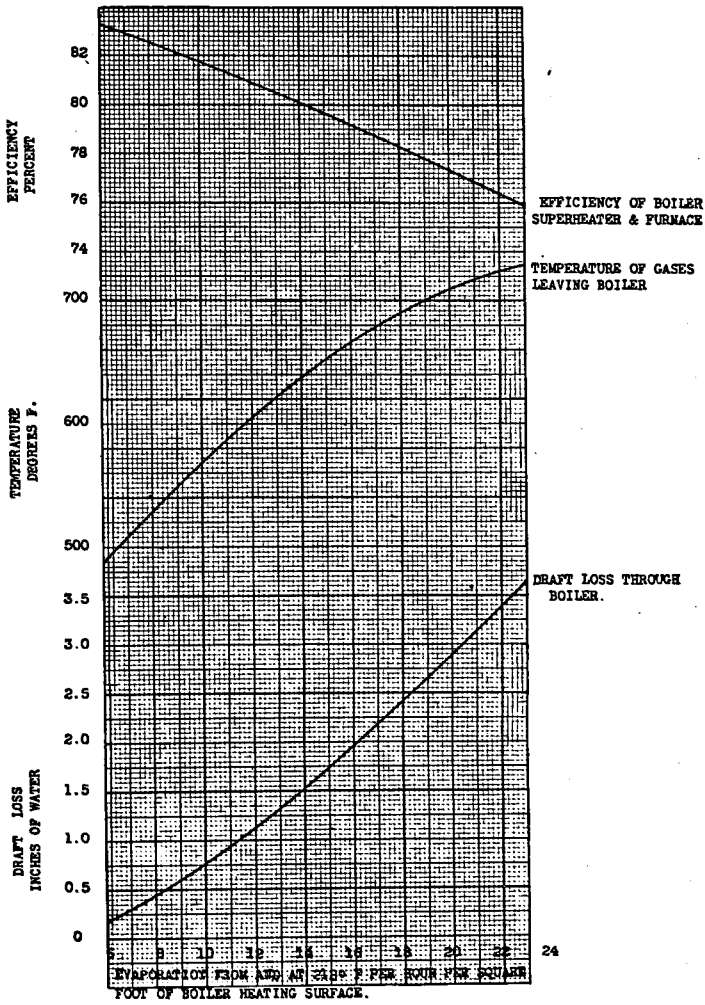


Fig. 17. Performance of Babcock & Wilcox express type of marine boiler shown in Fig. 12 with oil fuel.

burning the hydrogen component and the efficiencies are based on the high heat values.

The temperature of the gases leaving the boiler at different rates of evaporation are taken the same for all of the fuels, tests having

indicated that any difference due to using one or the other of the particular fuels considered will come within the usual variation of test results. Any delayed combustion between the boiler tubes will greatly affect the flue gas temperature and the figures given are on the basis of average results secured in actual tests. The temperatures will vary one way and the other from those shown by the curves, depending on the thoroughness with which the combustion is completed within the furnace chamber.

The performance of the Express type of marine boiler shown in Fig. 12, as obtained in tests made by the U.S. Navy Department at the U.S. Fuel Oil Testing Plant, Philadelphia, Pa., with the boiler run at about 295 lb. per square inch working pressure and about 50 degrees F. superheat, are given in Fig. 17. It will be noted that the boiler was operated at considerably higher capacities than in stationary practice and that the efficiencies are high irrespective of the smallness of the furnace and compact arrangement of the boiler.

COMPARISON OF POWER PLANT BOILERS OF 20 YEARS AGO WITH THOSE OF TO-DAY.

	20 years ago.	To-day.
Heating surface, average	2,500	12,000
,, ,, largest single boiler...	6,040	29,000
,, ,, largest single unit*	6,040	30,590
Working pressure in lb. per square inch	225	350 to 650 &1,200
Total temperature superheated steam, deg. F. Max....	550	700 to 750
Maximum rate of evaporation lbs. per sq. ft. per hour	5	8 to 15
,, ,, per boiler	30,000	300,000
Furnace volume in cu. ft. for each 10 sq. ft. of heating surface	0·5 to 1·0	2 to 8
Volume of boiler setting for largest boilers, cu. ft. ...	7,650	90,000
Height from bottom of walls of setting to centre steam and water drum for largest boilers, ft.	19	55
Boiler surface installed per max. kW. capacity, sq. ft.	7	1·5

*By a single unit is meant two boilers set over the same furnace.

STEAM GENERATION

RÉSUMÉ.

Le rapport décrit la pratique de la compagnie avec laquelle l'auteur est associé et qui représente d'une manière générale la pratique courante aux Etats Unis. La Compagnie a eu à exécuter des travaux dans la majorité des installations récentes les plus importantes et tout ce qui est contenu dans ce rapport est le résultat de son expérience et de ses travaux de recherche. Le sujet des hautes pressions de vapeur est examiné tout particulièrement, en raison du grand intérêt qu'il présente par sa relation avec le problème permettant d'obtenir des rendements plus élevés dans les stations centrales et aussi par suite des études importantes que la Compagnie a fait sur ce sujet. Il traite des chaudières fixes et de leurs surchauffeurs, économiseurs et réchauffeurs d'air et comprend suffisamment de renseignements sur les chaudières marines pour permettre de comparer certains points des installations fixes et marines.

Les points portant à la fois sur la puissance et sur le rendement sont discutés. La construction des foyers de grande capacité utilisés dans la pratique Américaine est traitée avec beaucoup de détails, y compris les parois refroidies par l'air et l'utilisation de tubes de chaudières pour refroidir les parois des foyers. Il y a une section sur l'exploitation des chaudières qui comprend par example les analyses des gaz des carneaux, l'utilisation des instruments et des appareils pour guider le chauffeur et signaler les difficultés que l'on peut rencontrer dues aux scories et au clinker.

Une attention particulière est donnée à la construction des chaudières pour hautes pressions et degrés de surchauffe élévés. Une description est faite d'une chaudière à circulation forcée, dénommée " Chaudière en série " sur laquelle des essais ont été effectués, on donne les raisons pour adopter ce qui est pratiquement une forme normale de chaudière avec des tubes de 2 pouces de diamètre et pour une pression de fonctionnement de 1,200 lb. par pouce carré (85 kilos par centimètre carré). Cette chaudière à haute pression est une unité commerciale de dimension courante, ayant un tambour de vapeur et d'eau de construction forgée et sans joints, avec un diamètre intérieur de 48 pouces et disposé pour évaporer 150,000 lbs. de vapeur par heure comme maximum.

Un nombre de chaudières récemment installées pour des services de station centrale sont décrites et des sections montrent les vues de coté de ces chaudières avec leurs surchauffeurs, économiseurs, réchauffeurs d'air et arrête-escarbilles, ainsi que des courbes donnant les caractéristiques de fonctionnement de différentes chaudières avec des combustibles variés.

THE USE OF STEAM AT HIGH PRESSURES AND HIGH TEMPERATURES IN CENTRAL STATIONS

WM. S. MONROE

The production of mechanical power from steam really began with the work of James Watt about 1767. For a century before that time such men as Savery, Papin and Newcomen had developed steam engines of various kinds for pumping water, but these were in the nature of independent experiments, and it was the genius and enterprise of Watt that developed the steam engine to a point where it became what we, in this day, would call a commercial undertaking.

About 1774 Watt became associated with Matthew Boulton, a prominent manufacturer, of Birmingham, and the firm of Boulton and Watt became the first practical engine builders of the world, and for half a century they were the leaders in the industry. It is interesting to us in the United States that it was a Boulton and Watt engine which ran Fulton's first steamboat, the "Clermont," that steamed up the Hudson River in 1807.

Watt was a thorough scientist and also an idealist. He was probably the first of the early experimenters on steam engines who had a vision of the value to mankind of the production of mechanical power from heat. He undoubtedly knew of the power in steam at high pressures, but he was too conservative to experiment much in that direction. The firm of Boulton and Watt confined themselves exclusively to engines operating on steam at atmospheric pressure, or a little above, and depended on the condenser to develop power from the low pressure steam. It is a matter of record that during Watt's lifetime, one of the successors of Newcomen built an engine to run on 120 pounds pressure (8.4 kg. per sq. cm.) but Boulton and Watt considered this a most hazardous undertaking, and made an effort to have Parliament pass a law preventing the use of steam at high pressures.

The rapid development of the steam engine during the first half of the nineteenth century is a matter of common knowledge.

but commercial steam pressures increased very slowly, although several experiments were made with pressures of 100 pounds per sq. in. (7.0 kg. per sq. cm.) or more. The first steamship to cross the Atlantic, the "Savannah," in 1819, used steam at 2½ pounds gauge pressure (0.175 kg. per sq. cm.). The steamship "Britannia," in 1840, operated at 12 pounds (0.84 kg. per sq. cm.), and as late as 1858 the steamship "Great Eastern," the marvel for a quarter of a century, ran on only 24 pounds pressure (1.68 kg. per sq. cm.) In 1876, at the United States Centennial Exposition at Philadelphia, the great Corliss engine, the largest engine built up to that time, which developed about 2,000 indicated horse-power and furnished power for all the machinery exhibits, ran on steam at 30 pounds gauge pressure (2.1 kg. per sq. cm.). Locomotive practice, however, had run to higher pressures. The locomotive engine always has been, and unfortunately is even in this day, a non-condensing engine. At the start of locomotive development Stevenson's famous "Rocket," in 1829, developed 50 pounds pressure (3.5 kg. per sq. cm.) on its boiler, and about 1870 a pressure of 100 pounds (7.0 kg. per sq. cm.) was common on locomotives.

Watt doubtless had an intuitive understanding of the relation between heat and work, but the steam engine had been in practical use for over half a century before that relation was clearly defined. In 1824 the French physicist, Sadi Carnot, began the modern science of thermo-dynamics, and developed the famous "Carnot Cycle" to represent the operation of the theoretical heat engine. This diagram, however, illustrated a purely theoretical engine, the most efficient possible, and applied to a heat engine operating on a perfect gas rather than to a steam engine. It was not until 1843 that James Prescott Joule definitely established that heat is a form of energy, and brought out the theory of "the indestructibility of energy," and made his famous determinations as to the mechanical equivalent of heat. Some years later, in 1851, Prof. William John Rankine modified the Carnot Cycle and formulated the one which bears his name, and which ever since has been used as the basis from which to compute the efficiency of energy transformation in steam engines and steam turbines.

A little more than a century after Watt began his work on steam engines appeared the first practical steam turbines. During the development of the steam engine, a number of turbines were built and experiments conducted on them both in Europe and

in America, and it is well to bear in mind that one of the earliest known forms of a steam prime mover was a reaction turbine, made by Hero, of Alexandria, about 120 B.C. In 1883, Dr. Carl Gustaf Patrik de Laval, of Sweden, built a steam turbine to run a cream separator, and experimented with it for many years. In 1887 he adopted the expanding nozzle and began to realise economies that compared favourably with the piston engines. Dr. de Laval's turbine, however, had a single nozzle and a single revolving wheel. It was essentially a very high speed machine because in order to realise any reasonable degree of efficiency the bucket speed had to be very high. This limited the de Laval turbine to small units of power, and compelled him to develop high speed gearing.

Sir Charles A. Parsons began experimenting with the steam turbine in 1884, shortly after de Laval, and he invented the scheme of " compounding the blading " and developed the reaction turbine in which the steam flows through a series of alternate stationary and moving blades of similar form, and by this device he so reduced the speed of the rotor that higher efficiencies could be obtained at speeds much more practical than in the de Laval machines. It was due to the activities of Sir Charles A. Parsons that the turbine became a commercial development, and his name stands in about the same relation to the steam turbine as does that of Watt to the steam engine. During the last decade of the 19th century Parsons brought the steam turbine to a point where it was a successful rival of the steam engine for ship propulsion and also for driving electric generators. From that day to this he has been a leader in turbine design and manufacture, and he has seen turbines grow in his factories from mere toys to units of 50,000 kW. capacity. The accompanying table, adapted from one in Richardson's " History of the Parsons Turbine," gives a brief historical summary of the Parsons turbine development, and indicates also the increase in steam pressure and temperature during this period.

In the late years of the last century, C. G. Curtis and W. L. R. Emmet in the United States, Rateau in France, and Zoelly in Switzerland, developed what are now different forms of the " Impulse Turbine." These all have the expanding nozzle of de Laval, but by using a succession of them with revolving blades between, reduce the shaft speeds to such as are consistent with generator operation.

The turbine is, of course, a rotary machine and is also inherently a much higher speed machine than any reciprocating engine. It is, therefore, fundamentally better adapted to driving electric generators than is the reciprocating engine. When the turbine industry started, generators could be built for speeds much higher than were practical for large reciprocating engines, so that in central station engineering the change from engines to turbines was overwhelmingly sudden, and coincided very closely with the beginning of this century. Furthermore, it was early recognised that turbines could be built in much larger generating capacities than engines. The first turbines driving electric generators operated at speeds from 10 to 15 times those of the best reciprocating engines, and for this reason the weight of materials per kilowatt of capacity was far less in turbines, and this contributed to a great reduction in the cost of generating units and, therefore, in the cost of central stations, and so also in the cost of electric power.

In 1901, the Westinghouse Machine Company in the United States, which company had a few years before taken a licence from Parsons, installed in the Pearl Street Station of the Hartford Electric Company at Hartford, Conn., U.S.A., a 1,500 kW. turbine (1,200 R.P.M.). This operated on 150 pounds pressure (10.5 kg. per sq. cm.) and about 30° F. (17° C.) superheat. In 1902, Mr. Charles H. Merz installed a Parsons turbine and generator of 1,500 kW. capacity, operating on 200 pounds pressure (14 kg. per sq. cm.) and superheat of 120° F. (67° C.) in the Neptune Bank Station near Newcastle-upon-Tyne.

During 1902 the Fisk Street Station of the Commonwealth Edison Company, Chicago, was designed by the late Mr. Frederick Sargent. This was the first important metropolitan central station to be built for steam turbines, and the initial installation consisted of three vertical Curtis turbines, built by the General Electric Company, of 5,000 kW. capacity each. The first one was put in service on October 3, 1903. These turbines operated on 175 pounds pressure (12.25 kg. per sq. cm.) and 125° F. (70° C.) superheat, with 2 inches (50.8 mm.) absolute back pressure in the condenser. They were built under the direction of Mr. W. L. R. Emmet, who for many years directed the turbine development of the General Electric Company, and who was one of the first to advocate building turbine units of large capacities. Ten years later a 25,000 kW. unit, built by

C. A. Parsons & Co., Ltd., was installed in this station and operated on 200 pounds pressure (14 kg. per sq. cm.) and 200° F. (93° C.) superheat. This was the largest turbo-generator up to that time. This station now contains 14 turbines of a total capacity of 230,000 kW.

At the time of the introduction of the steam turbine, say at the beginning of the present century, the more important central stations were operating on steam pressures of between 150 and 175 pounds per sq. in. gauge (10.5 to 12.25 kg. per sq. cm.). The reciprocating engines in these stations were running with about 50° F. (28° C.) of superheat, some possibly as much as 75° F. (42° C.) but anything above that was considered dangerous on account of the serious effect on the lubrication of the engine cylinder. The back pressure maintained on the engines was generally about 3 or 4 inches (76.2 to 101.6 mm.) of mercury in favourable conditions.

The first steam turbine stations started with steam-cycle conditions about where engines left off, but it was early recognised that the steam turbine could be adapted for expansion of steam to a much higher vacuum than the engine, and by doing so, a considerable amount of additional energy could be obtained out of each pound of steam. The next improvement was an increase in steam temperature because in the turbine there is always a slight clearance between stationary and moving parts, and no lubricant is required in any of the steam passages.

The adaptation of the steam turbine to higher pressures did not come as readily as the improvement in vacuum and temperature, and for some years after the introduction of the turbine many engineers felt that the ideal steam plant consisted in the use of high pressure reciprocating engines exhausting into low pressure steam turbines, and several plants were installed on this basis; more particularly some of the older engine plants were greatly improved both in efficiency and capacity by installing "exhaust steam turbines" to operate in connection with the old reciprocating engines, the turbine running on the exhaust steam from the engines.

In the design of the steam turbine there is always more or less compromise between the high pressure and low pressure parts. Theoretically it is desirable to run the high pressure part at a high speed, and the low pressure at a comparatively low speed, but turbines for central stations are limited as to their rotative

speeds to the possible generator speeds, and these in turn are limited by the number of " cycles " in the current generated. At the time of the introduction of the steam turbine both 25 and 60 cycle generators were used in the United States, and the former predominated, but of late years the 60 cycle generators have far outnumbered the 25 cycle. In Europe many different cycles were used, but 50 cycles seem now to be prevailing.

As the turbine industry developed various methods were devised for taking care of the compromise that is necessary to run the high and low pressure blading at the same rotative speed, and at the same time to obtain a reasonably high degree of efficiency at both ends of the cycle. The literature of steam turbine design is full of ingenious arrangements of blading intended to achieve this result. One of the principal devices for this purpose consists in making the low pressure part of the turbine " double flow," and many of the larger turbine units have been " compounded," that is, the high pressure part is a separate machine with a separate generator and runs at higher speed than the low pressure.

Aside from this difficulty in regard to speed, the turbine is much better adapted to the use of high pressure steam than is the reciprocating engine, due to the fact that it operates on a continuous flow of steam and at much higher steam velocities than the engine, and the passages subjected to the higher pressure are comparatively small in size.

From the beginning of the century to the outbreak of the Great War, steam pressures, as well as temperatures, increased gradually, so that in 1914 pressures in the larger stations were about 100 pounds (7 kg. per sq. cm.) higher than at the beginning of the turbine industry; that is, the larger stations were operating on 250 to 275 pounds pressure (17.5 to 19.25 kg. per sq. cm.) and superheat to about 150° F. (83° C.) which means a total steam temperature of about 560° F. (293° C.).

The improvement in the steam cycle during that period is best shown by means of the "temperature-entropy diagram," and Fig. 1 illustrates the difference in the efficiency of the Rankine cycle at the time of the introduction of the turbine, in comparison with the cycle employed in the larger stations in 1914. The area " A " represents the heat theoretically made available for conversion into work by the earlier cycle—175 pounds gauge pressure (12.25 kg. per sq. cm.) 50° F. (28° C.) superheat and 4 in. of mercury (101.6 mm.)

absolute back pressure. The area "B" shows the gain over the former cycle that was obtained by operating at 275 pounds gauge pressure (19.25 kg. per sq. cm.) 150° F. (83° C.) superheat and one inch (25.4 mm.) of mercury absolute back pressure. The thermal efficiency of the former is 27.3 per cent., that of the latter

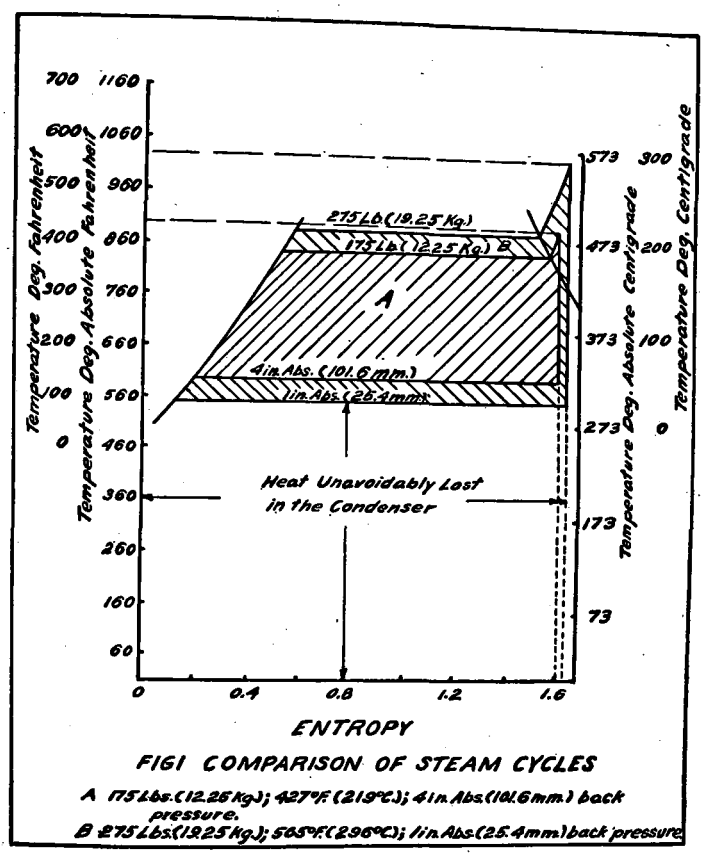


FIG. 1 COMPARISON OF STEAM CYCLES

A 175 Lbs. (12.25 Kg.); 427° F. (219° C.); 4 in. Abs. (101.6 mm.) back pressure.
B 275 Lbs. (19.25 Kg.); 565° F. (296° C.); 1 in. Abs. (25.4 mm.) back pressure.

one is 34.4 per cent., showing a 26 per cent. improvement so far as heat efficiency is concerned.

During the war there was very little change, as the plants which were built during that period were, for the most part, constructed in haste and under the stress of war conditions, but one or two in the United States were built for 300 pounds gauge pressure (21 kg. per sq. cm.) and the famous North Tees Station of the

Newcastle Electric Supply Company was designed in 1917 for a steam pressure of 450 pounds gauge (31.5 kg. per sq. cm.) and a steam temperature of 650° F. (343° C.). Several other new features were put into this station which will be referred to later.

When it comes to operating turbines on steam pressures above 350 pounds (24.5 kg. per sq. cm.) some difficulties arise which are not so apparent at pressures below that figure. As steam expands through a turbine the temperature rapidly falls, due to expansion and the conversion of heat into work, and a point is reached in the turbine where the steam loses all its superheat, and particles of moisture begin to appear in the steam. This moisture, or condensation, increases as the steam passes through the lower stages, and the admixture of water with gaseous steam increases the surface friction, and with high velocities erodes the leading edges of the blades, all of which contribute to reduce the blade efficiency of the lower stages. This is one of the main reasons why it is desirable to increase the temperature with increase in pressure. Assuming a turbine working on 300 pounds gauge pressure (21 kg. per sq. cm.) and 650° F. (343° C.) the steam will lose its superheat when expanded down to about 25 pounds gauge (1.8 kg. per sq. cm.). At 400 pounds initial pressure (28 kg. per sq. cm.) and 675° F. (357° C.) it would lose it at about 35 pounds pressure (3.5 kg. per sq. cm.) and the lower stages in the turbines would contain an increased amount of moisture. At 550 pounds (38.5 kg. per sq. cm.) and 700° F. (371° C.) initially, moisture would begin to appear at about 55 pounds (3.9 kg. per sq. cm.) pressure. With an initial pressure of 550 pounds (38.5 kg. per sq. cm.) it would be desirable to have a steam temperature of about 1,000° F. (538° C.) in order that there should not be too much condensation in the lower stages of the turbine. But steam temperatures are limited by the reduction in the strength of metals as the temperature increases. This condition leads to the desirability, when operating at the higher pressure, of "reheating" the steam after it has passed through part of the turbine, and a great deal of consideration has been given of late by turbine designers and central station engineers to the so-called "reheating cycle." This is merely a modification of the Rankine cycle, and it contemplates taking the steam out of the turbine after it has expanded through the high pressure portion, passing it through some kind of a reheater

in which the temperature is increased and returning it again to the turbine. Some idea of the gain that can be made in cycle efficiency by the reheat cycle combined with increase in pressure and superheat is shown by the temperature-entropy diagrams in Fig. 2. In this, the area "B" represents a turbine working on

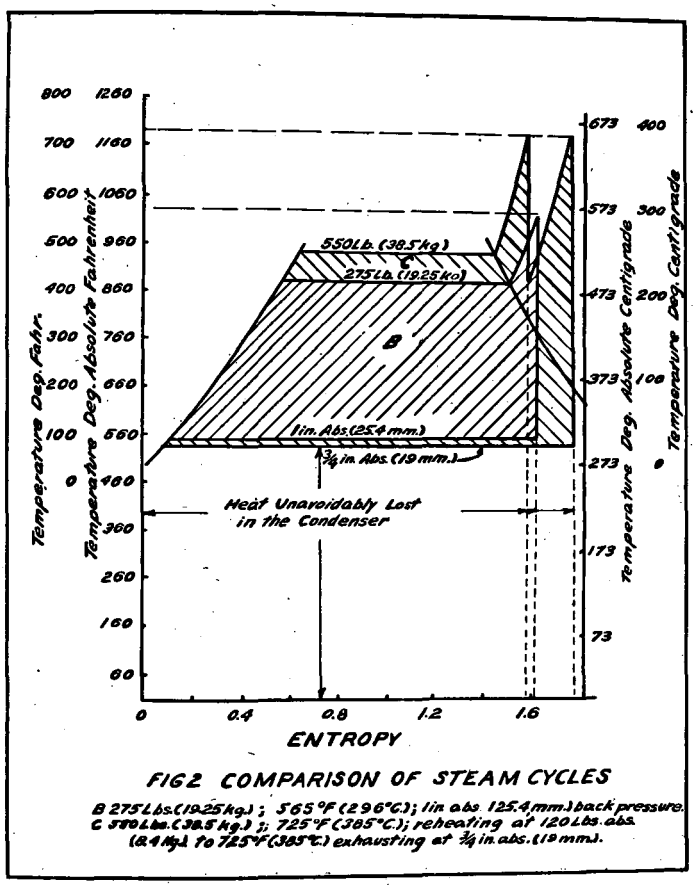


FIG 2 COMPARISON OF STEAM CYCLES

B 275 Lbs. (19.25 Kg.); 565°F (296°C.); 1 in abs. 125.4 mm.) back pressure.
C 550 Lbs. (38.5 Kg.); 725°F (385°C.); reheating at 120 Lbs. abs. (8.4 Kg.) to 725°F (385°C.) exhausting at ¾ in. abs. (19 mm.).

275 pounds gauge pressure (19.25 kg. per sq. cm.) 565° F. (296° C.) initial steam temperature and 1 inch (25.4 mm.) of mercury absolute back pressure, which was good central station practice before the war. This is the same as the area "B" in Fig. 1. Area "C" of Fig. 2 shows the heat available for conversion into

work by a turbine operating on 550 pounds gauge pressure (38.5 kg. per sq. cm.) 725° F. (385° C.) initial temperature, reheating at 105 pounds (7.4 kg. per sq. cm.) to 725° F. (385° C.) and exhausting into a vacuum of ¾ inch (19 mm.) of mercury absolute pressure. The thermal efficiency of the former cycle is 34.4 per cent., and of the latter is 39.8 per cent., which indicates an improvement in fuel efficiency of 15.7 per cent. These figures refer, of course, to the theoretical cycle and to the turbine efficiency only, without any allowance for the boiler room. It should be added that the efficiency of the 550 pounds (38.5 kg. per sq. cm.) cycle, without reheat is 38.7 per cent., which shows a theoretical heat saving of only 2.8 per cent., due to the reheating, but the actual gain will be more than that, because of the reduction in moisture in the steam through the lower stages of the turbine and the consequent improvement in the efficiency of the turbine blading. Just how much this will amount to will not be definitely known until we have more actual data on plants operating on a reheating cycle, but it is estimated by various turbine designers that it will amount to from 2¼ to 3½ per cent., so that the heat gain due to reheating to 725° F. (385° C.) should be from 5 to 6 per cent. These figures allow for a pressure drop of 10 to 12 pounds per sq. in. (.7 to .8 kg. per sq. cm.) through the reheater and piping, but if this pressure drop should be excessive, the value of the reheating will fall off rapidly.

As to the temperature that is practicable for either the initial or the reheated steam, it is limited by the falling off in the strength of metals with increase of temperature. As temperatures were increased in the earlier turbine installations, it was found that cast iron could not be used for valve bodies, fittings, or turbine parts, if exposed to temperatures over about 500° F. (260° C.). Castings were found to warp and deteriorate in strength in a comparatively short time when used for the higher temperatures. With steel, both cast and wrought, the limits are higher. Many tests have been made in the last few years to determine the variations in strength of metals with increase in temperature and these all indicate a quite distinct falling off in both elastic limit and ultimate strength at some point between 700° F. (371° C.) and 800° F. (427° C.). The curves of Fig. 3 show the results of such tests on some of the more important metals used in valves, fittings, and turbine parts. It must be added also that there are very few data as to the effect of time

on the strength of these metals at the higher temperatures. It is quite possible that over a period of months or years the strength of metals subjected to temperatures around 700° F. (371° C.) may show a falling off that is not apparent when they are tested after only a brief exposure. Most turbine designers and central station engineers are agreed that, in the present state of the art, the practical limit of temperature for continuous operation is about 750° F. (399° C.) and that 800° F. (427° C.) may be looked upon as the extreme limit for short periods. It is true that

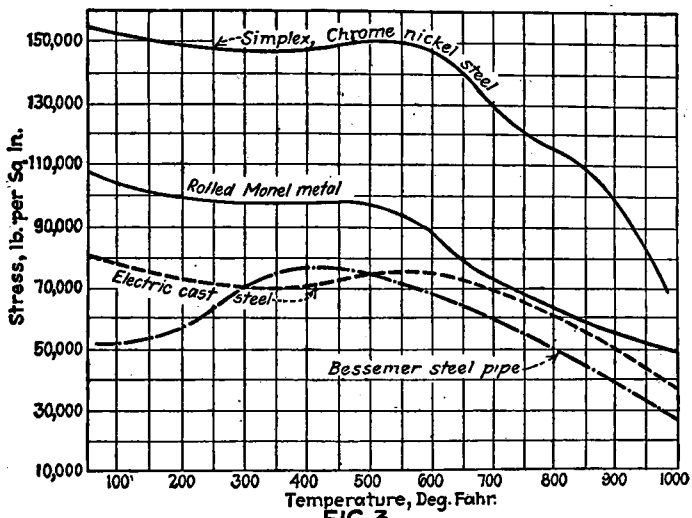


FIG 3

Ultimate strength of metals at high temperatures

temperatures higher than these are already being used in the oil refineries, but in comparatively small volumes, and there are no moving elements such as in a turbine.

There is another modification of the Rankine steam cycle which must always be taken into account in any consideration of high pressure steam plants, and that is the so-called "regenerating cycle." This consists of a scheme for heating the feed water by steam "extracted" from the turbine at various points. Very early in the development of the turbine, surface condensers became standard practice because in them the steam is condensed

into pure distilled water and can be returned to the boilers uncontaminated by oil or by the circulating water. The water is condensed at the temperature of the vacuum about 70° F. (18° C.) for one inch absolute vacuum (25.4 mm.) and in the earlier plants it was the general practice to heat the feed water by means of exhaust steam from steam-driven auxiliaries, and, later, economisers became quite general in the larger stations to heat the water further by means of the flue gases before it went to the boilers.

The value of regenerative feed heating for compound and triple expansion engines was pointed out by James Weir, of Glasgow, Scotland, before 1890, but its adaptability to the steam turbine was emphasised by Mr. S. Z. de Ferranti, of Manchester, England, some years later, and the cycle is usually associated with his name. The efficiency of the usual steam-driven auxiliaries is very low, and Mr. de Ferranti pointed out that it is far more efficient to heat the feed water by steam extracted from the turbine after it has done work through the higher stages and use motor-driven auxiliaries. To get the best results the heating must be done by a series of feed water heaters; that is, the condensate is first heated by a heater taking steam from one of the lower stages of the turbine at a pressure slightly above the absolute pressure in the condenser. The temperature of this steam, however, will be about 125° F. (52° C.) or 150° F. (66° C.) according to the "stage" at which the connection is made, so that by such a heater the water can be heated to something under that temperature. Then by putting it through another heater, taking steam from a higher stage of the turbine, the feed temperature can be increased accordingly. This process can be continued through a series of heaters until the feed water is heated up to any temperature less than the temperature of saturated steam at the initial pressure. To carry the regenerative cycle to its theoretical limit would require a very large number of heaters, one for each stage or row of blades in the turbine; but this, of course, is impossible in practice, and as a rule not more than three, or at the most four, heaters are used. There is a very distinct gain in the plant efficiency by this method of feed water heating, and it is now being used in a number of stations operating on less than 300 pounds pressure (21 kg. per sq. cm.). It unfortunately is impracticable to show the effect of the "regenerative feed-heating" on a temperature-entropy diagram such as those above given, nor is it possible to make any general-

isations as to its effect on the efficiency of the turbine, because it depends entirely on the temperature to which the feed water is heated, and the stages from which the steam is extracted. There is some question as to how far it is really efficient to carry this regenerative or "progressive" feed water heating, and it is intimately concerned with the kind and character of the boiler plant equipment.

The absorption of heat in the feed water by steam extracted from the low pressure stages of the turbine is much more efficient than is that at the higher stages because the steam extracted at the low stages has done much more work in the turbine. A high feed temperature means a correspondingly high temperature of the gases leaving the boiler or economiser, which leads to the use of "air economisers" to get the last heat out of the gases where a high feed temperature is used, and if the feed water is heated to within 75° F. (41° C.) of the temperature of saturated steam at the boiler pressure, it is hardly practical to use any water economiser, and a very large air economiser must be used to reduce the temperature of the flue gases to an efficiently low temperature. Other things being equal, the boiler plant efficiency depends on the flue gas temperature; the lower that temperature, the higher the efficiency, and approximately 35° F. (20° C.) increase in flue gas temperature means 1 per cent. loss in plant efficiency, and the comparatively small gain in turbine efficiency by the high temperature steam extraction, that is, from the high pressure stages, is likely to be more than can be made up by a commercially practical air economiser. In the writer's opinion, looking at the station efficiency as a whole, the best results will be obtained by using both water and air economisers, and a feed temperature somewhere between 220° F. and 250° F. (105° C. to 121° C.).

The first central station built for high steam pressure and using reheating, regenerative feed heating and air economisers was the North Tees station of the Newcastle Electric Supply Company, which was designed by Merz and McLellan in 1917. There were many delays in the construction of this station on account of war conditions, and it was not put into operation until early in 1921. The station is equipped with two 20,000 kW. turbines and ten boilers. The steam pressure is 450 pounds gauge (31.5 kg. per sq. cm.) and the temperature 650° F. (343° C.). In the high pressure end of the turbine the steam is expanded down to

about 65 pounds gauge pressure (5.9 kg. per sq. cm.) and then conveyed to the interstage superheaters with which five of the boilers are equipped. The steam is reheated to about 500° F. (260° C.) temperature and returned to the turbine. Feed water is heated by steam extraction to 300° F. (149° C.) and the boilers are each equipped with an air economiser, but there are no water economisers.

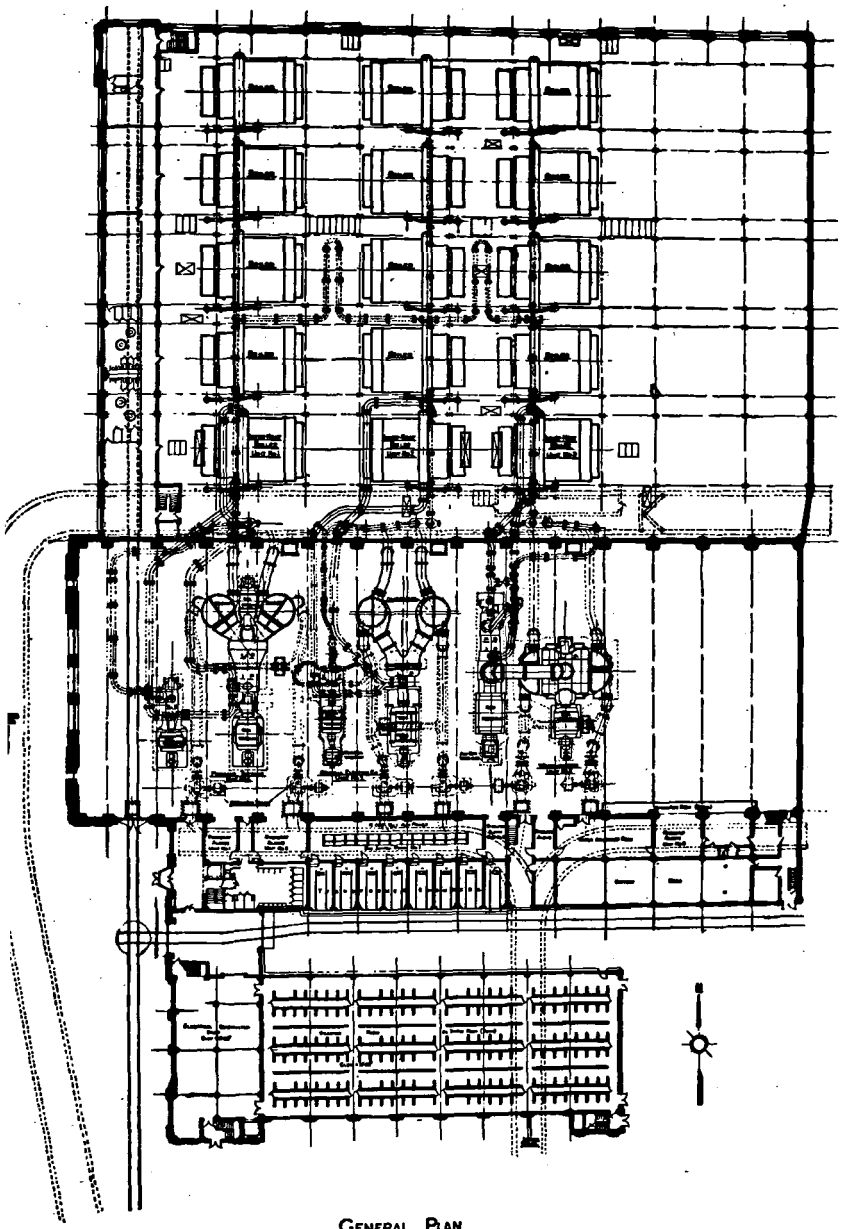
Four power stations are now under construction in the United States which are to use these features for improved economy. The Crawford Avenue Station of the Commonwealth Edison Company, Chicago, and the Philo and Twin Branch Stations of the American and Electric Company are all to be in operation this year. The Miami Fort Station of the Columbia Power Company (Cincinnati) is to be in operation next year. In all these stations the steam pressure is to be 550 pounds gauge (38.5 kg. per sq. cm.) at the turbine throttle and 725° F. (385° C.) initial temperature and reheating at 105 pounds gauge pressure (7.4 kg. per sq. cm.) to 700° F. (371° C.) temperature.

The largest and most important of these stations is the Crawford Avenue Station of the Commonwealth Edison Company at Chicago. Three turbine units have been ordered for this station, one from C. A. Parsons & Co., Ltd., Newcastle-upon-Tyne, England, of 50,000 kW.; one from the General Electric Co., U.S.A., of 60,000 kW.; and one from the Westinghouse Electric & Manufacturing Co., U.S.A., of 50,000 kW. These are all compound units.

The Parsons unit consists of three separate turbines: a high pressure turbine running at 1,800 R.P.M., driving a generator of 16,000 kW. capacity; an intermediate at 1,800 R.P.M., driving a 28,000 kW. generator; and a low pressure running at 720 R.P.M., and driving a 6,000 kW. generator. The intermediate and low pressure turbines are in tandem with one another so that they will look much as though they were one turbine with a generator at each end. All three turbines are "single flow."

The General Electric unit consists of a high pressure turbine driving an alternator of 17,000 kW. capacity at 1,800 R.P.M., and a low pressure turbine driving a 43,000 kW. alternator at 1,200 R.P.M. The turbines of this unit have impulse blading throughout and are single flow.

The Westinghouse unit is made up of a high pressure turbine and an intermediate on one shaft driving a 20,000 kW. alternator



GENERAL PLAN
CRAWFORD AVE. POWER STATION.
COMMONWEALTH EDISON CO.
CHICAGO ILL.

FIG 4

at 1,800 R.P.M., and a double flow low pressure turbine driving a 30,000 kW. alternator at 1,800 R.P.M. This unit employs "Parsons blading" throughout, and the last two rows of blades have a "divided exhaust" arrangement, a scheme for reducing the length of the low pressure blades originally developed by Mr. K. Baumann, of Manchester, England.

The generators are all of 60 cycles. The low pressure turbine is in each case equipped with two vertical condensers which stand

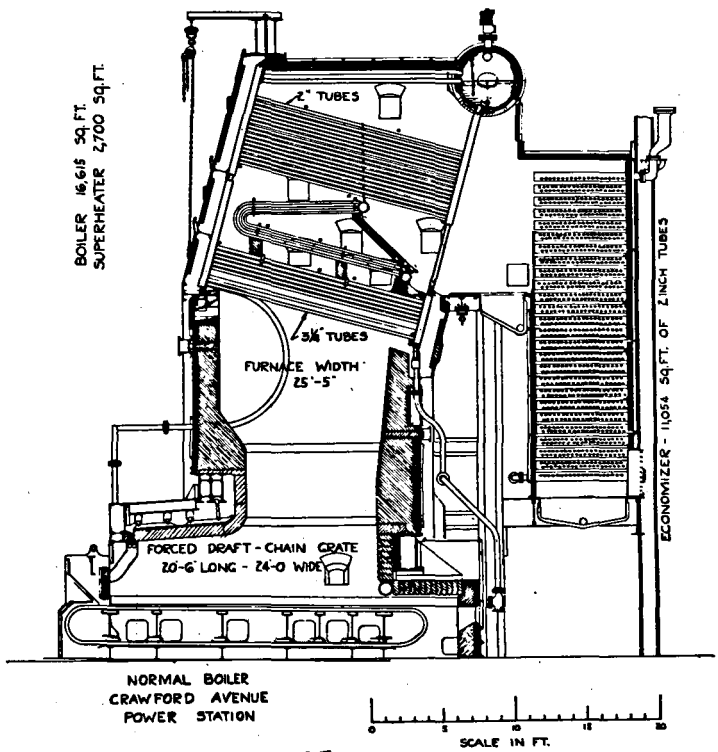


FIG 5

up adjacent to or at the end of the low pressure turbine. The vertical condensers are used because with them it is possible to have a very efficient connection between the turbine and condenser and also because the circulating water at the site of this station carries a large amount of sediment which will not foul the vertical tubes.

In each unit the steam is to be reheated after expanding through the high pressure turbine at about 105 pounds (7.4 kg. per sq. cm.) gauge pressure from about 410° F. (210° C.) temperature to 725° F. (385° C.). The Parsons Turbine is designed for heating feed water by steam extraction to 340° F. (171° C.) the General Electric unit to 245° F. (118° C.) and the Westinghouse to 220° F. (107° C.). The boilers on the Parsons unit will be equipped with both water and air economisers, those on the other units with water economisers only, though air economisers can be added if the expense is proved to be warranted. Fig. 4 shows a general plan of the Crawford Avenue Station.

There are five boilers on each unit, the boiler nearest the turbine in each case being equipped with a reheater. Each of the four "normal boilers" on each unit contains 16,615 sq. ft. (1,543 sq. m.) of boiler surface. The reheat boiler contains only 6,000 sq. ft. (558 sq. m.) of boiler surface, and the reheater containing approximately 41,000 sq. ft. (1,300 sq. m.) is mounted on top of the boiler. Fig. 5 shows a section of the "normal boiler" and Fig. 6 of the "reheat boiler." The boiler under the reheater will generate about 65 to 70 per cent. as much steam as each of the normal boilers, and is so proportioned that the furnace is the same under both boilers. The stoker under the reheat boiler will be operated so as to regulate the temperature of the steam leaving the reheater, and the primary object of the boiler under the reheater is to reduce the temperature of the furnace gases to something under 1,700° F. (927° C.) before they come in contact with the superheater surface, because if tubes containing only dry steam are in direct contact with a temperature as high as that of the furnace, there is likely to be trouble due to the burning of the tubes.

As to the operating efficiency that is to be expected from plants working on a regenerative and reheating cycle, such as that of the Crawford Avenue Station, it is obvious that we should expect considerable improvement over the results obtained in the larger stations of to-day. The temperature-entropy diagram referred to above (Fig. 2) shows 15.7 per cent. improvement in the 550 pounds (38.5 kg. per sq. cm.) pressure cycle over that of the 275 pounds (19.25 kg. per sq. cm.) but this does not take account of the regenerative feed heating; nor, as pointed out before, does it give full credit to the effect of reheating. There are a number of central stations in the United States and also in Europe which

are operating on 275 pounds gauge pressure (19.25 kg. per sq. cm.) that show an operating efficiency of 19,000 B.Th.U. (in the coal) per kWh. for monthly operation. There are some stations in the United States operating at 300 pounds gauge (21 kg. per

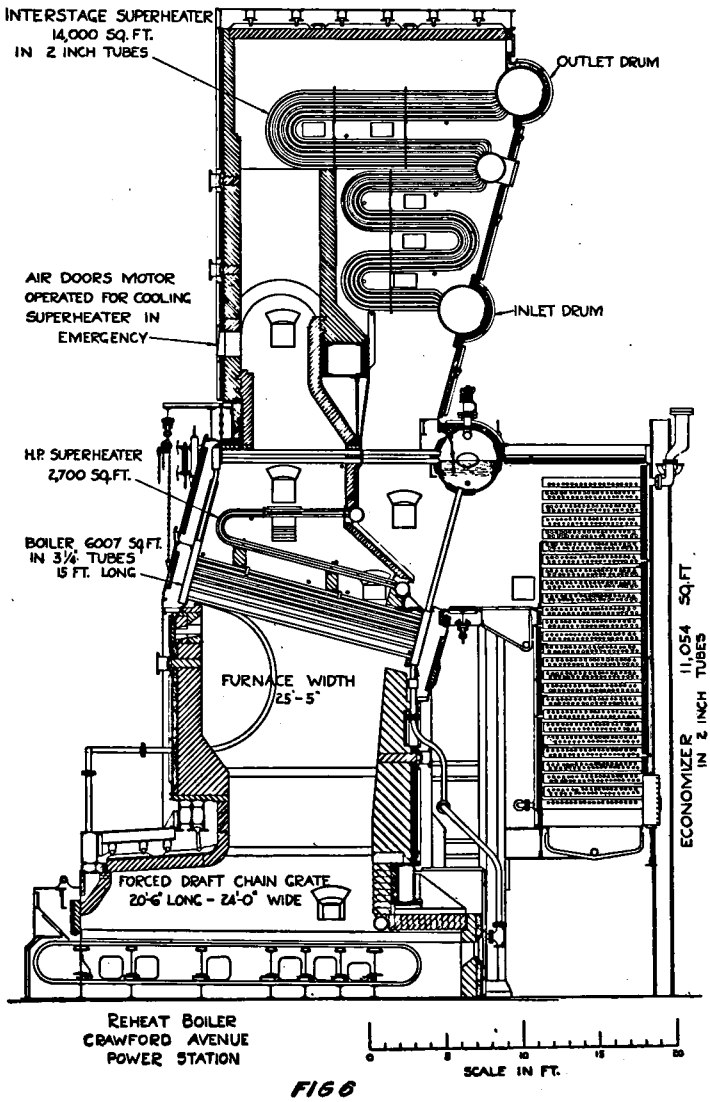
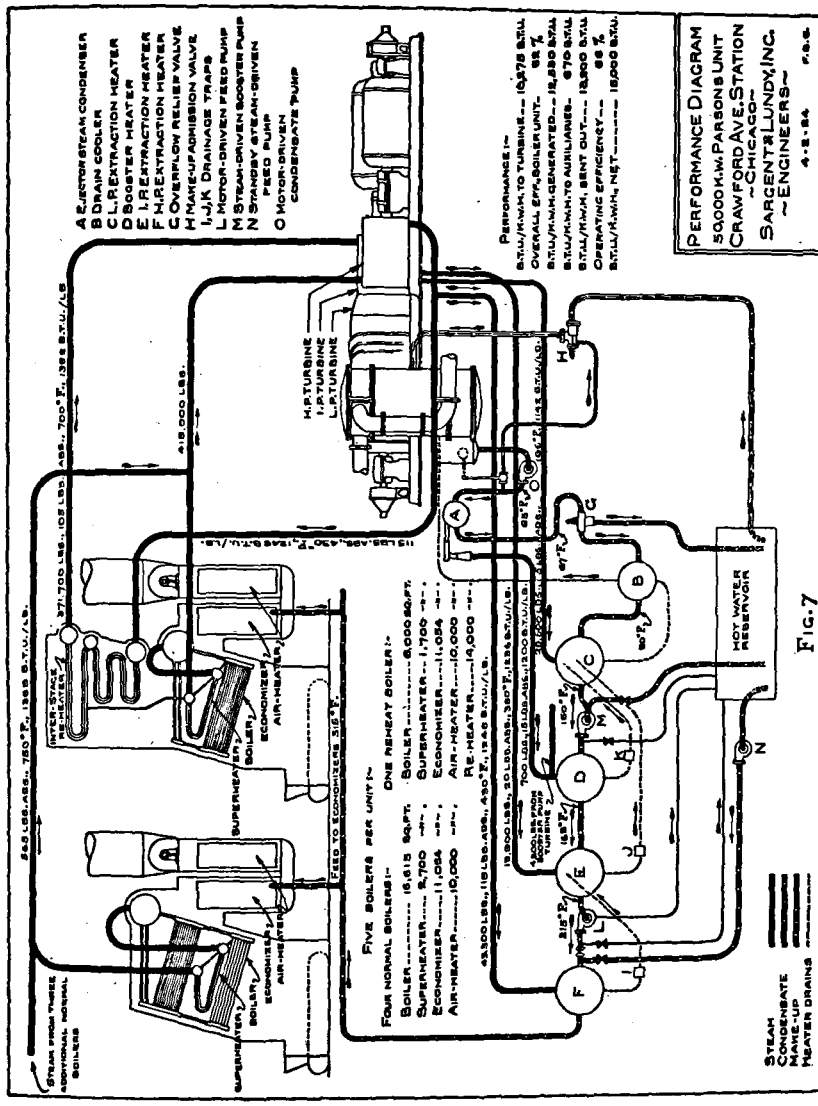


FIG 6


PERFORMANCE DIAGRAM
50,000 K.W. PARSONS UNIT
CRAWFORD AVE. STATION
~CHICAGO~
SARGENT & LUNDY, INC.
~ENGINEERS~
4-8-24 F.G.S.
A EJECTOR STEAM CONDENSER
B DRAIN COOLER
C L.P. EXTRACTION HEATER
D BOOSTER HEATER
E I.P. EXTRACTION HEATER
F H.P. EXTRACTION HEATER
G OVERFLOW RELIEF VALVE
H MAKE-UP ADMISSION VALVE
I, J, K DRAINAGE TRAPS
L MOTOR-DRIVEN FEED PUMP
M STEAM-DRIVEN BOOSTER PUMP
N STANDBY STEAM-DRIVEN FEED PUMP
O MOTOR-DRIVEN CONDENSATE PUMP
H.P. TURBINE
I.P. TURBINE
L.P. TURBINE
HOT WATER RESERVOIR
STEAM
CONDENSATE
MAKE-UP
HEATER DRAINS
FIVE BOILERS PER UNIT:-
FOUR NORMAL BOILERS:-
ONE REHEAT BOILER:-
PERFORMANCE:-
FIG. 7

sq. cm.) that under favourable load conditions get down to 18,000 B.Th.U. per kWh. for a month's operation. In Fig. 7 is shown a " Performance Diagram " of the Parsons unit of the Crawford Avenue Station, and this shows a theoretical fuel consumption at full load equivalent to 12,210 B.Th.U. in the coal per kWh. Allowing an " operating efficiency ratio," that is, the ratio between the theoretical plant efficiency and the actual monthly operating efficiency, of 88 per cent., which provides for " banked fires " and other " stand-by " losses and for loss of plant efficiency, due to irregularities of load, which is a conservative figure for a large plant burning a low grade of coal such as used in Chicago, this plant should average about 15,000 B.Th.U. per kWh. It must be borne in mind, however, that station efficiency depends upon many things besides the turbines and the steam cycle, the most important of these being the design of the boiler and furnace equipment, the load factor, which materially affects the stand-by losses, the quality of the boiler room operation and also the kind of coal burned. With a good grade of coal with comparatively low percentages of ash and moisture, it is possible to get considerably better average boiler room efficiency than with the lower grades of coal which have high ash and moisture content. This difference will amount to as much as 5 or 6 per cent.

If the high pressure power stations show a saving in fuel of only 15 per cent., in comparison with those built for 300 pounds pressure (21 kg. per sq. cm.), it means for every 100,000 kW. of installed capacity a saving, based on a 70 per cent. capacity load factor, of approximately 84,000 tons (76,200 metric tons) of coal per year, if a low grade coal—10,000 B.Th.U. per pound (1,100 cal. per kg.) is used, and about 60,000 tons (54,400 metric tons) per year if a high grade coal is used—say 13,500 B.Th.U. per pound (1,485 cal. per kg.).

As to the cost of these high pressure stations, it is impractical to make precise comparisons, because two stations cannot be designed and built under exactly similar conditions. Many things affect the cost, such as the size of the turbine and boiler units, the character of foundations necessitated by soil conditions, the track layout, coal handling and coal storage, the character of electrical distribution from the station, conditions as to circulating water, the character and quality of building, labour conditions, and other matters of that sort. But fundamentally the only items that cost more in the high pressure plants are the turbines, the pressure

parts of the boilers and economisers, the live steam piping, the reheater and reheat piping and the steam extraction heater system. The turbines cost but little more than in stations for lower pressure. In the boiler plant it is only the pressure parts which cost more; everything else is the same, and the boiler plant as a whole, including the coal handling equipment, should cost less, because less plant is required in the same ratio as the saving in fuel. The boiler with the reheater costs but little more than the normal boiler and does the same amount of work. The reheat piping and the valves and the necessary automatic devices are a positive addition to the cost, but the condensing plant should cost less because there is much less steam per kilowatt going to the condensers, and smaller condensers can be used. Taking it altogether, therefore, the plants for 550 pounds pressure (38.5 kg. per sq. cm.) should not cost much more than those for 300 pounds (21 kg. per sq. cm.). This is borne out by the plants which are now under construction, and which will cost but little, if any, more than plants which are being built for lower pressures. It might be added that one reason that these plants are not costing more is that the high pressure boiler that is being used has small tubes, and with its economiser is somewhat more compact than the older types and takes a less expensive building to house it.

It is often asked: How high will steam pressure and temperature go, and how rapid will be the increase? It has been pointed out that temperatures are limited by the strength of metals, in the present state of the art, to something under 800° F. (427° C.). If the temperature is not excessive, steel pipes and fittings can be made, especially in small sections, to stand almost any pressure. Some small installations are being built in the United States to operate on 1,200 pounds pressure (84 kg. per sq. cm.) and in Germany and Sweden there are a few experimental installations at very high pressures. In England one plant is said to be under way in which it is intended to run the pressure on the boiler up to "critical pressure"—that is the pressure at which water passes into steam without any latent heat—it is about 3,200 pounds per sq. in. (224 kg. per sq. cm.). While these installations will undoubtedly give us some valuable data about the action of steam at high pressures, and may lead to other important results, they must be looked upon as experimental, and the immediate commercial value is somewhat questionable. The gain in efficiency of the steam cycle goes up very slowly with increase in pressure

above 600 pounds (42 kg. per sq. cm.) and the auxiliary power increases very appreciably, due to the rapid increase in that required by the feed pumps. The reheat problem becomes much

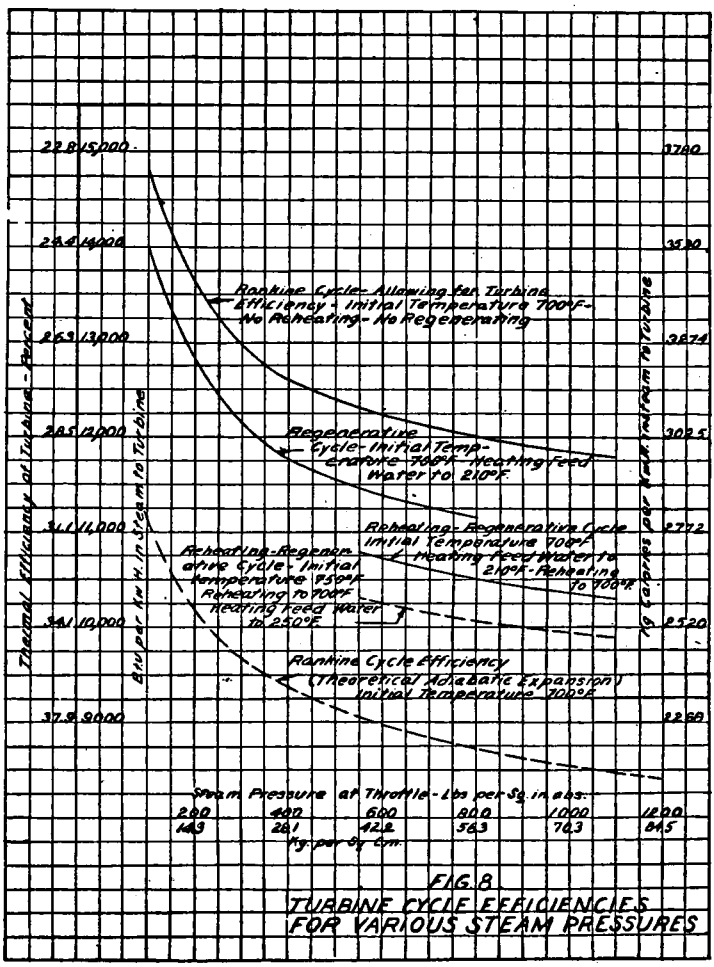


FIG. 8
TURBINE CYCLE EFFICIENCIES FOR VARIOUS STEAM PRESSURES

more complicated and more expensive. In fact, to get really efficient results with a steam pressure of 1,200 pounds (84 kg. per sq. cm.) requires reheating twice, first at about 400 pounds (28 kg. per sq. cm.) pressure and again at about 60 pounds (4.2

kg. per sq. cm.). Fig. 8 shows some curves which indicate the improvement in cycle efficiency with increase in steam pressure. No curves such as there shown can be considered exact because the cycle efficiency for any pressure depends upon the amount of steam extraction, the point at which reheating is done and details of that kind, but variations in these factors cannot seriously affect the shape of the curves, which all indicate the slow improvement by increasing steam pressure above 600 pounds (42 kg. per sq. cm.). Undoubtedly, within a few years, pressures above that will be used in many stations, but the gains in efficiency that can be made by further refinement of the steam cycle will be achieved only by the utmost care in design and the expense will increase rapidly as the pressure goes up.

There is every indication that in the future even more careful attention must be paid to the problems involved in the more economical methods of burning coal. The burning of coal in pulverised form has made great progress in the last two or three years, and undoubtedly with most kinds of coal, that method of burning will show higher efficiency than stokers. The cost of the pulverising equipment has been much higher than that of stokers, but by improvements in the equipment and in station layout, that difference can be greatly reduced. The new high pressure station for the Columbia Power Company at Cincinnati, U.S.A., will be equipped for pulverised coal. There are also possibilities of great commercial gains to be made by the partial distillation of coal before burning it under boilers, and on that account it is probable that in the future the central station industry, so far as its engineering is concerned, will have to work in closer relations with the gas industry.

It must not be forgotten also that there are possibilities of great saving in fuel by the use of other vapours besides steam. The most conspicuous work in that direction has been done with a mercury turbine by Mr. W. L. R. Emmet,* of the General Electric Company, U.S.A., whose name has been mentioned before in connection with the early turbine development of his company. Mr. Emmet has been working for 10 or 12 years on a combination cycle consisting of a mercury turbine and a steam turbine, in which the condenser on the mercury turbine forms a steam boiler and generates steam for the steam turbine. The first commercial

* See "Power from Mercury Vapour," by W. L. R. Emmet. (Transactions of W.P.C. Vol. II.).

installation of this kind is now in service at Hartford, Connecticut, U.S.A. The fuel efficiency that is theoretically possible by this combined mercury and steam cycle is far better than can possibly be reached by any form of steam cycle.

There may be obstacles in the way of gaining these various improvements in the efficiency of electric power stations, but the electric power industry demands that they be overcome. There is every probability that except for temporary fluctuations, the cost of coal will gradually rise over any long period of years, and the maintaining of cheap electric power, so necessary in these days for every human activity, will depend upon the most efficient possible use of coal in power production.

Electric power is one of the greatest products of human enterprise, and has probably done as much to improve the living and working conditions of mankind in the home and in the factory as any single development of this great era of science and invention. Coal is the major source of electric power, and the coal resources of the world constitute a storage of energy which is one of the priceless inheritances of civilisation. However extensive and magnificent these coal resources may be, they are not of infinite capacity and the coal most easy of access is already being rapidly consumed. The problem of the central station engineer is to conserve this reservoir of energy for the increasing demands of advancing civilisation.

PERFORMANCE OF PARSONS TURBO-GENERATORS AT DIFFERENT EPOCHS.

ENGLISH UNITS.

Date	Capacity Kilowatts	Steam Press. Lbs. per Sq. In.	Steam Temp. Deg. F.	Vacuum (30" barometer)	Steam per kWh. lbs.	B.Th.U. per kWh.
1885	4	60	308	0.0	200.00	200,500
1888	75	100	338	0.0	55.00	55,600
1892	100	100	388	27.0	27.00	31,050
1900	1,250	130	481	28.4	18.22	21,900
1902	3,000	138	595	27.0	14.74	18,500
1907—10	5,000	200	508	28.8	13.2	16,100
1912	25,000	200	588	29.0	10.32	13,100
1924	50,000	550	750	29.25	8.38	10,265

METRIC UNITS.

Date	Capacity Kilowatts	Steam Press. Kg. per Sq. Cm.	Steam Temp. Deg. C.	Abs. back Press. Mm. of Hg. (760 mm. bar.)	Steam per kWh. kg.	kg. Calories per kWh.
1885	4	4.2	153	760.0	90.72	50,526
1888	75	7.0	170	760.0	24.87	14,011
1892	100	7.0	198	76.2	12.25	7,825
1900	1,250	9.1	249	40.6	8.26	5,519
1902	3,000	9.7	313	76.2	6.69	4,662
1907—10	5,000	14.0	259	27.9	5.99	4,057
1912	25,000	14.0	309	25.4	4.68	3,301
1924	50,000	38.5	399	19.0	3.80	2,587

Note: The 50,000 kW. turbine is a compound unit with a high pressure, an intermediate, and a low pressure turbine, and is equipped for reheating at 115 pounds absolute from 430° F. to 700° F., and for extraction of steam from three stages of the turbine for heating feed water to 315° F.

RÉSUMÉ.

Le rapport traite du développement du cycle de vapeur vers l'emploi de plus hautes pressions et de températures plus élevées et les améliorations de rendement qui ont été obtenues par ce développement, également ce que l'on peut espérer dans un avenir immédiat.

L'histoire de la force motrice à vapeur, depuis les jours de James Watt, montre une augmentation très graduelle des pressions de vapeur et des températures jusqu'à l'époque de l'introduction de la turbine à vapeur et depuis ce moment, la pression et la température, ont toutes deux monté très rapidement.

Lorsque la turbine à vapeur fut introduite en premier lieu vers le début de ce siècle, les stations centrales les plus importantes utilisaient des pressions de vapeur d'environ 175 lbs. par pouce carré (12,25 Kg. par cm. carré) et des contre pressions d'environ 3 à quatre pouces (76,2 à 101,6 mm.) de mercure.

Au début de la grande guerre les pressions dans les stations centrales les plus importantes, étaient d'environ 250 lbs. (17,5 Kg. par cm. carré) et une température de vapeur totale d'environ 560°F. (293°C.), ceci indiquait une amélioration de rendement thermique d'environ 26 pour cent. Pendant la guerre il y a eu très peu de changement.

Comme les températures de vapeur sont limitées par la réduction dans la résistance des métaux lorsque la température augmente, le réchauffage de la vapeur, après que celle ci a passé à travers une partie de la turbine, devient désirable à des pressions au dessus de 350 lbs. (24,5 Kg. par cm. carré). Avec une pression initiale de 550 lbs. (38,5 Kg. par cm. carré) et une température de 725°F. (385°C.), le gain actuel dû au réchauffage de la vapeur à 725°F. (385°C.) est estimé à environ 5 à 6 pour cent. La limite actuelle pratique de la température de vapeur semble être d'environ 750°F. (399°C.).

Le système consistant à chauffer l'eau d'alimentation en extrayant de la apeur de la turbine, connu sous le nom de cycle " Régénérateur," permet un gain très intéressant dans le rendement de l'installation. Si l'on pousse ce cycle à sa limite, on est conduit à utiliser des " Economiseurs d'air " pour enlever la chaleur des gaz de carneaux. L'auteur croit que les meilleurs résultats seront obtenus en utilisant à la fois des économiseurs pour l'eau et pour l'air et une température d'eau d'alimentation comprise entre 220° et 250°F. (105°C à 121°C.).

La station de North Tees, de la Newcastle Electric Company, a été la première station centrale construite pour une pression de vapeur élevée et utilisant l'alimentation régénératrice et les économiseurs d'air. Quatre stations centrales sont actuellement en construction aux Etats Unis qui utiliseront ces caractéristiques en vue d'obtenir une augmentation de rendement. Dans toutes ces stations la pression de vapeur sera de 550 lbs. (38,5 Kg. par cm. carré) à la soupape d'admission de la turbine et 725°F. (385°C.) de température initiale et le réchauffage à 105 lbs. (7,4 Kg. par cm. carré) à 700°F. (371°C.) Ces centrales devraient présenter une amélioration très sensible de rendement sur celles actuellement en service.

Ii est impraticable de faire des comparaisons entre les prix de revient de stations centrales, mais les stations en construction indiquent que des stations ayant une pression de 550 lbs. (38,5 Kg. par cm. carré) ne devraient pas coûter beaucoup plus et même pas davantage que celles ayant une pression de 300 lbs. (21 Kg. par cm. carré).

Sans aucun doute on utilisera dans quelques années des pressions supérieures à 600 lbs. (42 Kg. par cm. carré), mais l'augmentation de rendement augmente très lentement avec l'augmentation de la pression au dessus de 600 lbs.

Il y d'autres possibilités d'amélioration dans l'économie d'une station centrale, telles que l'emploi de charbon pulvérisé, la distillation partielle du charbon avant de le brûler et l'utilisation de la turbine à mercure.

STEAM GENERATION

DISCUSSION

Chairman: DR. A. F. ENSTRÖM (SWEDEN)

Thursday, July 3rd. *Afternoon Session*

SIR JAMES KEMNAL (*Great Britain*), opened the session by summarising his paper, entitled, *Steam Generation.*

MR. W. S. MONROE (*U.S.A.*), after reading a summary of his paper, *The Use of Steam at High Pressures and High Temperatures in Central Stations,* mentioned the great debt the Central Station industry throughout the world owed to the distinguished English engineer and inventor, Sir Charles Parsons, whose activities in the development of the steam turbine had made it a commercial success.

DR. D. S. JACOBUS (*U.S.A.*), before presenting a summary of his paper, entitled: *Present Practice in Steam Generation in the United States,* said that they had, in America, taken to bigger boilers and larger furnaces. The larger boilers had come through the general trend of progress, as it was found that a large boiler could be operated with about the same number of attendants as a smaller boiler, thus leading to a decrease in the cost of operation, and they were more in harmony with the larger power plants now used. The larger furnaces had been brought about to meet the demands for securing higher efficiencies, and to overcome certain difficulties that had arisen in station practice through the use of the smaller furnaces, such as trouble through slag collecting on the tubes and through burning the tubes. There was also less trouble with the larger furnaces in the carrying over of cinders with the flue gases.

MR. O. A. WIBERG (*Sweden*), stated that owing to the scarcity of fuel in the Scandinavian countries during the war, he was at the time carrying out some investigations as to what could be done to reduce the coal consumption. In dealing with that problem, he had also considered the possibility of increasing the boiler pressure and also the size of the boiler. And though he was of the opinion that sectional water tube boilers had some appreciable advantages, he had made some experiments regarding the maximum pressure for which such boilers could be constructed. He had found that it was possible to build this type of boiler up to 1,000 lbs. per square inch. But considering that a new standard high pressure would be about 600 lbs. per square inch, he had constructed a boiler for this pressure. In constructing the boiler, special efforts had been made to obtain the highest possible elasticity and the best possible circulation of the water. The boiler was of the sectional type, but constructed in such a manner that the circulation was freer than in the ordinary boiler of this type. Both a heater and economiser were arranged around the boiler.

DR. FRIEDRICH MÜNZINGER (*Germany*), detailed four important circumstances which had a decisive influence on the development of high pressure boiler plant, *viz* :—

(1) Scientific research on the occurrences in water-tube boilers, which had been stimulated during the last eight years.

(2) Investigations concerning the properties of boiler plates and the influence of the manufacturing process on the durability of boiler plants.
(3) Progress in the production of special steel plates and their treatment for the manufacture of boiler drums.
(4) The acquisition and further development of the inventions and designs of Dr. Ruths for the construction of steam accumulators by a few prominent German companies.

MR. GEORGE E. TANSLEY (*Great Britain*), alluded to a speaker at the morning session who had held that economisers were not necessary, and who was in all his plants substituting airheaters. Sir James Kemnal had also said in his paper that in some cases economisers might be included, but that in other cases probably the application would have no advantages. Sir James had made a statement in his paper, to the effect that the heating of the feed water by economisers utilised temperature differences to better advantage. On that point he was quite in agreement. The function of the boiler was to generate steam, but if the boiler were made so large that it also took upon itself the function of heating the water, it became partly an economiser. If, as Sir James suggested, the boiler were to work at half-rating, this would simply mean that for the same steaming duty, double the boiler heating surface would be installed. In effect, it meant that there would be 50 per cent. boiler and 50 per cent. economiser. If the boiler were considered as being merely a generator of steam, and if at the same time these very high pressures were adopted, the temperature of the gases leaving the boiler would be somewhere in the region of 700°F. or 800°F., and to install airheaters to reduce these gases to say 300°F. would heat the air to such a temperature, that it would be impossible to use it in the furnace without doing considerable damage. He expressed the opinion that it would not be commercially advisable to heat air to a higher temperature than 300°F. That would mean that there would still be 300°F. or 400°F. available, and that unless the chimney waste were excessive, they would be compelled to use economisers.

With regard to these very high pressures, he thought the tendency might be in the future to work the generator portion of the boiler only at extreme pressure, and in some way relieve the remainder of the plant of at least a portion of this pressure.

He then referred to the two-stage system of boiler feeding, whereby the economiser, the feed piping and valves leading up to the economiser could be designed to work at a pressure of 100 lbs. or even 200 lbs. per square inch, or just sufficient pressure to prevent vapour forming in the economiser. The boiler feed water could then be taken from the economiser to a boosting pump, by which it would be forced into the boilers, and the whole of the plant on the pressure side of the boosting pump could then be worked at as high a pressure as might be desired. In reality, this was less complicated than installing a de-aerating system, in order to protect the steel economiser. It would make it possible to use the standard cast-iron economiser for the low pressure system, and only to use the very expensive steel construction for the actual steam generation at the extreme pressures which might be adopted in the near future.

MR. DAVID BROWNLIE (*Great Britain*), said he would like, in the first place, to refer to the origin of the use of high pressure steam.

Sir James Kemnal, in his paper, had given a somewhat misleading impression of the early history of steam. The invention of Thomas Savery (a retired British Naval Captain) who took out his patent in 1698—based presumably on the earlier work of Jean François, the Marquis of Worcester and Dens Papin—was not an engine in the ordinary sense of the word at all, but essentially a pulsometer pump. The first use of high pressure steam was by Trevithick, who worked at 25 lbs. pressure in the year 1800, and to him the real credit was due.

With regard to this question of super steam pressures, everyone must be amazed at the magnificent work that was being done on the subject, especially in Germany, the United States, and in Sweden, as well as in Great Britain.

He would suggest, however, that by far the simplest, most efficient, and

highly scientific principle appeared to be that of the " Benson " super-pressure generator, which had not been mentioned. Essentially, this consisted of a simple coil of ¾ in. steel tubing heated on the outside, through which was passed water at 3,200 lbs. per square inch pressure by means of a force pump, so that under the critical conditions at about 706°F., water was converted into steam at the same volume, and therefore without the absorption of latent heat.

He considered pulverised fuel firing to be in general superior to ordinary mechanical stoking, for British or any other coals, although remarkable advances in mechanical stoker efficiency were represented by such items as the suspended firebrick arch, rendering possible single stokers up to 24 feet in width, self-contained mechanical draught, water-cooled grates, and water-cooled steel tubes for furnace walls. He deplored the huge waste of heat in the warming up of rivers by the cooling water of the condenser, and urged the importance of improved scientific methods for the use of coal. The future, in his opinion, lay with low temperature carbonisation of coal and in the use of coil " boilers," the generation of power by the drop in the pressure from as high a figure as possible through steam engines or turbines down to 50 lbs. or so per square inch or less, and the use of this low pressure steam for process work so as to avoid entirely the latent heat of steam loss in the condenser.

MR. CHARLES F. WADE (*Great Britain*), suggested that insufficient attention had been paid in water tube boilers to further absorption of heat, after all the possible radiation transmission had been obtained. Prof. Nicholson's experiments should be applied in the case of water tube boilers, by paying more attention to increasing the velocity of the gases in the later banks of tubes. That had been done in some instances, and he believed, by increasing the baffling; but it seemed to be merely a compromise. The heating surface had been decreased in doing it. The water tube boiler was working the wrong way round altogether. Where transmission of heat by conduction was concerned, they should increase the velocity. He did not know of any water tube boiler that did not decrease the velocity very badly, just where it should be increased.

MR. GEORGE A. ORROK (*U.S.A.*), agreed with Sir James Kemnal, that we had come pretty near to the limit of the increase in efficiency in steam generation. He did not know of any other process where there was a change of state in the medium, where they had attained an efficiency of 92 per cent. He did not know of another process where the efficiency over a long period was of the order of 80 per cent. It was just possible that they might add another 1 per cent. to the 92 per cent. already attained. They might go perhaps to 94 per cent., though he did not think so himself. In this connection he remarked that most water tube boilers speeded up the gases at the end of the pass, as they ought to do where the heat was all carried by conduction. The velocity through the flues and stacks was lowered somewhat, as also was the velocity through the economiser, because the absorption power was quite large in that particular place; but in the last class of water tube boiler it was considerably higher than it was in the first class.

MR. W. H. PATCHELL (*Great Britain*), recalled his work twenty years before on the first big boiler. When they evaporated steam to develop 4,000 kW. on a reciprocating engine from one boiler, they thought they were doing pretty well.

In 1907, they made great progress and had never looked back. The straight tube, which used to be six feet from the floor, and was now anything from fifteen to twenty, and the big combustion chamber were really the secret of the big boiler. The boilers which were being put in at Trenton Channel would generate 20,000 to 25,000 kW. He expressed fear of nickel steel. It caused trouble enough to get work out of a boiler shop with straight steel. With a leaky roof, it was possible to get local hardening or to get troubles from which they would be very glad to be free. They had considered nickel steel three years ago in connection with the Trenton Channel boilers, but had decided against it, and they had been made of straight steel.

He had also been interested in the 1,200 lbs. boiler. The drums were four inches thick, and they had no weld in them. They were made out of a 200 ton ingot cropped down to 100 tons—a hole punched in the centre and expanded into a tube.

Sir Robert Hadfield had mentioned his steel, which would stand 900°C. They would have liked to have heard more about the use of it for boiler plates. There was much to be done yet before that material could be handled and made into plates. As regards the use of high pressure in itself, there was much to be said for it, and he was very glad indeed that he would see that 1,200 lbs. boiler in the course of the next two months. It was very pretty and easy to talk about exhausting into a turbine at that pressure, and then again into the ordinary steam main in the station. The steam supply for a 1,200 lbs. pressure turbine did not present very much difficulty; but if they remembered that they had 400 lbs. on the exhaust ends, and thought what size that exhaust end was going to be in the size of the turbine casing, and then thought how big a 400 lbs. joint was, they would be taking their faith in both hands when they made their joint on the turbine casing.

Mr. Tansley had mentioned two-stage economisers. He had seen two-stage economisers working: there was no harm in them at all. Which was the least trouble: two-stage economising with two separate sets of pumps, or some other methods of feeding their boilers? But he did not see that working in that way would eliminate the air from the feed water or enable them to do away with the de-aerators, which under high pressure were necessary.

Mr. E. KILBURN SCOTT (*Great Britain*), referred to the very high temperatures with pulverised fuel firing, and spoke of insulating bricks in the furnaces at Vitry which could be cut with an ordinary penknife, yet gave wonderful results in operation.

They were made of clay silica sand and carbon, and in burning, the carbon formed CO_2, and puffed up the material like dough.

Speaking of steels to withstand very high temperatures and pressure, Mr. Scott predicted trouble if there were free hydrogen present due to electrolysis or otherwise, as it was liable to pass into the steel and join with the carbon to form methane.

A DELEGATE, said that when the question of the use of economisers had been discussed, nothing had been said as to the absorption of waste heat. He had some data on two plants that were both the same age and had done about the same amount of work, one with economisers and the other without economisers. In one plant, there were twelve boiiers of 400 H.P. each, and they had had economisers installed when the plant was built. The plant had now been in operation for twenty-four years. In the other plant, the boilers had been installed without economisers. The economisers had fully proved that they did not only absorb waste heat, but acted as a boiler preserver; that is, the length of life of the boilers was increased by the use of economisers. In this particular plant, the biggest percentage of the feed water was make-up water. In the make-up water, drawn from a river, there was a great amount of scale-forming material. The cast iron economiser tubes absorbed a great percentage of these impurities, which otherwise would have gone to the boilers. Therefore, an economiser was a boiler preserver, as well as an absorber of some of the waste heat.

In connection with another remark that had been made, that the lower tubes of boilers did the greater portion of the work, he did not agree with that at all. If that were true, why did they not make a low boiler, and only have about half-a-dozen tubes high? Why did they build them so high, if the rest of the boiler did not do any of the work? He thought he had proved that the tubes did work to a considerable extent. About two months ago, in cleaning a boiler, they had taken the lower row of tubes and picked the whole of the scale that came out of it, and had put them into pans and marked the pan "No. 1 row," the bottom row. They had put them on the top of the boiler to dry the scale, and had then done the same with the second and other rows. This boiler was fourteen tubes high and fourteen tubes wide. They had found that the upper row of tubes had only 21 per cent. less scale than the

lower row of tubes. Consequently he thought it was wrong to assume that only the lower row of tubes in a water tube boiler did an appreciable amount of evaporation.

PROF. H. J. SPOONER (*Great Britain*), said that he would like to say a word or two about Mr. Jacob Perkins, whose son, Mr. Loftus Perkins, so splendidly carried on the experimental and pioneer work in high pressure steam. Just a hundred years ago, 1824, Mr. Jacob Perkins' application of these extraordinary high pressures had been before the public in the shape of his well-known steam gun. But the enormous pressures concerned in the working of that instrument of destruction had restricted its use.

If they were to make any reference to historical matters, they must get their history right; they must give credit to whom credit was due. Now, Mr. Loftus Perkins, by the mid-seventies, had had a number of tublar boilers working at a pressure of something of the order of 450-500 lbs., and when the Admiralty Committee on Boilers had been formed, they had got permission to examine one of them; after having taken out three tubes from different parts of the structure, they had been amazed at the wonderful condition of the internal surfaces of the tubes. In the experimental work that he had had to do under Mr. Loftus Perkins, he thought he had dealt with pressures up to 800 and 1,000 lbs. As to water gauges, he believed it was Mr. Loftus Perkins who had invented the mica gauge. Of course, it had been quite useless to attempt to use a glass gauge for these pressures.

DR. MÜNZINGER, said that nearly all recent publications and all the Conference papers on high pressure boilers were based on present-day designs. This applied equally to sectional and to vertical tubular boilers. The salient features of all these boilers had been designed under entirely different conditions about forty years ago, and were therefore little suited for the demands of modern operation. What was required was a radical departure from present designs. Two points were absolutely essential in that connection. First, absolutely pure and neutral feed water; the solution for this problem was still to be found. Secondly, flue gases entirely free from soot; a problem which was already met by pulverised coal firing.

Some gentlemen had expressed doubt as to whether nickel-steels were fit for boiler plates and had hinted at unsatisfactory experience with such steels for turbine blades and similar purposes. But alloy-steel for turbine blades, etc., contained 25 per cent. of nickel, and was a so-called austenitic nickel steel, whereas the nickel steel produced by Messrs. Krupp had only 3 to 5 per cent. nickel and a so-called perlitic structure, *i.e.*, it did not alter its structure in the range of temperatures in question.

MR. W. L. R. EMMET (*U.S.A.*), said that there had been during the meeting prolonged discussions concerning historical precedents for certain steam practices. It was fortunate that there was no history behind his own process, although something had been suggested before in the way of thought on lines theoretically similar. His attention had been drawn to the idea a number of years ago, but there had been a vast amount of special knowledge necessary to develop it. A short time ago he had published in the Journal of the American Society of Mechanical Engineers a paper which gave a full account of the work which he had done to date on this process. The plant installed at Hartford had been designed to give about 1,800 kW. from the mercury turbine. It had never been run above 1,500 kW. because there were certain shortcomings in the boiler. The boiler at higher loads was subject to certain expansion strains which developed minute leaks; while running at lower loads these strains were absent. This equipment had been designed two and a half years ago, and since then he had been continuously experimenting, and had developed a very much more practicable form of boiler. This boiler was illustrated in his paper, entitled: *Power Mercury Vapour.*

He was interested in what Sir Robert Hadfield had had to say about the possibility of high temperature steels, because he was approaching in the mercury vapour very close to the boiling point of steel; but he had run

successfully with pressures of 35 lbs. per square inch gauge or 812°F., without burning the steel. The conditions of boiling mercury were very peculiar. It did not wet the interior surfaces, and the heat transmission in the tube was greatly impaired by the formation of vapour. It produced a condition like water rolling on top of a red hot stove. To the liquid which was a good conductor, it delivered heat rather readily, and if there were sufficient circulation on the heating surface, it was possible to transmit a large flow of heat.

In the condenser boiler where steam was made by the condensation of the mercury vapour, the action was very good. They had delivered as much as 750 B.Th.Us. per degree difference of temperature per hour per square foot on this condenser, which was very large compared with steam. There was a vacuum of 29½ ins. in the condenser, and only 7 degrees temperature difference between the condensed mercury and the steam coming out of the pipe. To make a process of this sort practicable, it was necessary that it be 100 per cent. right, because they could not afford to release mercury and they must not lose it. He had built about fifteen to twenty mercury boilers altogether, but had never lost any appreciable amount of mercury. To work the mercury process to high pressures, it would be necessary to take ordinary steel and protect it by the system known as calorising, or to use such steels as Sir Robert Hadfield had mentioned in his paper. Calorising was a method developed in the research laboratory of the General Electric Company of America, which consisted in impregnating the surface of steel with aluminium. The aluminium penetrated to a certain distance, and it rendered the steel immune from oxidation to a high degree of temperature.

One gentleman had pointed out that gas velocity was wanted in the cold end of a boiler, but not in the hot end. That had been wonderfully illustrated in experience with mercury boilers. If the laws of radiation were applied to a boiler, it would be seen that in the hot end of a boiler, radiation cut a very large figure, and in the mercury boiler, all of which was operating in a zone of appreciable heat delivery by radiation, the heat transfer had been astonishing per unit surface. They had taken gases out of boilers of very small area, much colder than they would expect from general data on such subjects.

Another possible application of the process was the propulsion of ships. There was no reason why the mercury process should not go into ships ; and he had shown in his paper a drawing of a ship. It was a 3,000 H.P. vessel, showing the space occupied by equipment propelled by mercury. In making this comparison, he took a vessel which was now driven electrically from turbines.

With reference to high pressure steam, it was to be remembered that in high pressure steam, the heat of the liquid was relatively large in proportion to the heat of vaporisation. The higher they went in pressure, the more important it was to return the heat of the liquid by extracting steam for feed heating. If they did adequately return the heat of the liquid in high pressure steam, then it was hard to find anywhere to put the heat in the gases, because they could not use it in economisers. Theoretically, to use high pressure steam they must abandon the economiser.

With the mercury process, theoretically, air heating was peculiarly desirable, because by air heating they could deliver heat to the mercury ; whereas by an economiser they must deliver it to the steam, and it was desirable to put the heat on the top of their cycle.

MR. SAMUEL FERGUSON (*U.S.A.*), stated that Mr. Emmet's paper adequately described his revolutionary mercury system now in operation in one of the plants of his company. The unit was run daily by the regular station operators, and without difficulty, and on a commercial schedule of operation. It was interesting to note that in June 1924, 14 per cent. of the company's output, was generated by this method. This was more than experimental operation. They had operated long enough to feel sure that there were no inherent fundamental difficulties, and that commercial application was only a question of proper detail of design. They hoped that the operation of this first experimental unit had given the designing engineer sufficient data.

DISCUSSION

MR. T. NORDENSSON (*Sweden*), said that mercury after all was very much less abundant in nature than water. Was there no danger, if Mr. Emmet's system were going to be generally adopted, that the price of mercury was going to rise to such an extent that it would be prohibitive to work without steam? It would be very interesting to hear something of the price and supply of mercury.

MR. EMMET, said that with regard to the supply of mercury, all sorts of opinions had been expressed. The cost of mercury depended largely upon the richness of ore and the cost of mining. He had had various opinions, including the opinions of four of the largest and most experienced mercury producers in the United States, and every one of them had predicted that they would get all the mercury that they would want, even if they wanted four or even six times the present output of mercury; the idea being that the price would be raised possibly up to two or three dollars a pound, and on that basis the world would be ransacked for it.

DR. JACOBUS, said that at one time there had been a great many people who were just as sceptical in regard to the future of the steam turbine, as some, and probably the majority, were to-day with regard to this mercury cycle. Mr. Emmet had the enterprise and enthusiasm that had inspired his Company to build the first large steam turbines, which were used by Mr. Insull of the Commonwealth Edison Company of Chicago, in which development the late Mr. Fred Sargent had played an important part. After seeing the successful issue of his work on the steam turbine, he had turned during the war to the development of an electric steamship drive, where he had again made a success. He had now made possible the generation of power by the use of mercury, in a way that had given the highest theoretical efficiency, and had added another achievement to those that had gone before, any one of which would have served as a fitting memorial for the work of a lifetime.

MR. FERGUSON, stated there was one matter in connection with the mercury process which had not been clearly demonstrated, *i.e.*, the high temperature which was associated with the low pressure. Their difficulty had been to get a material that would stand a high pressure and a high temperature; he thought that the mercury process overcame that difficulty, because with the relatively low pressure they could have a high temperature, say, at 900°, which was quite possible with the mercury process, and steel could take care of that combination.

THE CHAIRMAN then closed the session.

STEAM UTILISATION

CHAIRMAN: MR. JOHN W. LIEB (U.S.A.)

Past President, American Institute of Electrical Engineers

STEAM TURBINES

HON. SIR CHARLES A. PARSONS, K.C.B., F.R.S.

I. THE STEAM TURBINE ON LAND AND AT SEA.

The modern compound steam turbine commenced its development for land purposes in year 1884; it gradually and steadily grew in size, and though at first it earned the name of ".steam eater," it soon improved and in a few years (by 1892) was able to rival the best reciprocating engines in economy of steam and coal for the generation of electricity.

At this period (1894 to 1897) it also entered into the field of marine propulsion.

On land, turbo electric generating units have been developed to very large sizes, ranging up to 60,000 kW., and in all large electric power stations using fuel, steam turbines now provide the motive power. Some of these stations reach a capacity of 500,000 kW., feeding into wide-spread distribution systems and covering large areas.

Land turbines having developed under less restrained conditions than those ruling on board ship, have led the way in economy of steam, and every means has been explored to render large power plants for the generation of electricity as thermally efficient as possible.

Considerable advance in thermal efficiency is being made at the present time. The structural design and the blading of the turbine having been developed to such an extent as to give nearly the maximum efficiency of conversion of the available energy of the admitted steam, attention has been turned to increasing this available energy by extension of the thermo-dynamic cycle. This involves progress in the performance of boilers and superheaters. By the use of higher steam pressures and temperatures together with the lowest possible exhaust pressure, and by other devices to be described later, it is expected in the future to reach an overall thermal efficiency (from fuel to electricity) of 30 per cent. which is not inferior to the best results attained by oil engines, even neglecting the cost of oil for cylinder lubrication.

On the electrical side improvements have been made in the design of large high-speed alternators. The high-speed alternator of large power, although having no great advantage as regards efficiency over the low speed type, is lighter for a given output, and occupies less engine room space, both important advantages. Moreover, it can be directly coupled to its steam turbine running at high revolutions, which is conducive to the highest overall efficiency.

High-speed alternators have a further advantage in that they can as a rule, even in the case of very large outputs, be finished at the manufacturers' works, with the stator core and windings complete; an important consideration from a constructional point of view. This is not the case with large output alternators of the low-speed type, owing to their great size and the limitations imposed by considerations of transport and shipment.

In marine work progress has been no less rapid, the direct coupled turbine of 1897 having been superseded in 1910 by the geared turbine, and the marine turbine has advanced in power from the 2,000 S.H.P. of the "Turbinia" to the 150,000 S.H.P. of H.M.S. "Hood."

The association of the turbine, essentially a high speed engine with a low speed propeller, put the marine turbine at a serious disadvantage so long as it remained directly coupled to the propeller shaft. The conditions for high propeller efficiency and high turbine efficiency were antagonistic, particularly in vessels of low speed. In spite of this difficulty, the direct coupled turbine soon established its superiority over the reciprocating engine for the propulsion of high speed vessels, such as warships, liners and channel steamers. A great advance was made by the introduction of gearing, the turbine having since been successfully applied to practically every class of vessel, and considerable improvement in economy effected by the increased efficiency of turbine and propeller when these are allowed each to run at its most efficient speed of rotation. The direct coupled marine turbine has now been completely displaced by the geared turbine.*

In the early direct turbines, the steam consumption was from 15 to 16 lbs. per horse power hour. With a geared installation of 3,000 S.H.P. consisting of three turbines and coupled to the propeller shaft through double reduction gearing, the consumption

* A full account of the adoption of geared turbines in the vessels of the British Navy was given by Engineer Comm. Tostevin, in a paper read before the Institution of Naval Architects in March, 1920.

has been reduced to less than 10 lbs. per S.H.P. hour for saturated steam, and 8 lbs. per S.H.P. hour with a superheat of 200° F.

Since the introduction of mechanical gearing the marine turbine has tended to become assimilated in type to the land turbine, the same conditions making for thermal efficiency, namely, high velocity ratios, high steam pressures and temperatures and high vacua, being equally applicable. Designs have been prepared for several marine installations of various powers on these lines, and proposals made to certain ship-owning companies. As an example, it is estimated that by such extension of the thermodynamic cycle, and with geared turbines designed for highest efficiency, the fuel consumption of a ship like the S.S. "Mauretania," at present driven by direct coupled turbines, could be reduced by over 40 per cent.

Mechanical gearing has also supplied the solution to the difficulties of the continuous current turbo dynamo. Moderate speed generators have now reached an output of 3,000 kW. from a single machine, the current collected from a single commutator being as much as 6,000 ampères, and, with the interposition of gearing, such generators can now be turbine driven.

Another considerable field of application for geared steam turbines is the driving of mills, such as textile, paper and jute mills. In these installations the high economy, powerful starting torque and smooth turning moment of the turbine are employed to great advantage. The last mentioned property is particularly advantageous in the case of mills in which the power is transmitted to the different floors by means of ropes, from a main rope pulley coupled to the prime mover through gearing.

It is estimated that the output of all the steam turbines built, both land and marine, has now reached the great total of over 120,000,000 horse power.

II. AN ANALYSIS OF THE PRESENT POSITION.

It is now well understood that in steam turbine installations where steam economy is of prime importance, pressure compounding, or the placing of many simple turbines in series on the steam flow, is essential; further, that one of the fundamental requisites for the attainment of high steam economy is the operation of the turbine at an appropriate overall velocity ratio, or ratio of mean blade velocity to steam jet velocity.

It is known from the laws of thermo-dynamics that the thermal efficiency of a heat engine depends chiefly upon the temperature range, that, in accordance with Carnot's principle, the temperatures at which heat is supplied and withdrawn should be as widely

separated as possible. A large temperature range must necessarily be accompanied by a large pressure range. This is exemplified in the case of steam by the fact that the latent heat, which is a large proportion of the total heat, is absorbed during the process of evaporation, and in order that this may take place at a high temperature, the boiler pressure must be high. Accordingly, the ratio of initial to final pressure in modern steam turbine practice is being increased, and in turbines under construction is in the neighbourhood of 1,500 to 1. The corresponding temperature range is from about 470° F. saturation temperature, raised to 750° F. by superheating, down to about 75° F., or a maximum drop of about 675° F.

It is interesting to recall that a century ago, the temperature range of the best reciprocating steam engines was so small that the disappearance of heat by conversion into mechanical work passed almost unnoticed, and that neither James Watt nor Sadi Carnot appreciated its real significance, in spite of Count Rumford's famous experiments on frictional heat in 1798.

In modern turbine design, there arises the fundamental question of high steam velocities versus moderate or low steam velocities. From the point of view of reduction of the number of stages, and therefore the overall length of a turbine for a given capacity, it is clear that high steam velocities are all to the good, but in proportion as the steam velocity is increased, the essential benefit of pressure compounding is sacrificed, for the advantage of that principle does not rest solely on the fact that the hydraulic head under which each simple turbine of the series works is reduced, but also on the evidence that the efficiency of conversion of the available energy of the steam into mechanical work in the nozzles and blading, decreases as the velocity is increased.

It will be recalled that de Laval's simple turbine, which to many would have seemed to offer the best solution of the economic utilisation of the enormous available energy in high pressure steam, fell short of anticipated results owing to the heavy nozzle losses which occur when very high expansion ratios are dealt with in a single pressure drop.

The high economy shown by the published test results of the Ljungström radial flow double rotation turbine, which operates with higher steam velocities than are usual in parallel flow practice, has been attributed by some mainly to the reduction of steam leakage at the glands and balancing pistons by means of a multiplicity of very fine labyrinth packings.

Recent researches in the laboratory, with fixed nozzles, but without blade rings, have confirmed that nozzle efficiency diminishes with increasing steam velocity, and it remains to find out the causes of this loss of efficiency and whether it may be possible to reduce or eliminate it.

Apart from the effect of jet velocity upon nozzle efficiency, there is also the fact that the stage efficiency of a steam turbine is lower with saturated steam than with superheated steam. Laboratory tests have proved that the weight of steam discharged by a nozzle using steam initially dry-saturated is appreciably greater than that which theory would indicate, and it is thought by some that the cause of decreased efficiency of stages using saturated steam is closely connected with this phenomenon. It is thought, in fact, that the steam, during expansion, becomes super-saturated, and does not give up so much of its latent heat as it would do under conditions of thermal equilibrium, with the result that the available heat for a given ratio of expansion is considerably less than that indicated by calculation on the basis of thermal equilibrium. This question is closely bound up with the thermodynamics of steam turbine design. All engineers engaged in such work are desirous of reducing the nozzle and blading calculations to as nearly an exact science as possible, and of placing test results of different turbines under different steam conditions upon a rational basis of comparison. Up to the present, although a good approximation has been attained, this problem cannot be said to have been completely solved, the influence of cumulative heat arising from expansion of the steam with a stage efficiency less than unity, and the above-mentioned fact of decreased stage efficiency in regions where wet steam is found having much complicated the problem. With regard to the design of blading of the impulse type, there are two schools of thought. One of these favours the proportioning of the passages so as to obtain as far as possible what is known as " free deviation "—in which the blades are arranged so as simply to deflect the steam jets issuing from the nozzles, without alteration to the steam pressure. The other favours the employment of a certain amount of pressure drop in the revolving blade passages. The latter procedure is conducive to higher stage efficiency, but involves some leakage radially over the shrouding, and also circumferentially in the case of partial admission ; in such cases the same principle is used as has for many years been standard in the case of reaction turbines, namely the adoption of large radial clearances, but reduced axial shroud clearances.

The question has arisen as to whether a compromise between the so-called " Impulse " and the so-called " Reaction " principle can be made to give a higher efficiency than either principle alone, and it is interesting to note that Impulse turbine builders and Reaction turbine builders are approaching this question from opposite standpoints. At the present time Reaction turbines are generally built with equal expansion ratio in the moving and guide rings of a reaction pair. Experiments have been made with a different division of the pressure drop, but up to the present, equal expansion ratio in the fixed and moving blading, and similar construction for these parts, have given the best all-round results.

Advance in the direction of increasing the thermodynamic value of the heat in the steam without unduly increasing the maximum temperature of the system, is being made by increasing its mean temperature of heat reception. One method of effecting this, is the adoption of regenerative feed water heating, by using steam tapped off from successive stages of the turbine. The necessity to heat the feed water, that is, to reheat the water of condensation, is the defect of the Rankine cycle. If, however, a perfectly regenerative process could be employed for heating the feed, the efficiency of the Rankine cycle for saturated steam would be brought up to that of the Carnot cycle. In such a process the steam tapped off has been expanded, doing work in the turbine, down to the temperature at which it is required to heat the feed water. Since a certain amount of heat is required for this purpose in any case, the work obtained from the tapped off steam is obtained merely at the expense of additional heat equal to the work done, or in other words at nearly 100 per cent. efficiency. Expressed in another way, the utilisation of some of the heat of the steam to heat the feed water reduces the amount of heat that is lost by condensation in the condenser.

A slight practical objection to such a system of feed water heating is the additional complication of the pipework involved, if a sufficient number of feed water heaters in cascade are employed to approximate to a thermo-dynamically reversible process ; but even with two or three stages, very considerable heat economy can be effected. As a compromise, feed water heating by steam extraction from a few stages of the turbine, in conjunction with economisers, is generally accepted practice in modern power stations, but there is a tendency to develop this system further so as to attain higher feed water temperature by the steam heating. It then becomes necessary as an alternative or partial alternative to the economiser,

to adopt some other means of absorbing the residual heat of the flue gases, such as a regenerative preheating of the air for the furnaces.*

As a second method of increasing the mean temperature of heat reception, an advance might be made if after superheating to the maximum temperature, further heat were added so as to maintain isothermal expansion throughout the initial stages of the turbine. This could only profitably be carried to such a point that subsequent adiabatic expansion in the turbine to the condenser vacuum would leave the steam just saturated. Such a method (of preliminary isothremal expansion) was proposed many years ago but the mechanical difficulties in the way of its complete realization would appear insurmountable. An approximate solution, however, is being worked out at the present time; in some installations the steam, after a certain amount of expansion in the turbine, is extracted and raised again to a high temperature in a reheater before re-entering the turbine. Reheating has also the additional advantage of extending the superheated field, and therefore of diminishing the range wherein moisture exists with consequent loss by water resistance, supercooling or increased viscosity. This process might, of course, be extended to include reheat at various stages of the expansion. With a single reheat a compromise must be accepted when selecting the stage at which the steam is taken from the turbine. If reheating is carried out too soon then the heat added—although at a high mean temperature—is only of small amount. On the other hand, if reheating is carried out too late, then the heat added—although of greater amount—is received at a lower mean temperature, so that the mean temperature of reception of the cycle is not much improved.

If a curve be drawn showing the estimated percentage gain in thermal efficiency on a base of the proportion of expansion carried out before reheating, it is found that there is a fairly definite peak indicating the most appropriate reheating point. The maximum estimated gain in the case of a single reheat to the initial temperature of 750° F. is in the neighbourhood of seven per cent.

Since reheating the steam increases the total available heat per lb. more blading is required in the turbine to maintain the same average

* Feed heating in a single stage by partly expanded steam is a well known procedure; it was proposed by James Weir in 1876, by Normand in 1889, and in progressive stages by Ferranti in 1906; with marine turbines it is general practice to utilise the exhaust steam from the auxiliary engines, at a pressure slightly above atmospheric for this purpose. Similar use can be made in power stations of any low grade heat that is available, such as in steam from turbine glands, ejector air pumps, etc.

velocity ratio; this and other considerations tend towards the desirability of carrying out the expansion in two or more separate cylinders, the exhaust steam from any one cylinder being reheated before entering the next. Where such reheating is adopted special means must be provided to prevent over-speeding of the machine owing to the large volume of steam stored up in the reheater and connecting pipes.

A third method of attacking the same problem is to increase the mean temperature of the heat reception by increasing the boiler pressure.

With a boiler pressure of 250 lbs. per sq. inch, a final temperature of 750° F. after superheating, and a feed water temperature of 79° F., the mean temperature of heat reception is about 360° F. But if the boiler pressure is increased to say 2,000 lbs. per square inch, still superheating to 750° F., then the latent heat is received at the increased temperature of the boiler, and the mean temperature is considerably increased, namely to 480° F. If, in addition, we assume the water is fed into the boiler at the boiling temperature by means of feed heaters in cascade in each case instead of at 79° F., the mean temperatures of heat reception are increased in the one case to 430° F., and in the other to 680° F.

Whilst such a pressure as 2,000 lbs. per square inch has not been actually adopted in any commercial plant, there seems to be no reason why it should not be practicable in a large steam turbine installation. In such a case there may be a small auxiliary high pressure turbine, having several stages of small diameter, running at high revolutions, and after dealing with the first few expansions, exhausting into turbines working at ordinary pressures. Such high pressure turbines are actually being built—one in this country for a pressure of 1,500 lbs. per square inch, and one in the United States of America for 1,250 lbs. per square inch.

With regard to the lower end of the temperature range the temperature of the cooling water here imposes the limit. An exhaust vacuum equivalent to 29·25 inches of mercury (barometer 30 inches) can be realised under favourable circumstances. This, however, involves the necessity of providing ample blade area and passage way for the great volume of low pressure steam.

Throughout the stages of a turbine, the criterion of efficiency is the velocity ratio, and the areas of the blade passages successively increase in such proportions as to provide the proper ratio between the blade velocity and the steam velocity. The axial component of the steam velocity is carried on from stage to stage without

appreciable loss. It is even built up to higher values as the peripheral and steam velocities increase. Its final loss at the exhaust end of the turbine, however, is practically unavoidable, and with the high peripheral speeds adopted in most low pressure blading at the present day, an exhaust blade area which gives a perfectly satisfactory velocity ratio may entail a loss of energy in the issuing steam, of considerable amount. Such loss is augmented if, for the sake of weight or cost, any sacrifice is made of the final velocity ratios, which sacrifice might otherwise be a perfectly justifiable compromise. It is evident, therefore, that the exhaust end of a turbine requires separate treatment in its design from the point of view of limitation of the leaving loss, that is, the energy lost in the issuing steam.

Broadly speaking, where high efficiency is the aim, this consideration imposes a limit upon the axial velocity of the steam in the final annulus. For a given vacuum, therefore, the area of the final annulus must increase in proportion to the output, and for a given output any increase in the vacuum involves an increase in the area of the final annulus. It will be seen, therefore, that any effort to extend the steam cycle by lowering the temperature of condensation, brings at once into prominence the problem of the exhaust end.

Various expedients have been adopted for the purpose of surmounting this limitation. One method, commonly employed in both land and marine turbines, is to carry out the final stages of the expansion by divided flow, as for example in a double ended low pressure turbine, the steam entering at the middle and flowing in each direction towards an exhaust at each end. In such an arrangement two exhaust pipes are provided and frequently two condensers. In another example of divided flow, some makers double only the last row or last few rows of blading, employing specially shaped passages to conduct the steam to the divided portion from the preceding stages.

The design of exhaust end advocated by Baumann is another attempt to overcome the same difficulty. In this device, instead of carrying over a part of the steam by special ports to additional blade rings, it is made to flow through inner annuli of the preceding blade rings, the vanes of these inner annuli being specially shaped to reduce the resistance involved to a minimum.

The area of the final annulus can be increased by increasing the blade height, and any means of extending the height permissible on a given diameter, is valuable for this purpose. Thus in many

turbines, the blades of the last stages are made of varying section and discharge angle, permitting a greater length ratio without unduly increasing the stress.

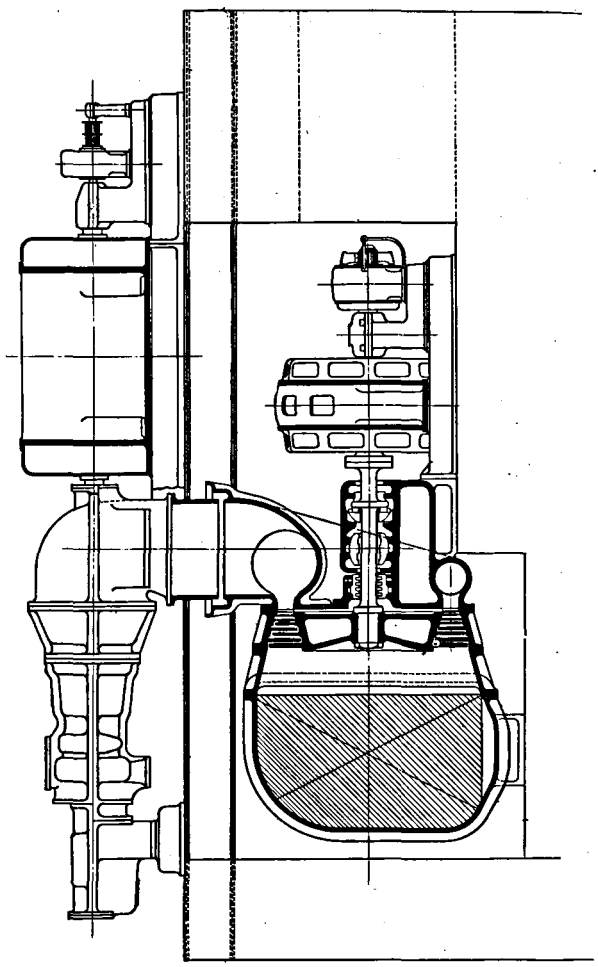


Fig. 1.
Scheme for Utilisation of High Vacuum (diagrammatic).

If no restrictions are imposed either upon the diameter of the exhaust end or upon the speed of revolution, a simple and probably the best solution of the exhaust area problem in large machines,

is to provide a separate low speed turbine of large diameter for the final stages of the expansion, having blades of normal profile throughout, and correspondingly high efficiency. This low speed turbine can be arranged in close proximity to the condenser, as illustrated diagrammatically in Fig. 1, so as to reduce to a minimum both the length and the resistance of the exhaust passages.

In the exhaust passage itself, it is not sufficient to provide area to reduce the mean velocity of the steam passing through it to a moderate value, but the exhaust steam must be distributed into the passage uniformly, so that the velocity is everywhere nearly the same. Neglect of this requirement leads to unnecessary hydraulic losses, and may also cause troublesome blade vibration in the final stages.

Many attempts have been made to obtain the benefit of the diffuser principle, which has been so commonly adopted in the case of water turbines, but in the case of steam turbines without substantial success. In any attempt to carry this principle into effect, ample exhaust pipe area should be provided, with progressively larger cross section on the way to the condenser, so that the exhaust steam from the last row of revolving blades is gradually slowed down, with a possible recovery of static head.

The practical difficulties in the way of such recovery of pressure in the exhaust steam are very great, and the best that can be done in this direction would appear to be to utilise the leaving velocity of the exhaust steam to overcome the resistance to flow in the exhaust passages, so that the absolute pressure at entry to the condenser is the same as at the exit from the blading.

III. AN APPLICATION OF THE FOREGOING PRINCIPLES.

Summarising the foregoing, there are four methods of improving the thermal efficiency of the thermo-dynamic cycle without increasing the maximum temperature :—

1. Increased feed water temperature, with regenerative heating of the feed water by steam drawn from the turbine.
2. Increased boiler pressure.
3. Reheating of the steam after partial expansion.
4. Increased vacuum and means to utilise it effectively.

An application of these principles is made in the turbine plant of 50,000 kW. normal capacity to be erected in the new Crawford Avenue Power Station, Chicago, and now nearing completion at Newcastle-on-Tyne. In this plant there are three cylinders in series on the steam flow, each driving an alternator, the three alternators being electrically coupled in parallel.

STEAM UTILISATION

Steam is generated at 600 lbs. pressure and supplied to the stop valve of the high pressure turbine at 550 lbs. pressure, superheated to 750° F. After expansion in the high pressure turbine to a pressure of 100 lbs. above atmosphere, it is led back through a well lagged pipe into a reheater in the boiler house from which it is returned to the I.P. turbine at a temperature of 700° F. The H.P. and I.P. turbines run at 1,800 R.P.M. and drive alternators of 15,000 kW. and 30,000 kW. capacity respectively.

Further expansion takes place in the I.P. turbine to a pressure of about 2·0 lbs. absolute, at which pressure the steam enters the L.P. cylinder, to be expanded to the condenser vacuum of 29·25 inches of mercury (barometer 30 inches)*

The low pressure turbine drives a 5,000 kW. alternator at 720 R.P.M. Owing to the lower revolutions of this turbine, the area provided in the final stage is so large that blades of normal profile, but set at a slightly greater discharge angle, can be employed. The steam is condensed in twin surface condensers with the tubes vertical and having a total surface of 56,000 square feet. Fig. 2 is a sectional elevation of the I.P. and L.P. units. The whole installation of turbines, alternators and condensers is illustrated in Figs. 3 and 4. Fig. 3 is a photograph of a model which can be seen on stand A8, Avenue 8, in the Palace of Engineering.

About 22 per cent. of the total steam entering the turbine is used for feed water heating; it is extracted from the turbines at three points, the feed water being heated up from 65° F. to 315° F. in three stages before entering the economisers.

A heat consumption of 10,265 B.Th.U. per kWh. is anticipated, or a thermal efficiency (from steam to electricity) of 33·2 per cent.

For recovery of the heat in the flue gases, economisers are used for a final stage of feed water heating, and air preheaters, a regenerative process being employed in the latter to heat up the incoming furnace air.

The boiler plant is expected to have an efficiency of 86·5 per cent. After allowing about 3 per cent, for the total power absorbed by the auxiliaries, an overall thermal efficiency (from fuel to electricity) of 27·80 per cent. is anticipated. This is on the basis of a boiler pressure of 600 lbs. per square inch. A schedule is given in the appendix of the thermal efficiencies it is estimated could be realised with higher boiler pressures, up to 2,000 lbs. per square inch.

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* The condensing water is obtained from Lake Michigan and its temperature is as low as 35°F. during the winter months.

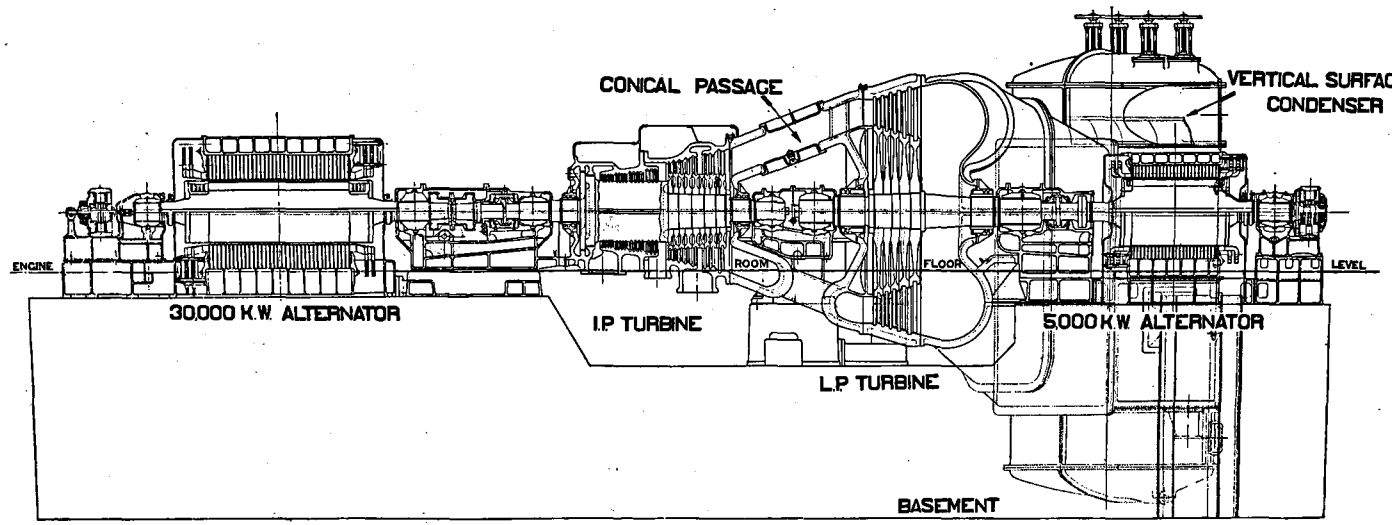

Fig. 2
Sectional Elevation of Intermediate Pressure and Low Pressure Turbo-Alternators of 50,000 kW. Plant.

Some details of the turbines and alternators will be of interest.

The three cylinders contain 64 simple turbines arranged in series, the first having blades $2\frac{1}{2}$ in. long and $\frac{3}{4}$ in. wide on a mean diameter of $30\frac{1}{2}$ in. and the last having blades 40 in. long and $3\frac{3}{8}$ in. wide on a mean diameter of 160 in.

In view of the low density of the steam, the passages from the I.P.

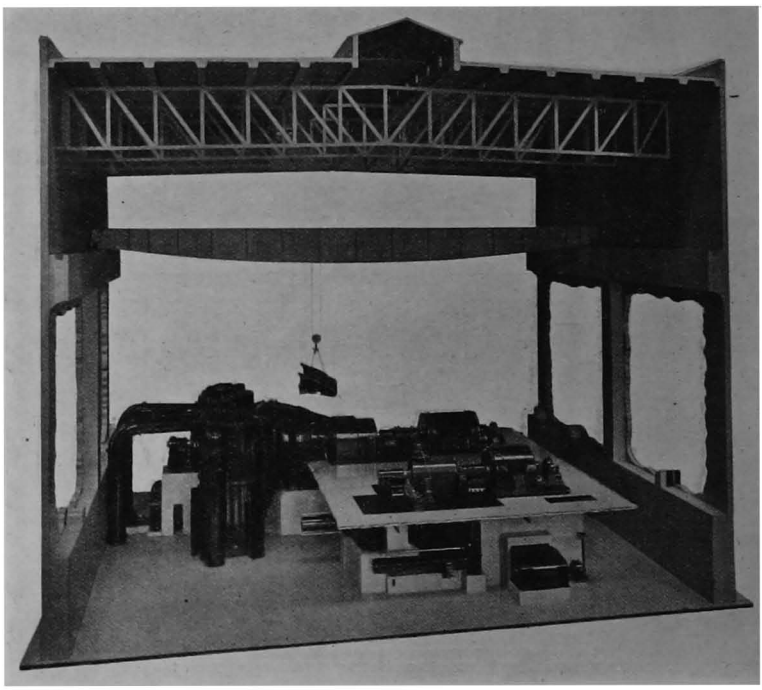

Fig. 3.

Reproduction from photo of 1/12th scale model of the 50,000 kW. plant for Chicago, exhibited at The British Empire Exhibition.

turbine onward have been specially designed to have the minimum of resistances and to avoid any sudden enlargements which would produce eddies or shock. The I.P. turbine discharges its steam directly into the L.P. turbine through a conical annular space surrounding the intermediate bearings, and the energy of the leaving velocity of the I.P. exhaust is thus conserved. (See Fig. 2).

The maximum blade tip velocity is reached at the last ring of the I.P. turbine, where it is 760 feet per second; in the L.P. turbine, which runs at 720 R.P.M., the maximum tip speed is 626 feet per second. (Fig. 5).

On the constructional side the most important feature of a turbine is its blading. There is probably no other part upon which so much

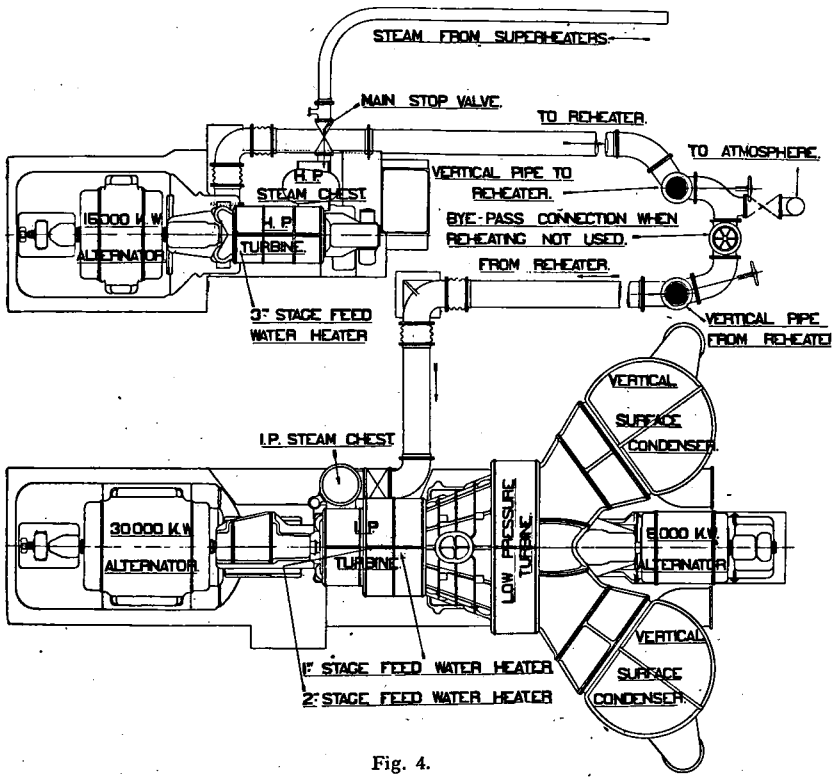

Fig. 4.

Arrangement of 50,000 kW. Turbo-Alternator and Surface Condensers, shown in plan.

ingenuity has been expended, and there are wide differences in practice both as regards materials used and the methods of manufacture and of attachment. The best known system is that in which the blades are made of rolled brass strip fixed into the rotor or casing by caulking spacing pieces between the blade roots.

This system has been widely adopted in the past for both land and marine turbines, and has proved very satisfactory where the stresses and temperatures are moderate. When properly carried out, this method gives a strength of attachment practically equal to the breaking strength of brass blades.

Many manufacturers and users now favour blades integral with their roots, and with such a formation higher stresses can be employed with suitable material. Such integral blades have until recently been formed by milling from the solid bar.

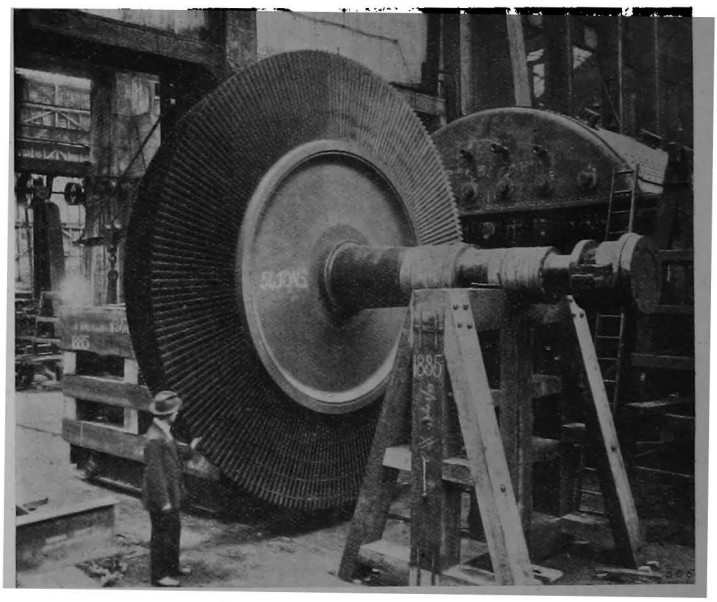

Fig. 5.

The rotor of the Low Pressure Turbine of the 50,000 kW. plant for Chicago.

The roots are machined to suitable shapes or are serrated and attachment is effected by driving up the combined pieces in accurately machined or serrated grooves or slots.

Recent improvements in the methods of manufacture have, however, been developed at Heaton Works by means of which it is now possible to roll the blade integral with its root or spacing piece, and at the same time to form a radius at the junction of the

two. This method of manufacture has the advantage of retaining the valuable feature of working the material so that the grain or fibre is developed into the right direction for strength. It also subjects it to a strenuous test and has been found to detect faulty material with considerable certainty.

For these reasons such methods of rolling give a superior product to that attainable by milling from the solid or by processes of drop forging or stamping, and are at the same time less costly.

In the 50,000 kW. turbine previously mentioned, the blades throughout are of mild steel, formed integral with their roots by this method of rolling. They are fitted in serrated grooves in both rotor and cylinder, being inserted and driven up tight. The blades of the H.P. turbine and of the first half of the I.P. turbine are fitted with "end-tightened" shrouding made of manganese copper and brazed over tenons on the ends of the blades. "End-tightened" blading was introduced commercially in the year 1912, and has been widely adopted in land turbines of the reaction type and in several mercantile marine installations. In this type of blading the necessary running clearances are maintained in an axial direction, instead of radially, so that they can be made small, and adjusted and regulated under the control of the thrust bearing, which determines the position of the turbine shaft axially in its cylinder. The minimum radial clearances of the portion of the blading that is end tightened is $\frac{1}{2}$ in., whilst the radial clearances in the remainder of the blading range from $\frac{1}{8}$ in. up to $\frac{1}{4}$ in.

Each turbine shaft is fitted with an emergency governor and these are interconnected so that any one of them will trip all steam admission valves simultaneously and at the same time open a large vacuum breaking valve. In order to meet the special conditions that arise when reheating is adopted, the governing of the turbine has been arranged so as to avoid any danger of over-speeding due to stored steam. This is done by the provision of an independent governor valve on the inlet to the I.P. turbine, which receives steam from the reheater. The governor controlling this valve is set to operate at a speed about 2 per cent. in excess of that of the main governor, and with this lag will control the rate of steam admission to the I.P. turbine whenever the load on the plant is suddenly reduced. In case this valve should close for any reason, whilst the main H.P. inlet remained open, a relief valve of ample area is provided on the exhaust pipe of the H.P. turbine and set to open at 130 lbs. per square inch above atmosphere, whilst an increase in

pressure to 140 lbs. will operate an additional tripping device and shut off the main steam supply.

The alternators are wound for a three-phase supply at 13,000 volts, and embody the latest British practice. No main field

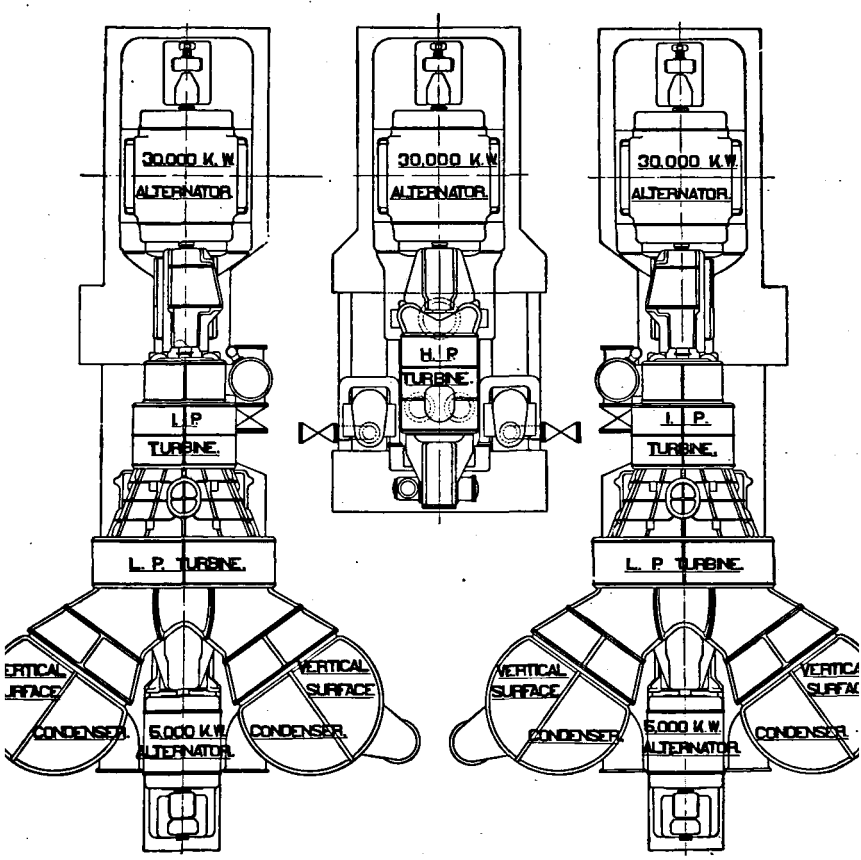

Fig 6.

Plan of scheme for increasing the capacity of the Turbo Alternator in Fig. 4 to 100,000 kW.

regulators are used in their operation, the regulation being carried out by means of well designed exciter field rheostats.

The ventilation is effected by means of the closed circuit system employing surface air coolers and separately driven fans, which

TABLE SHOWING THE OVERALL THERMAL EFFICIENCIES WHICH IT IS ESTIMATED COULD BE REALISED WITH INCREASED BOILER PRESSURES, UP TO 2,000 lbs. PER SQUARE INCH.

(Based on the Callendar Tables and Formulæ for the properties of steam).

Column No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Case No.	S.V.P. lbs. gauge.	S.V.T. °F.	°F. initial super-heat	Assumed reheat pressure lbs. abs.	Reheat temp. °F.	Restored super-heat °F.	Exhaust vacuum ins. Hg. Bar. 30·0″	Stage feed water heating from 65°F. up to (°F.)	Thermal efficiency (from steam to electricity)	Assumed boiler plant efficiency (including all aux.).	Overall Thermal efficiency (from fuel to electri-city).	Per cent. Re-duction in fuel consump-tion.	Equivalent lbs. of fuel oil per B.H.P. hour.
I.	250	750°	344°	65	700°	402°	29·25″	360°	31·6	84·0	26·52	——	0·501
II.	500	750°	281°	100	700°	372°	29·25″	420°	33·5	83·5	27·97	5·45	0·475
III.	1,000	750°	204°	150	700°	343°	29·25″	510°	35·2	83·0	29·20	10·08	0·455
IV.	1,500	750°	153°	250	700°	299°	29·25″	550°	36·6	82·5	30·20	13·82	0·440
V.	2,000	750°	114°	400	700°	254·5°	29·25″	600°	37·5	82·0	30·75	15·90	0·432

NOTES :—

S.V.P. = Stop valve pressure.

S.V.T. = Stop valve temperature.

Feed water heated to within about 50°F. of boiler temperature by means of steam withdrawn from turbine blading at several points.

Boilers equipped with economisers or air pre-heaters or both, so as to recover heat from the flue gases and maintain high thermal efficiency.

Dynamo efficiency taken as 96·5 per cent. at full rated output.

Gross calorific value of fuel oil taken as 18,500 $\frac{\text{B.Th.U.}}{\text{lb.}}$

have a much higher efficiency than high speed fans integral with the rotor shaft.

The stator frames are being built in one piece, and the alternators are to be shipped completely wound.

Since, when starting up the plant, there will be insufficient steam to drive the L.P. turbine, the alternator coupled to this turbine will be run up as a synchronous induction motor. The three alternators will then be synchronised together and operated as one unit, giving a combined normal output of 50,000 kW.

The Crawford Avenue Power Station has been laid out for a total capacity of 500,000 kW. Fig. 6 shows how readily such an installation as the one described can be developed into one of 100,000 kW. without increase of the largest component units by replacing the H.P. unit by one of double the steam capacity, and by duplicating I.P. and L.P. units. There would thus be three alternators of 30,000 kW. output and identical design, and two smaller alternators of 5,000 kW. driven by the low pressure turbines.

RÉSUMÉ.

Commençant sa carrière en 1884, la turbine à vapeur compound moderne est devenue le facteur principal dans le développement de toutes les grandes stations centrales utilisant du combustible, de même que pour les navires de guerre et les navires marchands.

A l'heure actuelle des progrès considérables sont effectués dans le rendement thermique et grâce à l'utilisation de pressions de vapeur et de températures plus élevées, à une pression d'échappement aussi basse que possible et grâce aussi à d'autres dispositifs qui sont décrits dans ce rapport, on espère arriver dans l'avenir à un rendement thermique global de 30 pour cent entre le charbon et l'électricité, rendement qui n'est pas inférieur aux meilleurs résultats atteints par les moteurs à huile lourde.

Dans la marine l'utilisation faite au début avec la turbine, qui est essentiellement une machine à grande vitesse, pour commander directement une hélice à faible vitesse, avait placé la turbine marine dans une situation très désavantageuse.

Un progrès important, cependant, fût réalisé par l'introduction de la réduction d'engrengages, la turbine ayant été depuis appliquée avec succès pratiquement à toutes les catégories de navires et une économie considérable ayant été réalisée par l'augmentation des rendements de la turbine et de hélice lorsque l'on peut faire tourner chacune, à sa vitesse de rotation la plus efficace.

Depuis l'introduction du réducteur d'engrenages, la turbine marine a eu une tendance à se rapprocher comme type de la turbine terrestre, les mêmes conditions existant pour le rendement thermique, notamment une haute vitesse périphérique, des pressions et des températures de vapeur élevées et un plus grand vide. On estime, par exemple, que par l'application similaire

du cycle thermodynamique avec des turbines à engrenages étudiées pour la rendement le plus élevé, la consommation d'un navire tel que le Mauretania, à présent commandé par turbines accouplées directement, pourrait être réduite d'environ 40 pour cent.

Le réducteur d'engrenages mécanique a également fourni la solution des difficultés de la dynamo à courant continu. Des génératrices à courant continu à vitesse modérée ont maintenant atteint une puissance de 3.000 kW. par unité, et avec l'interposition d'un réducteur d'engrenages de telles génératrices peuvent maintenant être commandées par turbine.

On estime que la capacité totale des turbines à vapeur dans le monde entier, à la fois terrestre et marine, a actuellement atteint un grand total supérieur à 120.000.000 de chevaux.

On sait que le rendement thermique d'une machine thermique dépend essentiellement de l'écart de température, et dans ce but la température initiale a été augmentée dans les installations modernes jusqu'à 750°F., ce qui constitue actuellement la limite.

Il y a toute fois au moins quatre méthodes différentes d'améliorer le rendement thermique du cycle thermodynamique, sans augmenter la température initiale. Ces méthodes sont :

1. Augmentation de la température de l'eau d'alimentation en chauffant l'eau d'alimentation par régénération à l'aide de vapeur prise à la turbine.
2. Augmentation de la pression de la chaudière.
3. Réchauffage de la vapeur après expansion partielle.
4. Augmentation du vide et moyens de l'utiliser effectivement.

Une application de ces principes à une installation actuelle a été faite sur un turbo alternateur de 50.000 kW. et son installation de condensation actuellement presque terminés à Newcastle-on-Tyne et qui seront installés ultérieurement dans la nouvelle station centrale de 500.000 kW. à Crawford Avenue, Chicago, U.S.A.

Les conditions d'établissement prévoient de la vapeur à 550 lbs. à la soupape d'admission, surchauffée à 750°F. ; elle sera ensuite réchauffée à 700°F. et le chauffage de l'eau d'alimentation poussé jusqu'à 315°F. à l'aide de vapeur extraite. On a compté sur un vide de 29,25″ de mercure (barométrique 30,00″), la température de l'eau de refroidissement pouvant atteindre 35°F., pendant les mois d'hiver.

Toutes les aubes sont en acier doux, chaque aube étant manufacturée en une seul pièce avec son bloc à l'aide de méthodes de laminage récemment mises au point et distinctes du système par fraisage, forgeage ou estampage ; l'avantage de ces méthodes de laminage réside dans le fait que la matière est travaillée de telle façon que le grain ou la fibre est développé dans le sens convenable pour résister aux efforts centrifuge et de flexion qui se produisent pendant le service de la turbine.

Les hauteurs des aubes varient de 2½″ de longueur sur un diametre moyen de 30½″ pour la première rangée d'aubes, à une longueur de 40″ sur un diamètre moyen de 160″ à la sortie du dernier étage de la turbine à basse pression.

On compte obtenir pour cette installation un rendement thermique global de 27,80 pour cent. (entre la combustible et l'électricité), en travaillant avec de la vapeur ayant les conditions spécifiées ci-dessus.

Une illustration (figure 6 de ce rapport) montre comment une installation de ce genre peut être étendue et transformée en une installation ayant une

capacité de 100.000 kW. ; sans augmentation dans les dimensions des parties essentielles les plus grandes.

Un appendice est également donné montrant les rendements thermiques (du charbon à l'électricité) que l'on estime pouvoir être réalisés avec des pressions de chaudières plus élevées atteignant jusqu'à 2.000 lbs. par pouce carré (140 kg. par cent. carré) en utilisant des températures correspondantes plus élevées pour l'eau d'alimentation à l'aide de vapeur extraite de la turbine.

Dans le but de faire une comparaison avec les résultats obtenus avec un moteur Diesel, et en supposant une valeur calorifique de 18.500 B.Th.U. par 1 lb. d'huile lourde, les rendements donnés dans le tableau correspondent à une consommation de 0,475 lbs. d'huile lourde par cheval-heure avec une pression de vapeur de 500 lbs., par pouce carré, et 0,432 lbs., par cheval heure avec 2.000 lbs. par pouce carré, ces chiffres comprenant la force motrice nécessaire pour entrainer toutes les machines auxiliaires requises pour la station centrale.

STEAM TURBINES FOR HIGH PRESSURES

Ir. C. F. STORK

The manufacture of steam turbines in the Netherlands was first undertaken by the Engineering Works Gebr. Stork & Co. They have taken up the construction of the well-known Zoelly turbine, co-operating with the German Zoelly Syndicate. This syndicate is made up of various German members besides the firm of Escher Wyss of Zurich.

The first turbine of 1,020 kVA. and 1,500 r.p.m., together with a generator from the Siemens Schuckert Works, was supplied to the Dutch Government Colliery " Wilhelmina " at Heerlen.

Within a very short period the designers of the Zoelly turbine raised the number of revolutions to 3,000, at the same time increasing the power ; finally, units of 8,000 to 10,000 kW. have been supplied of late years.

So far, the Engineering Works Gebr. Stork & Co. are the only Dutch Works that have supplied stationary steam turbines in the Netherlands. The construction of marine turbines of the Parsons, Zoelly and other systems has been undertaken by various large engineering works that are connected with dockyards (the " Maatschappij De Schelde " of Flushing, " Fijenoord " of Rotterdam, " Werkspoor " of Amsterdam).

Marine turbines have been applied as propelling engines in the new cruisers and torpedo boats of the Dutch Navy, in passenger steamers of the " Rotterdamsche Lloyd " and in freighters for various companies. Nearly all of them have single or double gearing.

Especially of late years, as far as the larger units are concerned, the designers of disc turbines have had to cope with difficulties resulting from high stresses of material and corrosion of the blades in the low pressure parts of the turbines. It has proved to be a rather difficult matter to find the happy mean between the various requirements that must be made for a good turbine : high economy, to be attained by high steam pressure and high superheating on the one side, and safety of working on the other side.

The keen competition has resulted in a struggle of the various

turbine builders to show low steam consumption figures, and it can hardly be denied that every single one of the designs that has been applied in order to obtain these figures has been made at the expense of the safety of working. This is the reason why, in the course of 1923, it was decided to design and to build a turbine on entirely new principles.

Some time ago, the main ideas on which the Erste-Brünner based their design was expounded in a lecture by one of the technical managers of this concern, Mr. Loesel. In the following paper I shall take various particulars from this lecture, as nothing can give a better insight into the fundamental principles underlying the design of the Erste Brünner turbine.

Even in authoritative technical literature it has been proclaimed that a steam turbine, as a rule, will not work very economically in the area of the higher steam pressure, and for that reason the designers have tried to use the low pressure area to the best possible advantage by raising the vacuum to the utmost. It is evident that a considerable improvement would be obtained, if makers could succeed in reconstructing the high pressure and high temperature area so as to attain a favourable economy.

There were three points to be investigated :

1. Is is possible to reduce the steam consumption, or rather the heat consumption of the turbine ?
2. Is is possible to improve the economy at partial load ?
3. Is it possible to improve the reliability, especially in the larger units ?

Up to the present time, a maximum pressure of about 18 kg./cm.^{2} (250 lbs. per square inch), and a superheating up to about 375°C. (710°F.) have been used almost exclusively. Such pressure and temperature are lowered as soon as possible in one Curtis wheel or in one or two large single bladed impulse wheels. At full load, the pressure after the first expansion stage is usually only 5 to 6 kg./cm.^{2} (70 to 85 lbs. per square inch), and this pressure is diminished proportionally at partial loads. Even at full load, this expansion is not economical, and it is still worse at partial load.

Only after the first stage does the turbine begin to work more economically. In fact, it may be said that up to the present time low pressure steam turbines (exhaust turbines) have been used. The " Erste Brünner Maschinen fabrik " (Czecho-Slovakia) came to the conclusion that the heat consumption can be improved, mainly by increasing the heat drop in the area of high pressure and by building a very economical turbine for this area. In order to

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explain the meaning, I show a curve that has been provided by Mr. Loesel. Fig. 1 shows the relation between the heat drop and the back pressure at various initial pressures. The horizontal line indicates the heat drop between 1 atm. and vacuum. When the initial pressure is high, the high pressure part becomes more important, and consequently will affect the total steam consumption to a greater extent. For instance, the increase in heat drop at 30 atm. (425 lbs./sq. inch) and 400°C. (750°F.) superheat is 21·7 per cent.; at 50 atm. (710 lbs./sq. inch) and 400°C. (750°F.) it is

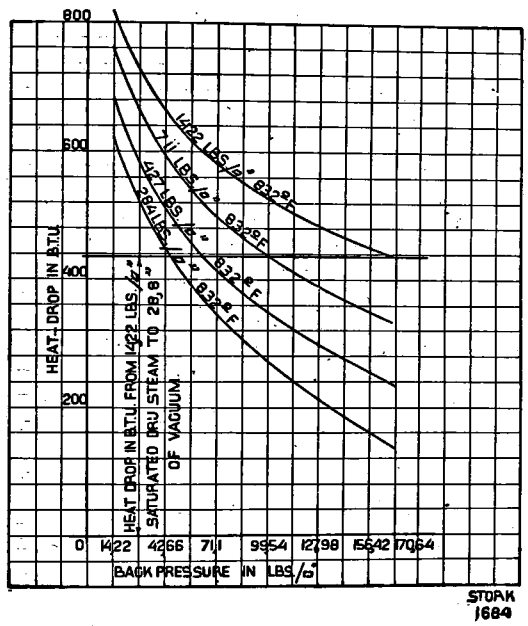

Fig. 1.

27 per cent.; and at 100 atm. (1,420 lbs./sq. inch) and 400°C. (750°F.) it is 30·7 per cent., as compared with the heat drop at 15 atm. (212 lbs./sq. inch) and 300°C. (570°F.) superheat and 93 per cent. vacuum (cooling plant).

The turbine designs that are known and have been executed cannot in an economical way take advantage of the heat drop, when this is increased in an upward direction; it is characteristic of all of them that in the first expansion stage, the steam will expand to a low pressure, in order to get low steam pressures and low temperatures

in the casing. Many firms will even mention this as an advantage. It is, however, clear that such a high pressure part which even now works much less economically than the low pressure part, may be called useless in the area of the higher pressures.

It is a well known fact that for the Parsons turbines and the reaction turbines, a quality figure has already been introduced which is applied by Brünn as a quality figure for the whole turbine.

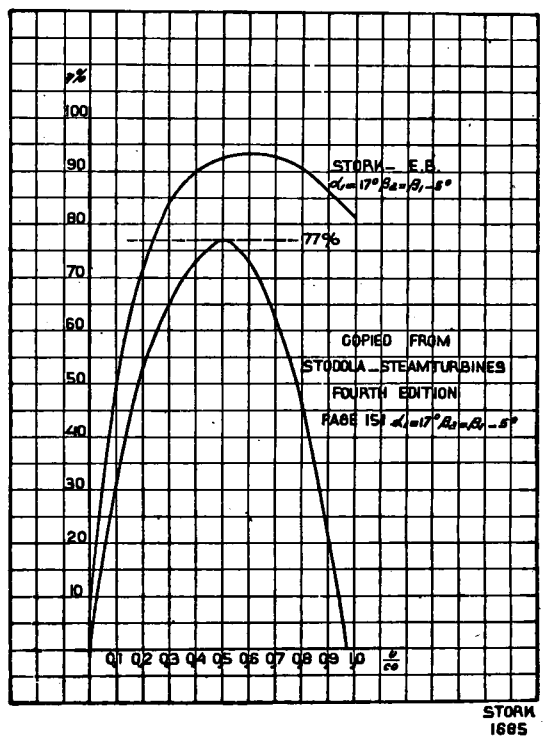

Fig. 2.

This is the coefficient: $\frac{\Sigma U^2}{H}$,

H being the total heat drop and

ΣU^2 the sum of the squares of the circumferential speeds of the blades, which utilise the heat drop H.

This quality figure is, in fact, a measure of the relation between the square of the circumferential blade speed and the square of the steam velocity that can result from the heat drop.

Investigation shows that all present turbines are defective in so far as the quality figure for the high pressure part is concerned, and that this figure is considerably worse than the figure for the low pressure part. It is, properly speaking, expected that the low pressure part will make up for the losses in the high pressure part. In order to make use of the high pressure heat drop in a steam turbine to a degree of efficiency that will be at least equal to the efficiency of the low pressure heat drop, it has been proved necessary to raise the quality figure of the existing constructions to a very considerable extent, so that the values of the low pressure part are reached and exceeded. This improvement will be brought about if the high pressure part is taken out of the existing single cylinder turbine and developed into a special high pressure turbine.

After long experiments, the Erste Brünner Maschinenfabrik has built a high pressure turbine, and the adjoining curves show the comparison in the expansion stages of the efficiency as compared with the efficiency of ordinary impulse wheels with a single row of blades. (Fig. 2.)

The new design is characterised by the flat course of the top of the efficiency curve, which is very important for variable loads.

Should it be possible to keep the losses that are not important for the low pressure part (for instance, wheel friction, ventilation, surging shocks, etc.), very low also for the high pressure part, the steam and heat consumption of the turbine then would be reduced considerably, in the first place because a greater heat drop is used in the turbine, in the second place because in the extended high pressure area the heat is used more economically

A proof of the accuracy of these statements and of the possibility of attaining these results was obtained by the exhaustive examination of a back pressure turbine of about 2,300 kW. built by the E.B. Maschinenfabrik for the Nestomitz Sugar Mill.

This examination was made by Prof. Josse, of Berlin, Prof. Dresden, of Delft, and Prof. Niethammer, of Prague, and was published in the "Ingenieur" of June 30th, 1923.

Subsequently, this turbine was examined again by Prof. Dr. A. Stodola, of Zürich, by means of his own Swiss instruments and with his own assistants exclusively. At these last mentioned trials, several representatives of competing firms were present.

The former observations were absolutely confirmed. At full load the diagram efficiency was found to be 84·2 per cent., and the overall efficiency 82·4 per cent.

It is also worthy of mention that the turbine from the start was running at 400°C. (750°F.) superheat and more, and that this temperature was exceeded also at the trials.

The Nestomitz sugar mill is selling the surplus kWh. to an overland

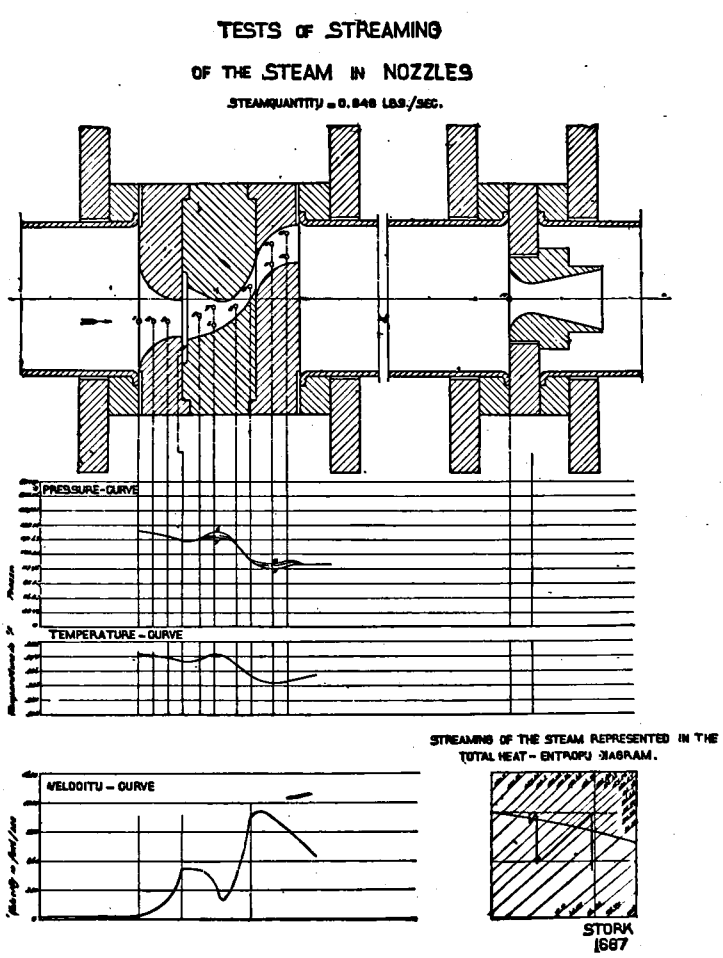

Fig. 3.

electrical power station, delivering all the exhaust steam used in the refineries. By good co-operation of the private industry and the overland power plant in this case, a very economical source of energy has been made efficient.

Now we may ask how this efficiency of this type of turbine has been reached.

The trials have shown that a high quality figure $\frac{\Sigma U^2}{H}$ is needed for the high pressure part, but that it is by no means immaterial in what way this is reached; in other words, that it is one thing to use the heat drop in one large wheel, or in a few large wheels, with high circumferential speeds, and another to use the same heat drop in a greater number of small wheels with low circumferential speeds. It proved to be the first essential point that the wheels should obtain steam around the whole periphery. If this does not happen,

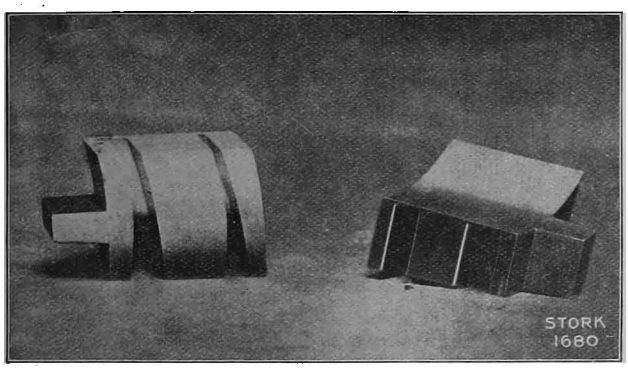

Fig. 4.

the part where there is no admission will have such a ventilating effect that the flowing of the steam in the admission part will be seriously interfered with.

In the second place, more than fifty steam flow trials have shown that transition of the steam to a different diameter will cause surging shocks, even at velocities far below the sound velocity. These surging shocks at the same velocities are more violent as the steam becomes greater in density, as the radius of curvature of the steam course is smaller, and as the transitions between the different diameters occur less gadually.

The result of one of these trials is represented by Fig. 3.

These trials completely explained the phenomenon that, up to this time, back pressure turbines have never been so economical as low pressure condensing steam turbines, even when the relation

U/Co has been taken at absolutely the same value. The result of the trials has shown that it is essential for a high pressure turbine that the steam velocity should be taken lower as the steam density (and consequently the steam pressure) becomes higher.

At these trials a great many details further appeared to which close attention should be paid, relative to the shaping of the guide and running blades ; but in the first place, the high pressure turbine must be built for admission of steam along the whole periphery and for small steam velocities.

Whereas, in the design at present in use, the steam, in the first stage, expanded mostly to about 6 kg./cm.^{2} (85 lbs./sq. inch) with a volume of about 0·33 m.^{3} per kilogram (5·3 cu. feet per lb.) of steam, this volume in the good high pressure turbine at an initial pressure of 35 atm. (500 lbs./sq. inch) will be about 0·09 m.^{3} per kg. (1·4 cu. feet/lb.), and at 50 atm. (700 lbs./sq. inch) about 0·06 m.^{3} per kg. (0·93 cu. feet/lb.).

The guide channels for these turbines are made very accurately, and consequently the results, as to the relation between the theoretical and the actual velocity of discharge are very favourable. Moreover, the design allows of the use of non-corrosive material. Fig. 4 shows construction of the guide blades.

The first of the three initial questions can be answered in the affirmative. A great number of trials and practical operations of turbines have shown that in the high pressure area, at least the same economy can be attained as in the low pressure area.

We thus see that the high pressure area can be used with good efficiency, and that this is another way of enhancing the economy of the cycle.

We now come to the second question, *viz.*, whether it be possible to improve upon the economy at partial load.

The greater number of turbines, especially in electrical power plants, will run at loads that are variable to a great extent and any turbine that shows a flat economy curve, *i.e.*, that does not show a great difference of steam consumption between full load and, for instance, quarter load, will be far superior.

There is only one way to give this curve a favourable aspect, namely, by keeping the pressure after the first guide disc as high as possible, in other words, by seeing that in the first stage the expansion is as slight as possible.

The usual turbine designs do not satisfy this requirement, neither are they able to do so. The large turbine casings with large diameter diaphragms and large diameter stuffing boxes are by no means

reliable when high steam pressures and high temperatures are applied.

The so-called "Governing by cutting out nozzles" before the first stage, is not a standard for economy at partial load

If the first expansion stage utilises a great heat drop (which unavoidably will be incidental to a lower economy at full load), then this heat drop will be ever increasing as the load decreases.

The pressures in the different stages decrease approximately in the same ratio as the load, in other words, at quarter load the pressure after the first stage will be lowered to about quarter of the pressure at full load.

The less the load, the more the expansion stages after the first stage are eliminated and the greater the part of the energy that has

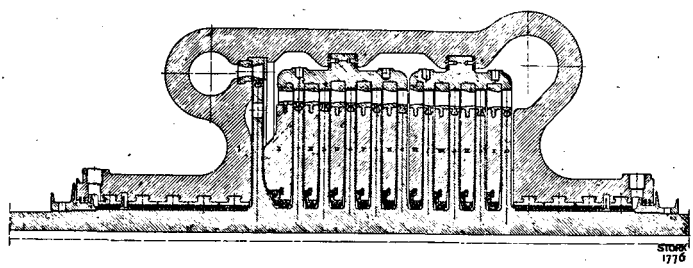

Fig. 5.

to be taken up by the first stage. Moreover, the economy of this stage will suffer a great loss, as the ratio U/Co will become gradually worse.

If, on the other hand, the pressure after the first stage is kept very high, this pressure, even at partial load, will remain high, and then the expansion stages after the first stage can utilise a great part of the heat drop to high economy.

In that case the economy curve must be a great deal flatter than the curve of a turbine with throttle governing or a turbine governed by cutting out nozzles and with a great heat drop in the first stage.

In order to allow high steam pressures and high temperatures after the first stage, it has been necessary to make a different design for the casing, to insert the diaphragms in a different way, and to design a suitable gland.

The diaphragms are placed in loose bushes with self-tightening seams,

These suspended bushes are heated up to the same temperature as the internal parts by the surrounding steam flow. The whole is enclosed in a small cylinder that may be considered as a staying casing of a simple shape.

For high initial pressures, for instance of 50 to 100 atm. (700 to 1,400 lbs./sq. inch), this casing is of pressed steel.

The second of the three questions can also be answered in the affirmative The economy at partial loads can be improved by applying a high steam pressure after the first stage. The design has been made in accordance with this principle.

In conclusion, the third question is left to be answered: whether it be possible to raise the reliability, especially in large units.

It is a very favourable circumstance that the results that have been attained for the most favourable flow of the steam, will at the same time bring about the highest possible degree of reliability. In order to obtain the most favourable hydraulic effect we must apply low steam velocities.

It is not advisable for us to draw our conclusions exclusively from the hydraulic efficiency, *viz.*, from the favourable flow through the blades. The additional losses ought to be investigated, especially for steam of great density.

Hydraulically, the Parson's blade with about 50 per cent. reaction is excellent. But in the high pressure turbine it is extremely difficult to lessen the secondary losses, such as leakage, etc., whereas the reliability should not be jeopardized by infinitesimal clearances

Fig. 5 shows that the high pressure rotor has been built as a disc rotor, the shaft and the discs forming one solid forging. The sealing of the different expansion stages is effected by labyrinth glands in the diaphragms.

The distance of the bearings is very small, so that even for 3,000 revolutions per minute the shaft has been executed as a "rigid shaft," in other words, the turbine will run below the critical number of revolutions.

The discs, being of very small diameter, have a low peripheral speed and are very rigid. The critical speed lies far above the actual number of revolutions.

The stresses in the material, which are being increased all the time in modern turbines on account of competition, and have reached 2,000 to 2,500 kg./cm.^{2} (28,000 to 36,000 lbs./sq. inch), frequently causing accidents, have here been reduced to about one-quarter of these amounts. The rigid shaft has the great advantage that the labyrinth sealings of the stuffing boxes and the diaphragms can be

made to work with minute clearances, as the number of revolutions of the shaft, even when a turbine is started or stopped, does not pass through the critical speed and consequently the shaft is much less sensitive to vibration.

The cylinder is of very small length overall and small diameter, and consequently can easily stand the high steam pressures. When very high steam pressure is applied, the intermediate pressure cylinder is built in the same way.

The low pressure part, where the blades already have attained sufficient length, is executed as a reaction cylinder with moderate blade speed. The advantages of the good hydraulic flow can be utilised here to their full extent, whereas the short and rigid cylinder, at the very low initial temperature, offers an exceedingly great reliability. This low pressure part too has been designed with special care. As soon as the stress in the blades reaches a moderate limit, the low pressure cylinders will be applied.

We thus see that the third question can also be answered in the affirmative. The stresses in the material in this new turbine system are much lower than the stresses that have been admitted up to date; the construction guarantees the greatest reliability attainable even at high steam pressure.

From the above it will be evident that the advantages of the Erste-Brünner design are very important and it will cause no surprise that a number of the best and largest continental steam turbine manufacturers have decided to construct this turbine under licence of the inventors.

The Dutch licencees have already supplied, and are now making various turbines for the Netherlands, its colonies and for Belgium.

As an example of the results that have already been attained, we may mention that a back pressure tubine of 750 kW. has been made and carefully tested by the Engineering Works Gebr. Stork & Co. With a steam pressure of 7·25 kg./cm.^{2} (103 lbs. per sq. inch), a temperature of 325° C. (617° F.) and a back pressure of 0·7 kg./cm.^{2} (10 lbs. per sq. inch), a steam consumption of 14·2 kg. (31·2 lbs. per kW.) at full load was found, corresponding to an overall efficiency of 77 per cent. for the turbine only.

This figure is very favourable, as it must be taken into account that the turbine was constructed to be able to work with a great overload and consequently the efficiency at normal load had to suffer. If this had not been the case, an overall efficiency of 80 per cent. could have been attained, which may rise in other cases to 85 per cent.

At present a turbine of 16,000 kW. is in course of construction for a steam pressure of 35 kg./cm.^{2} (500 lbs./sq. inch) and a superheat of 400° C. (750° F.) For this turbine, a steam consumption of 3·83 kg. (8·44 lbs.) per kW. has been guaranteed, corresponding to an overall efficiency of 86 per cent. for the turbine alone.

For further particulars of the power station in which the above turbine will be put to work, I would refer to the paper of Mr. J. J. L. Smits which is to be presented at this Conference.

RÉSUMÉ.

L'auteur expose en premier lieu le développement historique de la construction des turbines à vapeur aux Pays-Bas, puis les nouvelles conceptions dans le domaine de la construction de ces turbines, formulées en premier lieu par Monsieur Loesel, Directeur de l'usine très connue de Brünn en Tchéco-Slovaquie, la " Erste Brünner Maschinenfabrik," qui a ouvert de toutes nouvelles voies pour la construction des turbines à vapeur. Par sa construction, M. Loesel améliore d'abord la partie à haute pression des turbines en ce qui concerne le rendement à pleine charge, conformément aux résultats qu'il avait obtenus à la suite d'un grand nombre d'essais intéressants. En second lieu, la construction spéciale de cette turbine permet d'améliorer le rendement à charge réduite.

En troisième lieu, l'amélioration du rendement, obtenue dans un grand nombre d'étages par le système d'admission et de détente de la vapeur dans ces étages, est combinée avec une diminution des vitesses périphériques des roues motrices.

Cette diminution des vitesses périphériques a pour conséquence qu'on peut employer des matériaux ayant une résistance normale tout en étant en même temps très anti-corrosifs. Ces circonstances augmentent la sécurité du service.

Le résultat de ces avantages est, entre autres, que pour les turbines à vapeur à 3,000 tours per min., construites d'après ce nouveau système et pour l'emploi de vapeur à haute pression, de haute température et d'un vide élevé, on peut obtenir un rendement s'élevant jusqu'à 86 pour cent. En outre, par suite du perfectionnement de la partie à haute pression, on peut également obtenir un rendement allant jusqu'à 85 pour cent avec des turbines fonctionnant sans condensation et à une pression initiale peu élevée.

Les explications sont complétées par les résultats obtenus dans différents essais, et par la description d'une turbine en construction de 16,000 kW. à 3,000 tours, qui sera bientôt mise en service, et pour laquelle, à une pression de vapeur de 35 atm. et une température de vapeur de 400°C., on a garanti une consommation de vapeur de 3,83 kg. par kW. Différents détails de construction sont donnés à l'aide de dessins et de photographies.

EXTRA HIGH-PRESSURE STEAM TURBINES

V. NORDSTRÖM
Chief Engineer, de Laval's Angturbins Co., Stockholm.

The developments in steam engineering during recent years are, above all, characterised by efforts to obtain a better utilisation of the working power of steam by means of increased steam pressure. While 16 kg. per sq. centimetre was regarded as being about the upper limit some ten years ago, modern power plants are designed for pressures of 30 kg./cm.^{2} and more, and steam pressures of from 50 to 100 kg./cm.^{2} are within the range of practical possibilities.

Theoretically, the prospects of gaining a higher technical efficiency by this means are very good, since the adiabatic drop in heat obtainable by the higher pressure demands less expenditure of heat for the generation of the steam. Some doubt has been expressed, however, as to the possibility of utilising this extended range in heat, owing to the greatly increased losses in the turbine. The difficulties obviously become greater as the pressure of the steam is increased, inasmuch as the losses in the turbine discs due to friction and leakage are increasingly harder to control, the denser the driving medium is. Fortunately, there is a way of getting around this difficulty; in this case as in so many others, relating to steam turbine design, the solution is to be found in fitting a gearing between the high pressure and low pressure sections of the machine.

The friction work of a turbine disc may be approximately denoted by the formula

$$Nf = c\, d^2\, u^3\, \gamma$$

in which d is the diameter of the disc and u its peripheral velocity, γ being the density of the medium causing the friction. By means of introducing n for the revolutions made by the turbine the equation may be given the following form:

$$Nf = c_1 d^2\, (nd)^3\, \gamma$$

If Nf is to be kept constant at an increased γ while other conditions and u remain unchanged, the result will plainly be as follows:

$$n = c_2 \sqrt{\gamma}$$

As, however, γ is approximately proportional to the admission

pressure p the matter may also be expressed in the following way:

$$n = c_3\sqrt{p}.$$

Thus, if it is a question of designing a steam turbine for a pressure of 100 kg./cm.^{2} having no greater friction losses in the discs than a turbine of the same capacity designed for 10 kg./cm.^{2} and a speed of 3000 rev. per minute, the turbine for the higher pressure should be given a speed of $3000\sqrt{10}$ or 9500 R.P.M.

Owing to the greater adiabatic drop in heat obtained with the higher pressure, the number of discs or the peripheral speed must be increased, however, in order to obtain the same blade efficiency. From this it follows, that in order to keep the friction losses down, the rotary speed of the turbine must be still further increased, and, as there is no possibility of directly utilising the power produced at such a high speed, the solution suggested by Dr. Gustaf de Laval in the early nineties must be adopted. In designing his steam turbine plants for 100 and 200 kg./cm.^{2} pressure he evolved the toothed gearing for reducing the speed, and the same principle has since been successfully employed and further perfected by the A. B. de Laval's Angturbin in designing steam turbines for high pressures.

The conditions touched upon here naturally refer only to the high pressure section of the turbine, the one in which the friction losses are of paramount importance. In selecting the speed at which the low pressure turbine section is to run, efforts must be concentrated on obtaining as large outlet areas as possible in the last of the blades in order to get the best effect out of the vacuum; *i.e.*, the rotary speed must be low, to keep the blade velocity within reasonable limits. For turbo-generators of sizes from 500 to 5000 kW. the dimensions will as a rule be satisfactory if the low-pressure section is coupled direct to the generator, the speed of the high pressure section being fixed independently in accordance with the principles stated above.

The introduction of toothed gearing between the high pressure and low pressure sections cannot be regarded as any real disadvantage, as its efficiency is extraordinarily high—98 per cent. and over—and the reliability is beyond dispute when the gears are correctly designed, the material properly selected, and the manufacturing methods perfect.

A. B. de Laval's Angturbin have built back pressure, extraction, and condensing turbines on this principle for several years past, even for ordinary steam pressures, and have gained highly satisfactory results.

To support this, may be cited a 600 H.P. turbine which consumed only 3·9 kg. steam per brake horse power hour at 17 kg./cm.^{2} pressure and 325°C. steam temperature.

The very high steam pressures make it possible to use a much higher temperature than that which has been regarded as suitable heretofore. The steam turbine must in consequence be adapted to withstand this higher temperature, if the advantages of the high steam pressure are to be fully utilised. Thanks to the small size of the turbine when designed for such high speed, there are no insuperable obstacles in the way of achieving this end. Special care must be exercised, however, in selecting the material for parts exposed to the superheated steam in the high pressure turbine, and it goes without saying, that no cast iron must under any circumstances be used.

The equipment of a turbine for high pressure steam is on the whole, the same as for a standard turbine.

Concerning partial admission, it might appear as if the arrangement would be superfluous in the present case, since the importance of this system for the economy of the machine diminishes when the range between admission and discharge pressure is increased. A closer investigation of the problem shows, however, that about the same gain is possible as at a lower admission pressure. If the gain is expressed in units of power (and not in per cent.) this applies to condensing turbines as well as to back pressure turbines. Thus the same reasons for fitting turbines designed for ordinary pressures with partial admission, hold good also in the case of extra high pressure turbines. It may be said as a general rule, that the question for or against partial admission depends upon how great the variation in steam consumption is expected to be.

The very high steam pressures may in the first instance find employment in back pressure turbines, where the economy of this arrangement is quite obvious. The gain in energy expressed in per cent. is really so considerable that the figures are apt to be quite astounding. The gain ought not to be estimated in this way, however, which would be misleading, but should be based on the actual fuel saving. Looking at the matter in this light, it will be found that the gain under certain circumstances can be quite as large for a condensing plant, as for an extraction turbine, or for a combination of a back pressure and a condensing turbine. The deciding point is, here, how high superheat can be employed at the higher steam pressure. It is indeed most probable that higher temperatures than the ones heretofore regarded as most suitable at

standard steam pressure, may be used, because the greater heat capacity of the high pressure steam will reduce the difference in temperature between the superheater coils and the steam. Only experience can show, however, how far the superheating can be carried in excess of present practice.

In the following tables, the fuel saving has been given on the basis of different assumptions as regards steam temperature at higher steam pressures. The figure adopted for comparisons is 20 kg. pressure and 350°C. steam temperature. It has been assumed in case of extraction turbines that the gain in power due to the higher pressure is exactly sufficient to make the condensing section superfluous. The gain for this type of turbine, therefore, is expressed in maximum figures.

Proper consideration has been given to a certain loss of efficiency in the turbine as a result of the higher admission pressure; the greater work entailed on the feed pumps, on the other hand, has not been estimated, which, in most of the cited cases, makes figures for the saving slightly too large.

TABLE I.

Saving in fuel consumption at 50 and 100 kg./cm.² steam pressure, in comparison with 20 kg./cm.² steam pressure and 350°C. steam temperature.

(λ = 750 Cal.).

Exhaust conditions	96 per cent. vacuum		1 kg./cm.² back press (gauge)		3 kg./cm.² back press. (gauge)	
Admission pressure kg./cm.²	50	100	50	100	50	100
λ = 750 Cal.	8·5	11·5	10·0	13·0	9·5	13·0 per cent.
350°C. steam temp.	7·5	9·0	9·0	11·0	9·0	11·5 ,,
400°C. ,, ,,	10·0	11·5	10·5	13·0	10·5	13·0 ,,
500°C. ,, ,,	15·0	16·5	15·0	16·5	14·5	16·5 ,,

If, on the other hand the saving is determined in per cent. of the fuel consumption for energy production, the result will be as shown in Table II. It should, however, be borne in mind, that these figures refer to a smaller amount of fuel than the corresponding figures in Table I, and that the product of the said amounts and the percentage gain are in both cases equal.

TABLE II.

Saving in fuel consumption *for power purpose* at 50 and 100 kg./cm.² steam pressure in comparison with 20 kg./cm.² steam pressure and 350°C. steam temperature.

(λ = 750 Cal.).

Exhaust conditions	96 per cent. vaccuum		1 kg./cm.² back press. (gauge)		3 kg./cm.² back press. (guage)	
Admission pressure kg./cm.²	50	100	50	100	50	100
λ = 750 Cal.	8·5	11·5	42	48	47	53 per cent.
350°C. steam temp.	7·5	9·0	40	45	46	51 ,,
400°C. ,, ,,	10·0	11·5	44	48	49	53 ,,
500°C. ,, ,,	15·0	16·5	51	53	55	57 ,,

RÉSUMÉ.

Le développement de la technique de la vapeur pendant ces dernières années est caractérisé surtout par les efforts tentés pour obtenir une meilleure utilisation de la force motrice de la vapeur en élevant sa pression. Alors qu'il y a un peu plus de dix ans on considérait une pression de 16 kg./cm.² comme la dernière limite de ce que l'on pouvait se permettre, on projette maintenant des centrales modernes avec des pressions de 30 kg./cm.² et plus ; des pressions de vapeur de 50 à 100 kg./cm.² sont même déjà des réalités actuelles.

Théoriquement on peut envisager comme particulièrement fondée la perspective de pouvoir de cette manière obtenir un meilleur rendement thermique. Cependant on a émis des doutes sur la possibilité d'employer rationnellement, dans une turbine à vapeur, cette chute de chaleur plus grande, car une plus forte pression augmente considérablement les pertes dans la turbine. Il est évident que les difficultés croissent avec l'augmenation de la pression de la vapeur, en effet les pertes par friction des disques des turbines et les pertes dues aux fuites doivent être d'autant plus difficiles à contrôler que le fluide est plus dense ; mais heureusement on peut vaincre les difficultés en augmentant la vitesse de rotation que l'on réduit ensuite à l'aide d'engrenages, moyen qui est employé avec un succès complet par la Société des Turbines à vapeur de Laval.

L'économie totale de combustible réalisée en utilisant une haute pression de vapeur est indiquée au tableau I, et l'économie de combustible obtenue pour la production de force motrice seulement au tableau II.

Dans ces tableaux le rendement un peu diminué aux pressions de vapeur très hautes est considéré, d'un autre côté on a tenu compte du travail de la pompe d'alimentation, il en résulte que les chiffres cités indiquent dans la plupart des cas une économie un peu trop forte.

STEAM TURBINES AND CONDENSING EQUIPMENT

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This paper, while intended to cover the tendencies of American practice in Steam Turbines and Condensers, is written from the standpoint of a representative of one of the principal manufacturers of the United States who commenced the manufacture of steam turbines under a license from C. A. Parsons & Company in 1895. It is therefore written with less intimate knowledge of the practice of other American builders.

Because of restrictions of space, the subject matter is limited to large turbines and condensers as used by public utility companies, and further limited to the turbine and condenser proper. Therefore detailed discussion of lubricating, regulating, and such ancillary apparatus is excluded.

Designers of steam turbine machinery in the United States are fortunate that the Prime Mover's Committee of a national organization known as the National Electric Light Association, and the Steam Turbine Committee of the Association of Edison Illuminating Companies, both of whose memberships principally comprise representatives of operating companies, concern themselves deeply in matters of design as well as operation. These Committees record all interruptions to service, and at regular intervals confer with the designing engineers at the works of the various manufacturing companies, giving them the benefit of their experiences and learning the latest developments of the manufacturer.

The character of the problem of the design of the steam path of the turbine has completely changed with time. In the early turbines the problem was one of securing efficiency of the elements in the high pressure range of the turbine because generator designs permitted only low rotative speeds and high vacuum was uncommon, and there never was difficulty in securing ample blade areas at the last row.

Generator capacities at given speeds have now increased to such an extent and the employment of higher vacua has become such every day practice that the problem in design of the steam path is largely concentrated at the last rows of blades. The problem of the high pressure range of the turbine has become automatically easier because of the increased volume of high pressure steam. This point of difficulty of securing large low pressure areas is, I believe, more

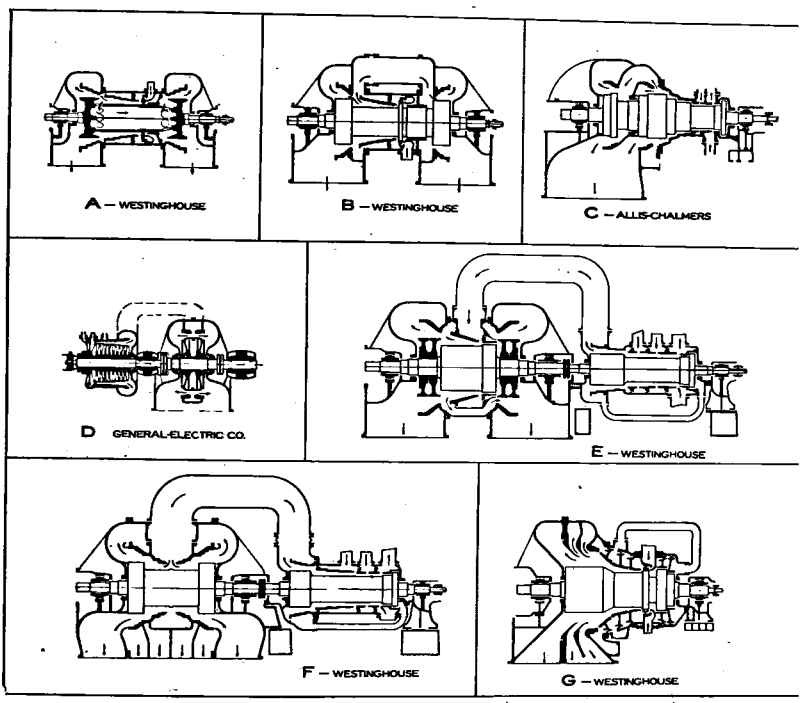


Fig. 1.

pronounced in Europe than in America because of a difference of practice in the respect of voltage regulating characteristics of alternators. The design of turbines for the various capacities differs further on the two sides of the Atlantic in many instances because of varying conventional frequencies requiring different rotative speeds.

Various methods of increasing low pressure blade areas have been adopted, as follows :—

First : By increasing blade speeds and blade dimensions, involving higher stresses.

Second : By providing multiple steam paths in the low pressure range, which, generally, may accomplish a doubling of the area without increase of stresses or of blade dimensions.

Third : By compounding the turbine in separate elements, driving separate generators, usually at different speeds. These have come to be known as " cross-compound " turbines.

A series of the outstanding methods of securing multiple paths for low pressure steam is shown in Fig. 1, all of which have been successfully employed by various manufacturers.

Schemes such as *A* and *B* with double flow low pressure elements employ simple turbine elements. They have, however, the disadvantage of two separate exhausts, requiring somewhat costly provisions for expansion of the turbine cylinder in the way of flexible expansion joints at each opening. An alternative is to connect each exhaust opening to a separate condenser with provision for the condensers translating with the movement of the turbine parts. The latter scheme is less general, although it has been employed in a number of cases.

Double flow turbines with two exhaust outlets led to the development by the Westinghouse Co. of rubber expansion joints which have been eminently satisfactory. The first large ones for 85 sq. ft. exhaust area have been in operation since 1918. The spare rubber portions acquired at that time have never been installed.

The type of turbine shown at *C*, Fig. 1, has been adopted lately by the Allis-Chalmers Co. for some machines of 20,000 kW. and 30,000 kW. operating at 1,800 R.P.M.

Tandem compound turbines, such as shown at *E* and *F*, are old in principle. They were introduced by Parsons as early as 1899 for what were then large machines (1,000 kW. for the Elberfeld Corporation) and were adopted in the United States shortly thereafter for machines of not much greater capacity. The design permits a simplification of structure and hence enhances reliability, although at increased cost. This increase becomes less apparent as machines of greater capacity are reached. Obviously, like other compounded arrangements, the design will lend itself to abnormally high pressure installations.

A compound tandem machine of the impulse type with double flow low pressure elements is shown at *D*, Fig. 1. It was introduced by the General Electric Company in about 1914 and at that time several large machines around 30,000 kW. capacity were built.

The design was subsequently abandoned in favour of the single case machine. The General Electric Company's engineers have generally expressed themselves as not favouring the compounding of turbine cylinders. They are building a number of single cylinder machines of 35,000 kW. capacity to operate with 550 lbs. steam pressure, superheated to about 700 degrees F., employing one stage of reheating. The first of these units is for the Philo Station of the American Gas & Electric Co. However, a 60,000 kW. machine for similar operating conditions for the Crawford Ave. station of the Commonwealth Edison Co., is of the cross-compound type.

A turbine with multiple exhaust blading is shown at *G*, Fig. 1. This form of double tiered low pressure blading was introduced by Karl Baumann of the Metropolitan-Vickers Electrical Co. in 1919, and is now employed in modified form by the Westinghouse Co. in later designs. It permits the same low pressure blade areas to be secured as with the double flow forms, *A*, *B* and *C*, without increase of stress, and, like form *C*, has the advantage of a single exhaust opening, permitting the condenser to be bolted directly thereto without the intervention of an expansion joint.

A series of outstanding arrangements of cross-compound machines under heading 3 is shown in Fig. 2.

Type H was devised in 1914, on the occasion of the Westinghouse Co. being called upon to build machines of 30,000 kW. capacity, which was nearly twice as great a capacity as had been built up to that time. This capacity gave the builder an opportunity to set a new era in steam consumption performance, and it was desired that this step in capacity and economy should be attended with a step in increased reliability. With this in view, a two speed cross-compound machine was selected, in this instance, 1,500 and 750 R.P.M., respectively, and of the type shown at *H* in Fig. 2. Others were built later for 60 cycle service, as shown at *I*.

The two generators are tied together electrically and operated as a single unit, the sole object of the design being to secure increased efficiency and reliability. It was apparent, however, that in an emergency, the elements of any cross-compound turbine might be operated separately, and in later instances, the Westinghouse Co. was called upon to produce cross-compound turbines to operate in this manner. Generally, the generators were connected to different bus bar sections, so that in the event of any electrical disturbance in one, and the circuit breaker of that generator opening, its turbine element would be automatically cut out of service, the remaining elements of that turbine continuing in operation. The thought

was the installation of a unit that might be regarded as too large for the system, but securing steam consumption incidental to a large unit, and in a measure possessing the flexibility of a number

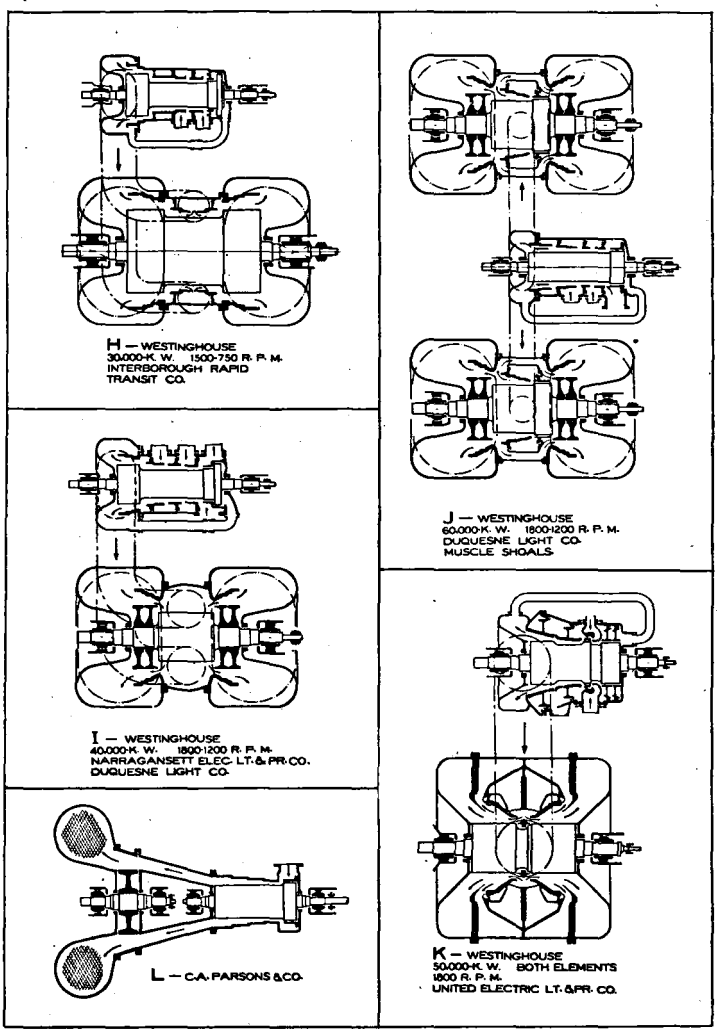


Fig. 2.

of smaller units. This led to the arrangement of a three cylinder compound machine comprising one high and two low pressure elements, as shown at *J*.

The steam flow through the two low pressure elements is in parallel, and therefore, with the three generators of equal capacity, the heat drop through the low pressure elements is twice that through the high, so better steam consumption is secured with the lows operating alone with live steam direct, thus contributing to the economic performance of the individual elements.

For instance, the 60,000 kW., 3-cylinder machine at the Colfax Station of the Duquesne Light Co., operating with 265 lbs. of steam, 175 degrees superheat and 28½ in. vacuum, has the following steam consumption guarantees :—

Three elements in operation ..	50,000	kW. load—	10·93	lbs. per	kWh.
One low pressure cut out, the high pressure and one low pressure in operation	36,000	,, ,,	12·5	,,	,,
The high pressure cut out, the two lows operating alone with live steam	50,000	,, ,,	13·5	,,	,,

The high pressure and one low pressure element operating with normal steam flow for the high pressure would, of course, overload the one low pressure element. However, the 20,000 kW. generators are capable of sustaining a load of 30,000 kW. for 30 minutes, and the low pressure elements are limited to that amount by a safety valve connected to the receiver pipe. Thus the two units can, during that interim, sustain a load of 45,000 kW.

Means of automatic controls, which will provide for automatically cutting out one of the elements, permitting the remaining two to continue in operation, while simple enough to make reliably operative, involve an undesirable complexity from the standpoint of power house operation. Furthermore, the sudden admission of live steam direct to the low pressure turbine elements incidental to the cutting out of the high pressure turbine is, to say the least, an exacting operating condition and troubles have resulted therefrom in one or two instances. Most of those experienced have been due to unnecessary defects in blading. There were two cases, however, of disturbances in the labyrinth packing or dummy, which were attributed to distortion incidental to the sudden operation of the low pressure turbines with live steam.

The present tendency is to abandon the practice of operating the elements of cross-compound turbines individually, and to regard

them strictly as single units. There has existed some misapprehension on the part of those who have not operated this type of machine that they bring about switchboard complication. This is contrary to fact, for the generators are coupled solidly electrically, becoming in effect a single winding divided into two or more parts. The unit is started by first closing the field circuits and then opening the one main throttle when the elements come to speed in parallel and are synchronised as one machine, Beyond two independently controlled field rheostats instead of one and two sets of wattmeters, P.F. meters and ammeters, the operation is no different from that of a single cylinder machine.

Further development of the cross-compound principle, in which multiple exhaust blading has been introduced, is shown at *K*. It is employed by the Westinghouse Company for some 50,000 kW. turbines now under construction for the United Electric Light & Power Co., New York, and for the Crawford Ave. Station of the Commonwealth Edison Co.

Lastly, at *L*, is shown the arrangement of a two-speed tandem compound machine devised by C. A. Parsons & Co., also for the Crawford Ave. Station of the Commonwealth Edison Co., and this opportunity is taken by the author to express commendation of the excellence of this particular arrangement. One reason for which it commends itself is that the expansion of the interconnecting piping between the elements may be provided for by permitting the high pressure turbine to slide on its sole plate in an axial direction. With the elements of a cross-compound turbine set side by side, expansion joints or their equivalent must be installed and arranged in such manner that no excessive forces will be exerted on the turbines.

The history of turbine progress, at least with the C. A. Parsons Co. in Europe and the Westinghouse Co. in America, has been that with increases of capacity, builders have turned to compounded turbines, either tandem or cross-compound and, as the art progressed, they have subsequently produced the same capacities in single cylinder units. It would seem, however, at least, from the viewpoint of to-day, that turbines of 50,000 kW. maximum continuous capacity and greater and for turbines of almost any large size where steam pressures higher than 400 lbs. are employed, the compound principle in one form or another will be adhered to. The General Electric Co. has, however, produced eminently successful machines of 50,000 kW. capacity at 1,200 R.P.M. as single complete

expansion machines for the Detroit Edison Co. and are installing another for the Brooklyn Edison Company.

Much interest of turbine design is centered in the proportions of the last row of blades. Greater capacity may be secured merely by increasing the high pressure areas, with a penalty of increasing leaving losses. The true economic capacity of a turbine designed to expand to a given back pressure, however, is to be measured by the annulus occupied by the last row of blades, regardless of the type of turbine.

Table I. gives a tabulation of some representative machines in which Column XIV gives the actual annulus of the last row of blades. Columns XV and XVI give the area in square feet per thousand kilowatts of capacity referred to the point of best steam consumption and the maximum continuous rating, respectively. Under Column XVII, all turbines are reduced to an equivalent geometrically similar turbine of the same peripheral speed at 1,800 R.P.M., which would have the same leaving loss, centrifugal stresses and relation of critical speed to running speed as the original. The blade areas and consequently steam flow and capacity will vary inversely as the square of the R.P.M. This would seem to be the best method of bringing turbines of different speeds to a common basis of comparison.

Column XX gives the stress in the blade of either the original turbine or the equivalent 1,800 R.P.M. turbine due to centrifugal force alone based on blading of the density of steel and with the assumption that the blade form is of parallel section from end to end. In practice, blades may have a tapered section, thus materially reducing the actual stresses. This tapering has been employed in some later designs. The figures under Column XX might be regarded as representative of an index to which the design has been carried in order to secure increased low pressure areas without reducing rotative speed.

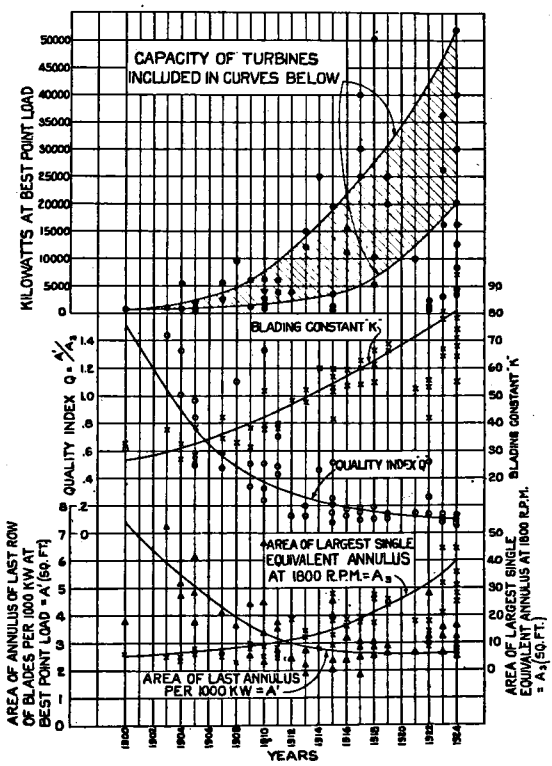
Column XXII, termed "Quality Index," is a figure which combines the features of conservative design and low stresses with large low pressure areas. It is merely a figure of the sequence of quality on the sole basis that low stress and low terminal loss are desiderata. This figure with its terms to some fractional exponents might be properly regarded as a quality factor.

Column XXI gives the K for the various machines and represents the sum of the number of turbine elements reduced to a common blade speed. In calculating the K constant, —

1 - two row impulse element is taken as equal to 16 rows re-action blading, *i.e.*, 8 pairs of rows.

1 - one row impulse element is taken as equal to 4 rows re-action blading.

Certain notable marine turbine installations have been added because of the extreme last blade values reached due to their being direct connected to the propeller shaft and designed for low speed.



PROGRESS OF TURBINE CONSTANTS

Fig. 3.

In contrast with this is a marine geared outfit which brings the values for last blades comparable with modern power house practice.

The curve in Fig. 3 shows how these important low pressure blade characteristics and the value *K* have varied in successive designs as represented in Westinghouse practice. The low pressure blade

areas and values derived therefrom do not permit comparison between turbines designed for various back pressures. Small relative areas are therefore to be expected for the early machines designed for low vacuum. The curve gives evidence that earlier machines were designed generously in this respect.

In comparisons of low pressure blades designed for equal velocity

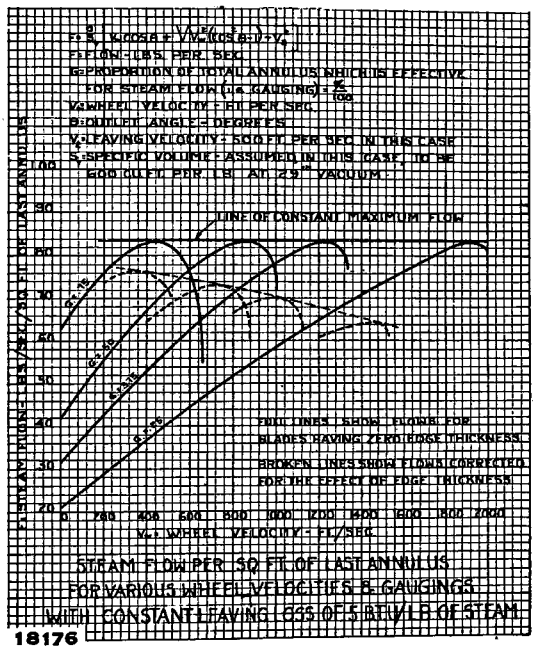


Fig. 4.

ratios, low blade speeds have the advantage of smaller velocity components parallel to the axis of the turbine, and hence lower leaving losses. The two-speed cross-compound turbines lend themselves to this feature, as the design may be carried to the extreme of low rotative speed of the low pressure element, permitting any degree of low leaving loss desired without sacrifice of efficiency in

the high pressure ranges of the turbine. Single port blades of conventional form may be employed eliminating the losses incidental, for instance, to the inner tier of multi-exhaust blading.

The last row of blades will pass the same maximum volume per square foot of annulus for any blade speed and have equal leaving loss provided a blade angle is selected appropriate to the particular blade speed. The curves of Fig. 4 have been drawn on a basis of 5 B.Th.U. leaving loss per lb. of steam. They show, for example, that with 440 ft./sec. blade speed and 75 per cent. opening, ·83 lb. per sec. at 29 in. vacuum will flow per square foot of annulus. Any variation of blade speed from this will require less steam flow to secure the same low leaving loss. Similarly, with 1,220 ft. per sec. blade speed and 37½ per cent. opening, the same steam flow will obtain with the same leaving loss. The curves in full lines have been drawn without allowance for edge thickness loss. This increases with the higher blade speeds. The dotted curves show the corresponding figures corrected for edge thickness loss.

Concerning the blading occupying the steam path in the high pressure portions of the turbine, the re-action type of element, while possessing the highest inherent efficiency, suffers the disability of high leakage loss unless the steam volumes are relatively large as compared with the impulse type where leakage only occurs where the relatively small diameter shaft passes through the diaphragms. It has the further disability that a greater number of rows of re-action blading are required than number of stages in an impulse turbine for the same blade speed and heat drop. On the other hand, the impulse type departs from the simplicity of the re-action type because of its intercellular construction involving a shaft of relatively small diameter with discs pressed thereon, which tends to limit the number of stages in a given turbine because of the lesser strength of shaft if maximum advantage is to be taken of low leakage. For this reason, the elements are made to occupy small axial space and present a difficult engineering problem of design to avoid lateral vibrations. There have been some unfortunate experiences with some large impulse type machines on account of nodal vibrations of discs, causing rupture. The writer is not competent to discuss the details of this matter beyond stating the subject has had very expert attention at the hands of the manufacturer's engineers, and it is believed the design can be controlled to the extent that no resonance will occur under any anticipated operating condition. The construction of

diaphragms of sufficient strength to sustain the stage pressure differences with nozzle partitions cast or otherwise secured therein is quite a problem as compared with the inexpensive and easy one of attaching reaction blading to the bores of turbines cylinders or blade rings. However, any turbine may have its first element of impulse type without the mechanical difficulties mentioned above and be free from leakage. It would seem, generally, that all turbines may, with advantage, have at least the first high pressure element of the impulse type, changing to the reaction type in the low pressure zones, the point of change and the employment of either single or multiple velocity impulse elements depending upon the steam volumes involved. This is less true of two-speed compounds because the higher rotative speed high pressure element permits greater blade areas allowing the reaction elements to be advantageously carried into the higher zones of pressure.

A means of carrying the reaction principle to smaller steam volumes is made possible by the principle of "end tightening" developed by C. A. Parsons & Co. for the purpose of reducing leakage, and has been adopted in the United States by the Allis-Chalmers Co. The tips of end-tightened reaction blades are provided with shrouds which overhang on one side and operate with fine clearances sideways against the base of the complementary blade which is made to extend above the surface of the blade carrying element. This may become of more general practice. It is at present regarded, by the author at least, as not being conducive to reliability. It is in effect carrying the system of dummies of the side clearance type further through the turbine. This form of labyrinth packing has been attended with no few cases of difficulty, at least with Westinghouse turbines, which led to its rejection in favour of the radial type, which is further discussed under the subject of labyrinths. If end-tightening of reaction blading is adopted, turbines must be built with full size dummies and have no inherent end thrust.

Impulse turbine elements used to be regarded as highly advantageous in lending themselves to fractional admission of steam; that is, the nozzles occupying a fraction of the circumference, and were appropriate to low rotative speed turbines. This involves at least two serious losses, one the windage of the idle blades, the other known as displacement loss, which is the energy required to sweep out the inert steam from the blade passages when they come within the active arc of steam admission. Therefore, to-day, in all impulse turbine design, nozzles are made to occupy as much as possible of

the whole circumference. This displacement loss for each nozzle group is expressed as follows :—

$$W_d = \frac{8{\cdot}5\ h\ b\ V_w}{S_v}$$

Where :

W_d = displacement loss—lbs. steam per hour
h = mean blade height (inches)
b = blade width (inches)
V_w = mean blade velocity—ft. per second
S_v = specific volume corresponding to steam condition in impulse wheel chamber.

This displacement loss explains why individual or group control of nozzles does not produce the gain in efficiency sometimes expected The greater the arc occupied by the nozzles, the smaller the blades will be, resulting in both lower displacement and windage losses.

In any turbine blading, the larger the blade passage, the greater the efficiency because of the lesser ratio of perimeter to area, and hence, less friction loss. Because of higher steam velocities and greater energy conversion in impulse elements, any departures from ideal blade form are more marked in results as compared with reaction elements.

The opinion is generally held that nozzle efficiency falls off more rapidly after passing the critical velocity. Some experimenters have held the opinion that maximum efficiency occurs at that velocity and there is a good deal of conflicting data on the subject, much of which is based on experiments with nozzles discharging against a target.

In an actual turbine, however, blade losses may be totally different from experimental data of this kind because of the effect of the moving edges, displacement, entrainment, etc. Many factors may obscure results. For instance, small turbines with wide blades, having small arcs of admission might show superior results from such experimental tests, while, in practice, they would be less efficient because of high displacement loss.

It would seem evident that the highest blade efficiency is secured with lowest velocity, and that impulse blade efficiency is affected by the ratio $\frac{T}{R}$,

which is the ratio of the steam stream thickness to the radius of curvature of the concave surface of the blade.

Edge thickness loss is greatest with low values of $\frac{T}{R}$.

Loss due to friction on the blade, compression effects of the steam due to reversal of direction, stream interference and "straight blow-through," all increase with high values of $\frac{T}{R}$. Consequently, it is evident that as the edge thickness loss decreases with increase of $\frac{T}{R}$, a point of minimum loss occurs at some relatively low value of $\frac{T}{R}$ for each steam velocity and blade width. These thoughts are expressed qualitatively in Curve Fig. 5. In practice, curves have

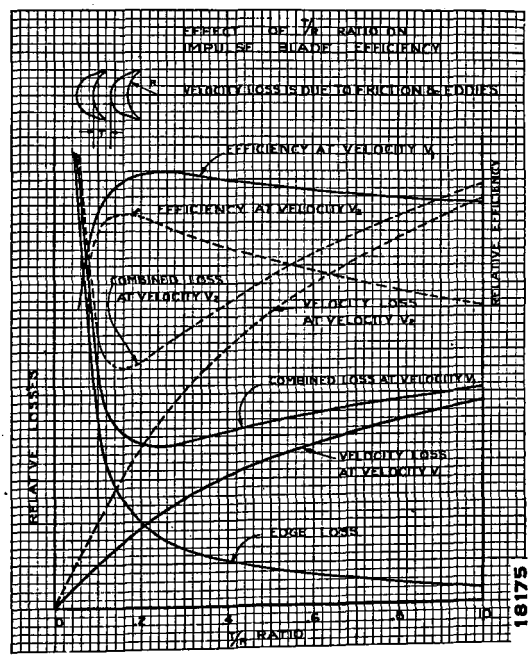


Fig. 5.

been determined by the analysis of results from actual impulse wheels. The edge loss remains constant for any value of $\frac{T}{R}$. The

velocity losses increase with the higher velocities; hence $\frac{T}{R}$ should have lower values with higher steam velocities as shown by the curve. By increasing the width of blades, further reduction of loss may be secured with lower values of $\frac{T}{R}$ because of the reduced edge loss, and with fewer edges passing in front of the nozzle, less disturbance of the stream lines occur.

The values of $\frac{T}{R}$ employed in Westinghouse turbine practice for two row impulse elements vary from ·3 in the first moving row to ·6 in the second moving row for steam nozzle velocities of approximately 2,000 ft. per second.

Practical designing and the employing of desirably low values of $\frac{T}{R}$ lead to wide blades and have resulted in Westinghouse impulse blades being wider than those of other manufacturers.

The results obtained with blading designed with the above points in view seem to justify the above conclusions. A notable point is that with this form of blade, an erosive cupping action so often seen within the blade passages of narrow impulse blades has not been observed even with many year's operation with wet steam and steam velocities exceeding 3,000 ft. per second. It is obvious that a given degree of erosion is far less detrimental to the efficiency of a wide blade than a narrow one.

EXHAUST CHAMBERS.

More attention is being given to the form of the exhaust chamber of the turbine with the object of diminishing eddies and pressure drop. This would seem as desirable as similar development in hydraulic turbines and as important as the form of inlet passages to blowers, centrifugal pumps, etc. Later Westinghouse machines are provided with diffusing passages from the blades to the turbine outlet, giving an additional advantage of distributing the exhaust steam equally over the entrance to the cooling surface of the condenser. This should make possible an increase in exhaust steam velocity of which advantage has not yet been taken.

FEED HEATING.

All manufacturers of large turbines are making provision for bleeding the turbine for stage feed water heating, effecting considerable saving over the older practice of heating feed by the exhaust

from wasteful steam driven auxiliaries. The effect of this on the turbine is beneficial in reducing congestion in the extreme low pressure blading. For example, a turbine heating its own feed in two stages, say at 144 degrees F. and 206 degrees F. will require about 4·1 per cent. more steam supplied at the throttle, but will deliver 7·7 per cent. less steam to the condenser than if regeneration by feed heating were not resorted to. This either permits lower terminal loss or a correspondingly higher rating of the turbine as desired. The above percentage will, of course, increase if a greater number of stage heaters are employed.

GENERATOR AIR COOLERS.

Surface type generator air coolers are beginning to be employed, the surface comprising tubes with the outer surface increased by means of fins soldered thereon. The advantages of less dirt in the windings and less oxygen present to support combustion in case of generator trouble are obvious. In some cases, condensate is used exclusively for cooling. In others, combinations of this with other sections using raw water are employed. Some plants have installed a water to water cooler for use in time of need when the condensate is deficient in quantity because of light load or hot because of some condenser disturbance.

While a large proportion of the generator losses may be absorbed by the feed water in this manner, the actual gain is not great if the feed is also heated by bleeding the turbine. In this case, the effect of the generator losses being added to the feed water is to reduce the amount bled at the lowest stage, resulting in a saving of about $\frac{1}{4}$ to $\frac{1}{2}$ per cent.

Simplicity of operation is, of course, a desideratum. Therefore, if the use of condensate for this purpose also includes some other means of cooling which will require manipulation which must be remembered at a time of disturbance, it would seem a cooler through which is passed water from the main circulator is to be preferred. This should be arranged and piped up in such a way that any one section can be cut out at any time for cleaning.

The experience of the General Electric Co. has been a progress from a turbine comprising two stages each with 3 or 4 velocity extractions to a greater number of stages with two velocity extractions, known as Curtis turbines, finally reaching their highly successful turbine comprising one two-row velocity stage at the high pressure end and followed by single velocity stages of the order of Rateau elements for smaller capacities at given R.P.M., and for

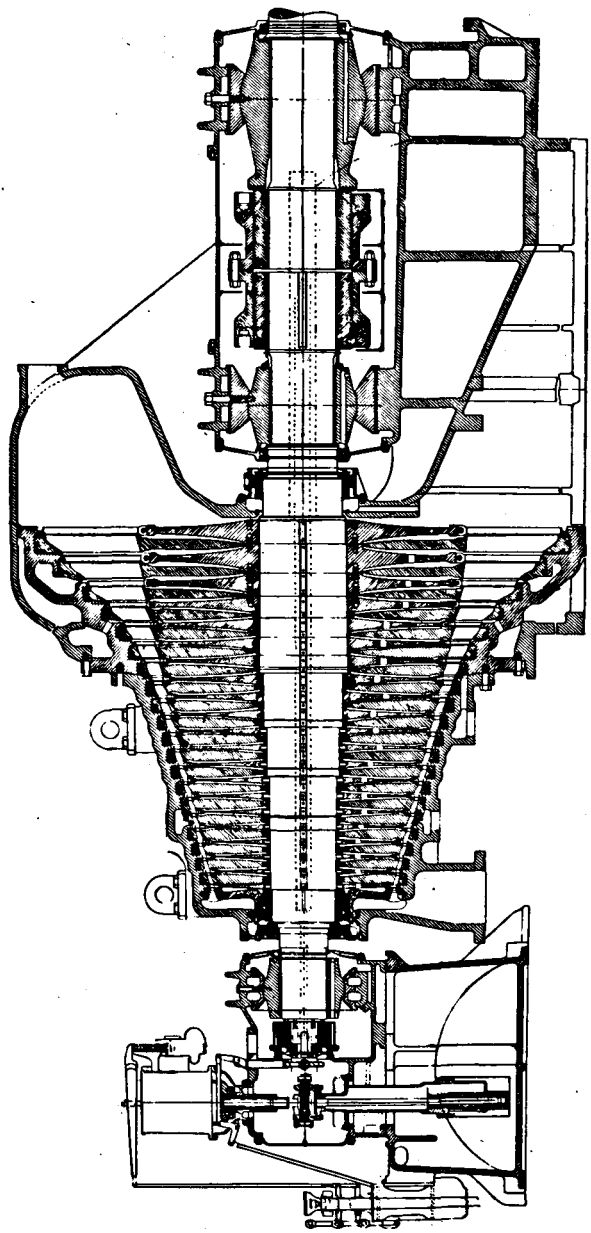


Fig. 6 — 50,000 K.W.-1200 R.P.M. GENERAL ELECTRIC COMPANY

the larger machine a turbine comprising single velocity stage elements only, of which a large number has been installed. Their latest design of a 50,000 kW., 80 per cent. Power Factor, 1,200 R.P.M. turbine is shown in Fig. 6. The unit is designed to operate with 265 lbs. pressure, 200 degrees superheat and 1 in. abs. back pressure. At 40,000 kW., the guaranteed steam consumption is 10·05 lbs. per kWh., which is equivalent to an efficiency ratio of 77·67 per cent. including all losses except those on account of extraction for feed water heating. Provision is made, however, for bleeding approximately 75,000 lbs. per hour from the 10th stage and 45,000 lbs. from the 15th stage. The overload valve by-passes into the 6th stage.

The turbine comprises twenty-one single row impulse stages, the mean diameters of elements increasing from 60 in. for the first wheel to 136½ in. for the last wheel. The last blades are 30½ in. long. The progressive increase of diameter from stage to stage without abrupt changes in diameter provides a continuous steam path minimising eddies and conserves residual velocities to the maximum degree. The small diameter of high pressure wheels permits the nozzles to occupy the whole circumference.

The diaphragms from the first to the sixteenth stage are made of steel plate with removable nozzles. The last five diaphragms are of cast steel with alloy steel partitions cast therein.

The diaphragms are in halves, the upper halves being secured to the casing, and lift up with the casing cover.

The design is characterised by low blade speeds in the high pressure zone giving :

1. Generous dimensions of buckets, even in the first stage.
2. Low windage losses.
3. Relatively small pressure drop per stage, reducing leakage loss.
4. Small pressure drop per stage, permitting the diaphragms to be designed with low stress and with moderate dimensions.
5. Reduced dimensions of casing, wheels, diaphragms, etc., to a minimum in the zones of greatest temperature.

The discs are carefully designed to avoid axial vibration. If there is possibility of this, the design is checked by operating each wheel in a special casing at full speed.

In order to obtain assurance of the homogeneity of the material of discs and their freedom from internal defects, the General Electric Company has applied the principle of " Magnetic Analysis," making use of apparatus built especially for the purpose by the Burrows Magnetic Equipment Corporation. By means of this apparatus, a strong magnetic field is passed laterally through the disc, the

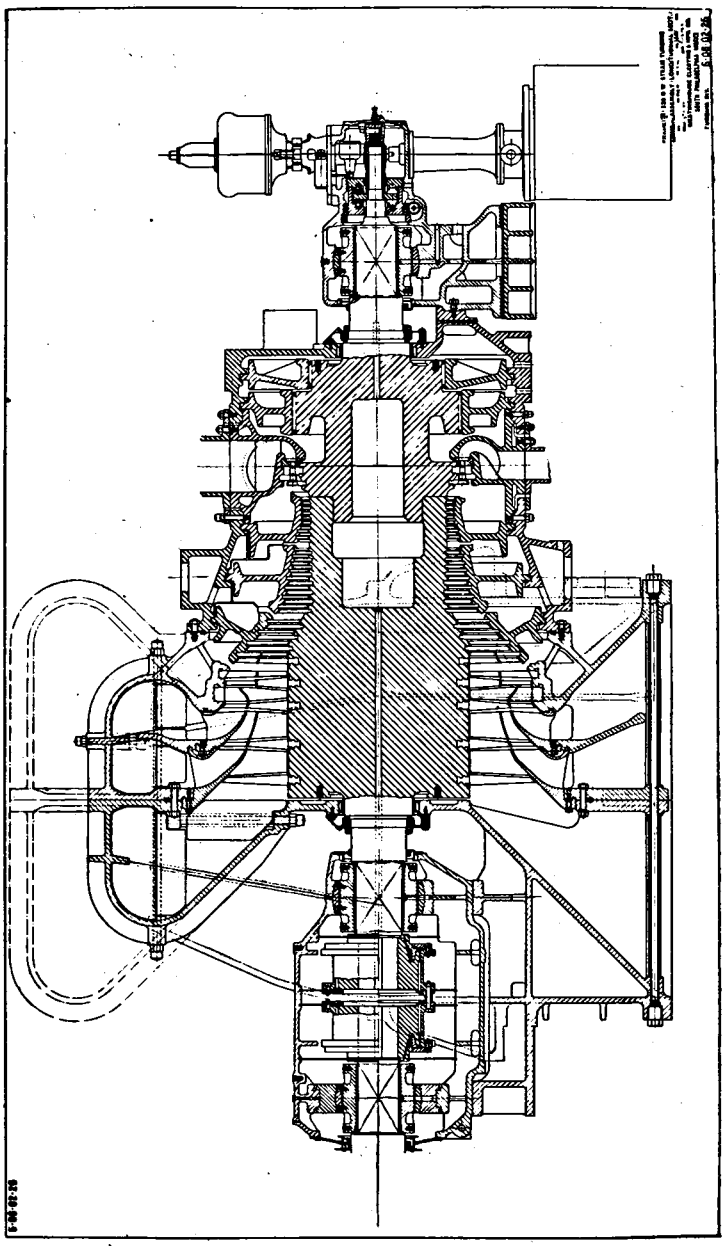


Fig. 7.

searching coils covering a small area at a time until the entire surface has been explored. Variations of magnetic resistance effect currents in a coil which automatically record themselves on a chart.

The experience of the Westinghouse Company commenced with

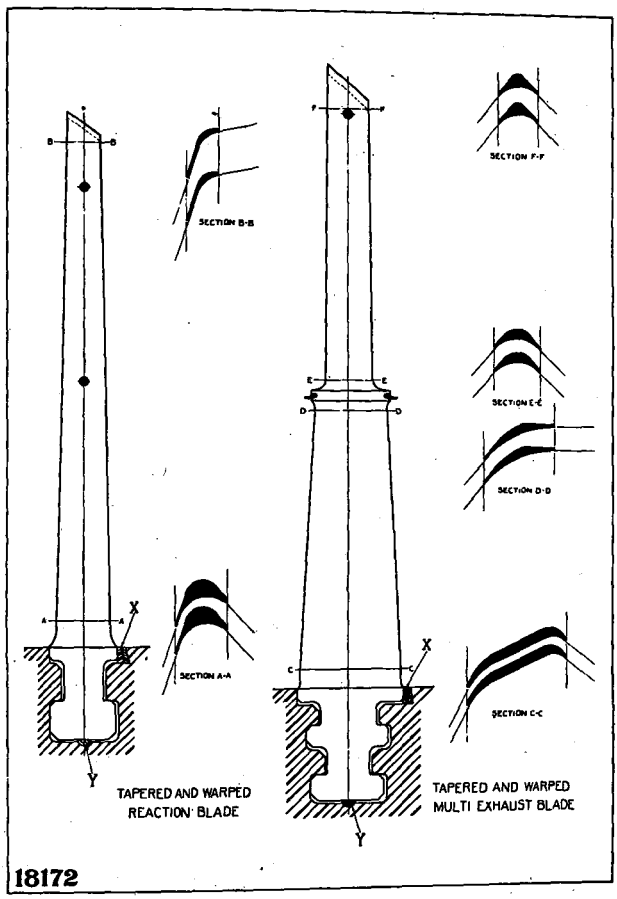


Fig. 8.

reaction turbines of the Parsons type of that day. They later substituted an impulse element for the high pressure portion of the reaction turbine employing double flow low pressure elements for the larger capacities. Later they developed cross-compound

turbines for the largest capacities and substituted the multiple exhaust blading for the double flow low pressure element.

The Allis-Chalmers Co. has not departed from the reaction type since they commenced the manufacture of turbines.

A modern Westinghouse 35,000 kW., 1,800 R.P.M. turbine is shown in Fig. 7. A number of these and others of similar design of different capacity are under construction and in course of installation. The last blade characteristics of the 35,000 kW. size are given in item 33, Table I. The features of design in which it differs from older practice are as follows :—

Employment of multiple exhaust blading. These blades are of warped surface and of tapering section so that the maximum stresses in the blade due to centrifugal force do not exceed 20,000 lbs. The average stress in the drum is 18,000 lbs. Both are calculated on a basis of 20 per cent. overspeed. The design of blade is shown in Fig. 8.

The exhaust chamber is provided with partitions for diffusing, as before described, and arranged with a single exhaust opening permitting the condenser to be bolted rigidly to the turbine without the intervention of costly expansion joints.

The steam expands through the nozzles from initial pressure to approximately 120 lbs. absolute ; the mean speed of the impulse element being 463 feet per second.

The impulse blades are wide for the reasons stated in the foregoing, their widths being 2½ in.,2 in. and 1½ in., respectively, for the three rows of blades.

The nozzles are in three groups, the first group giving the capacity for the best point of steam consumption. This group occupies nearly half the circumference. The nozzles are formed from forged steel by a simple operation in a gear cutter, which also provides grooves into which are fitted stamped steel partitions. The whole is welded together by means similar to the Hyde process.

The reaction blading is arranged on conical surfaces to avoid eddies incidental to the offsets in cylinder bores when increasing from one blade height to the next. Actual tests of small turbines show a gain in efficiency of 2½ per cent. for this construction in the low pressure portion.

In order to make the turbine adaptable to extreme conditions of bleeding for regenerative feed heating, four bleeder outlets are provided at approximately 3½ lbs. abs., 16 lbs. abs., 50 lbs. abs., and 120 lbs. abs. at the point of maximum efficiency.

A convenient way to provide openings for these bleeder connections

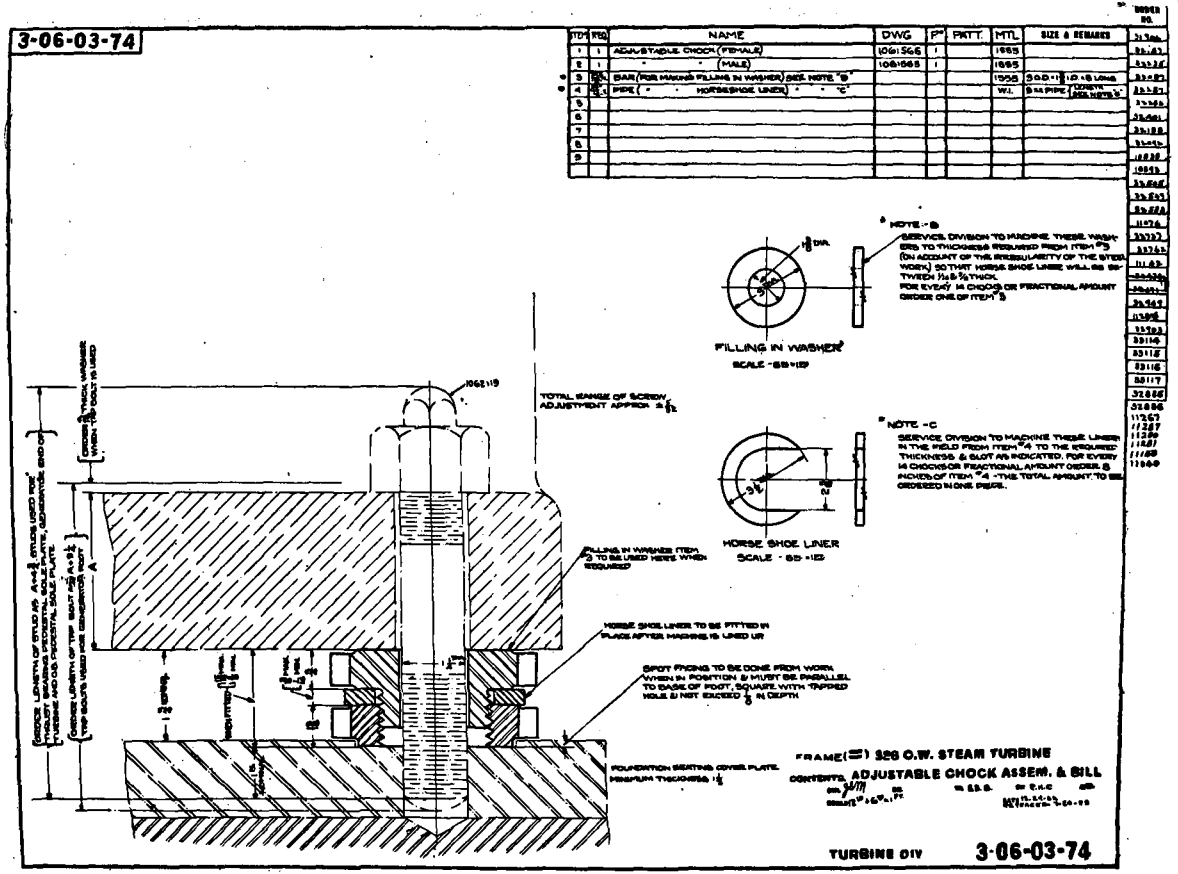

3-06-03-74
NAME
DWG.
MTL.
SIZE & REMARKS
ADJUSTABLE CHOCK (TIE-PLATE)
(MALE)
BAR (FOR MAKING FILLING IN WASHER) SEE NOTE "B"
PIPE (" " HORSESHOE LINER) " "C"
FILLING IN WASHER
SCALE - 6S-1-12
NOTE - B
SERVICE DIVISION TO MACHINE THESE WASHERS TO THICKNESS REQUIRED FROM ITEM "3"
NOTE - C
SERVICE DIVISION TO MACHINE THESE LINERS IN THE FIELD FROM ITEM "4" TO THE REQUIRED THICKNESS & SLOT AS INDICATED. FOR EVERY 14 CHOCKS OR FRACTIONAL AMOUNT ORDER 2 INCHES OF ITEM "4" - THE TOTAL AMOUNT TO BE ORDERED IN ONE PIECE.
HORSE SHOE LINER
SCALE - 6S-1-12
TOTAL RANGE OF SCREW ADJUSTMENT APPROX.
FILLING IN WASHER ITEM "3" TO BE USED HERE WHEN REQUIRED
HORSE SHOE LINER TO BE FITTED IN PLACE AFTER MACHINING IS LINED UP
SPOT PRICKS TO BE DONE FROM WORK WHEN IN POSITION & MUST BE PARALLEL TO BASE OF FOOT, SQUARE WITH TAPPED HOLE & NOT EXCEED 1/8 IN DEPTH
FOUNDATION SEATING COVER PLATE. MINIMUM THICKNESS 1/2
FRAME(=) 328 O.W. STEAM TURBINE
CONTENTS ADJUSTABLE CHOCK ASSEM. & SILL
TURBINE DIV
3-06-03-74

Fig. 9.

is to carry the groups of stationary blading between the bleeder stages on separate blade carrying elements. This also has other incidental advantages, such as simplification of the main cylinder structure, and the manufacturing advantage of the stationary blading being carried in a number of separate and replaceable elements.

It would be a gain if the lower stages of the turbine where the steam is wet could have the moisture abstracted as precipitated. An attempt is made for the first time to accomplish this in part in this design. Erosion of turbine blading shows plainly that the moisture in a turbine occupies the outer zone of the steam path, so these later machines are arranged with the adjacent edges of the blade rings brought close together so that the velocity of the steam going to the heater at full load approximates 150 ft. per second, and it is believed some proportion of the moisture will be carried away when the turbine is operating with full flow to the feed heaters. The effectiveness of this will be definitely determined in the near future.

The stationary blade rings are in the form of a circular I beam to give rigidity and reduce the liability of becoming out of round in the event of any local heating. They are supported adjacent to the horizontal joint of the turbine and held concentric at that point. They are free to expand in the cylinder and may therefore heat and cool at a different rate to the turbine cylinder proper without straining of the cylinder structure.

The blade rings are set in grooves in the cylinder in a manner similar to the practice in the case of diaphragms of impulse turbines. The pressure difference, however, is greater, and to avoid cutting of the surfaces by steam leakage, monel metal strips are employed which will reduce the cutting action to a minimum and which, if destroyed, are easily replaced and the parts restored to original condition.

Inasmuch as bedplates add nothing to the stability of an installation, they have been eliminated and the turbine elements secured directly to seating plates forming the upper surface of the foundations which are either of concrete or structural steel. An innovation is the setting of the parts on permanent screw chocks shown in detail in Fig. 9. Expansion of the exhaust chamber is provided by supporting its feet on self-aligning surfaces mounted on wedge chocks, shown in detail in Fig. 10. An important adjunct to the supporting system is a process of levelling by means of a radial beam and sensitive level centred on a post mounted on the turbine by means of which accurate alignment of the parts is secured and the structure assembled without stress by means of an organised

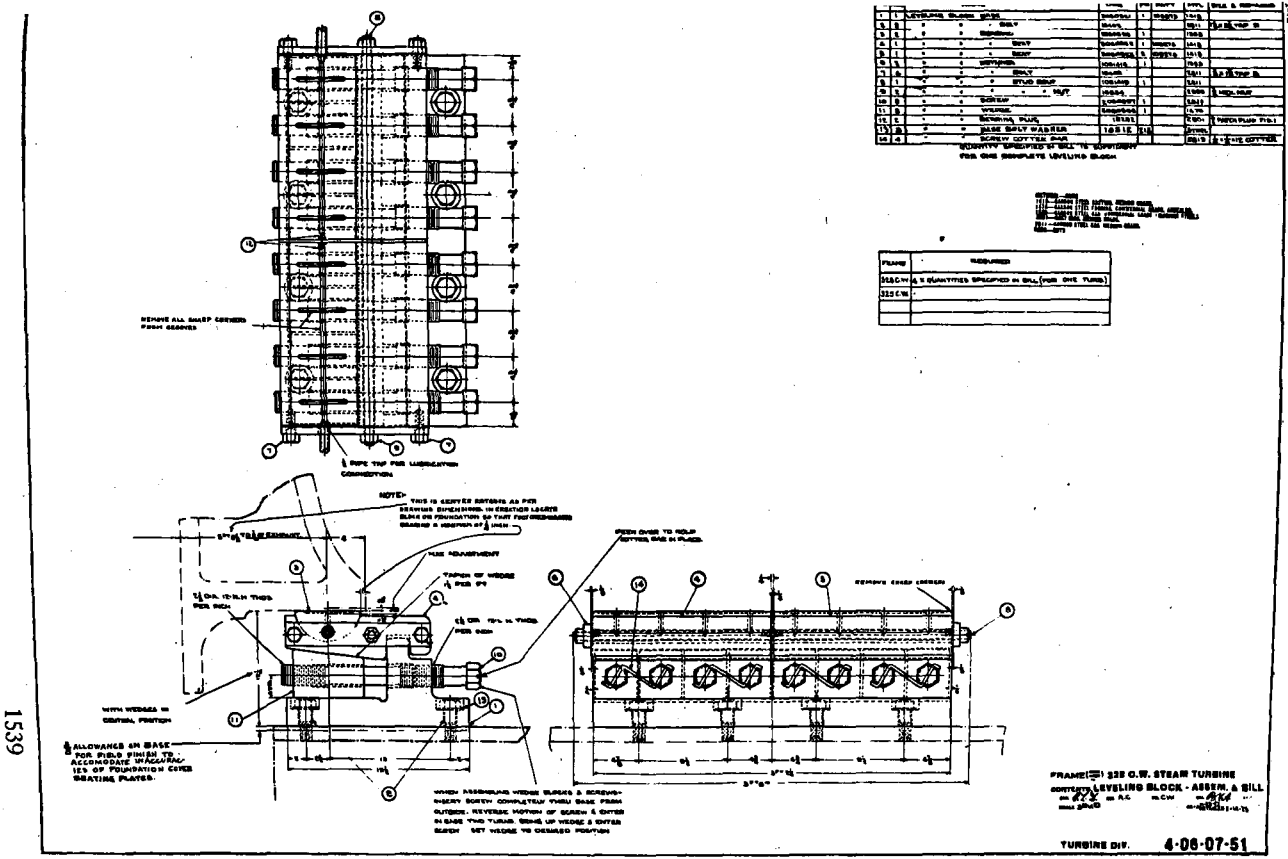

REMOVE ALL SHARP CORNERS FROM CASTINGS
NOTE:
TURBINE DIV.
4-06-07-51

Fig. 10.

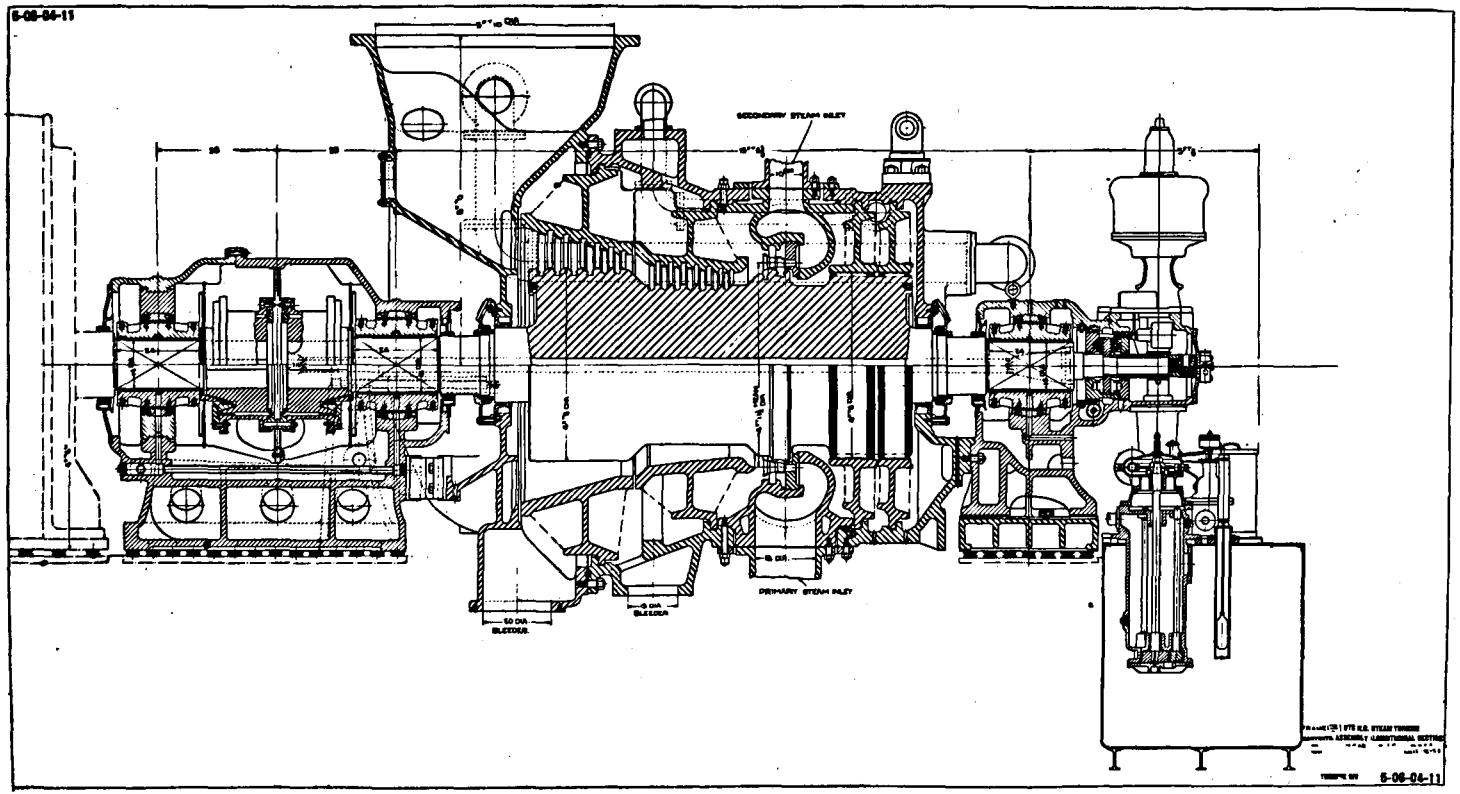

5-08-04-11
SECONDARY STEAM INLET
PRIMARY STEAM INLET
50 DIA
BLEEDER
5 DIA
BLEEDER
5-08-04-11

Fig. 11.

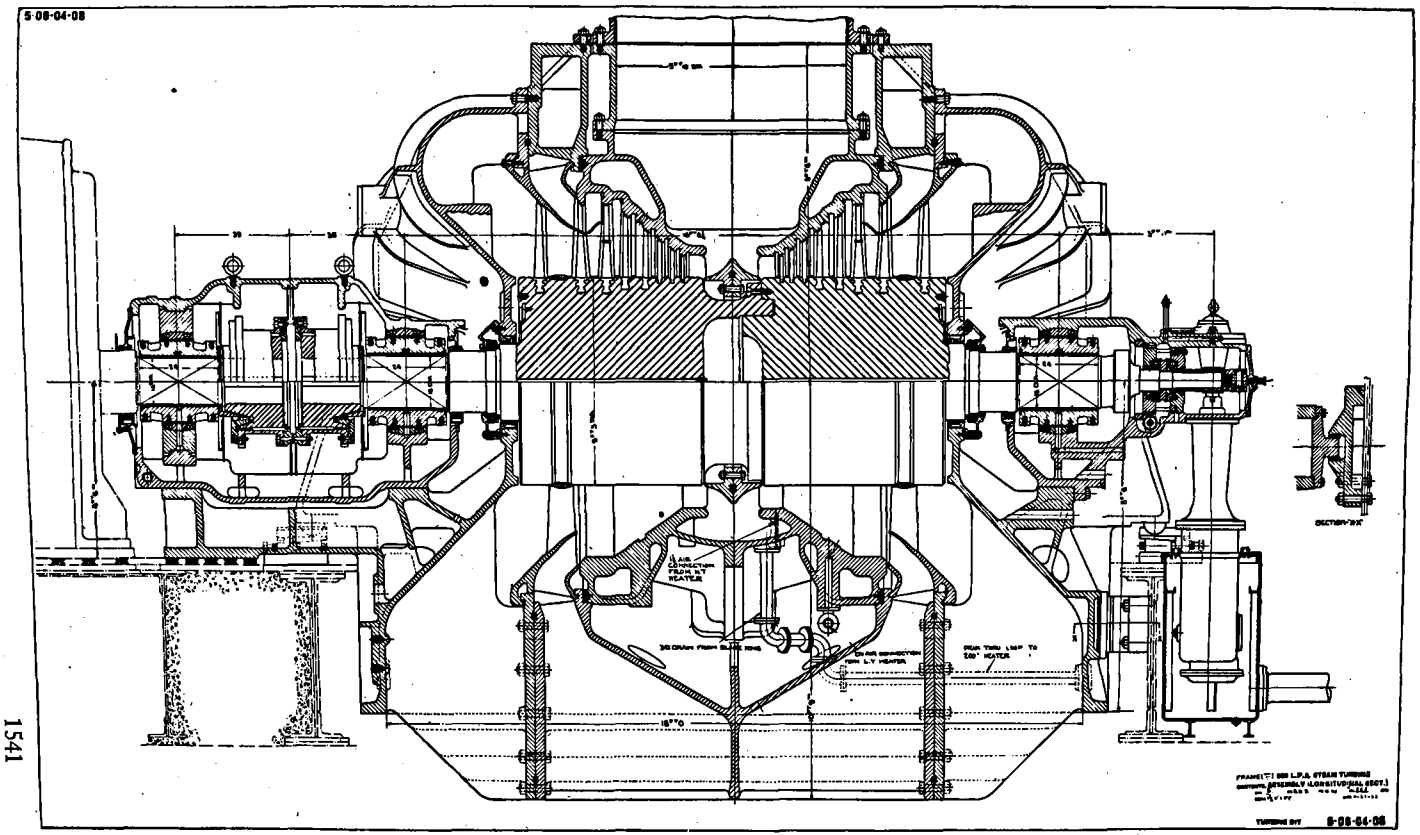


Fig. 12.

system which may be readily checked at subsequent times with the turbine in or out of operation.

Later designs of turbines are under construction One for the United Electric Light & Power Co., of 50,000 kW. capacity, with best point of steam consumption at 40,000 kW., is of the cross-compound type shown at *K* in Fig. 2, the high pressure element being shown in detail in Fig. 11, the low pressure element being shown in Fig. 12, in both of which have been embodied the general features of construction described above. The low pressure blade characteristics are given in item 36, Table I. The simplicity of structure incidental to cross compounding should be evident in comparing this with the smaller capacity machine of Fig. 7.

Another installation of a 50,000 kW. turbine is of particular interest as it is for the base load station being built for the Commonwealth Edison Co. at Crawford Ave., where the operating conditions will be 550 lbs. steam pressure, superheated to 725 degrees total temperature, the steam expanding through high pressure turbine elements, then being reheated to 700 degrees and returned to lower pressure turbine elements. This station will be doubly interesting because, to begin with, it will comprise three turbine units each built by a different company. All will be cross-compound turbines. One, of 60,000 kW., is being built by the General Electric Co., in which a separate high pressure, 1,800 R.P.M. generating element will, at full load, expand steam to 120 lbs. abs. pressure at which it is reheated, the steam being returned to a single low pressure, 1,200 R.P.M. turbine expanding to the condenser pressure.

Another, of 50,000 kW., being built in England by C. A. Parsons & Co., is of the type shown at *L* in Fig. 2, with the addition of a high pressure 1,800 R.P.M. generating element which, at full load, will expand steam from the initial pressure to 115 lbs. abs., at which it is reheated and returned to lower pressure elements of the two speed tandem type shown at *L* in Fig. 2. These elements operate at 1,800 and 720 R.P.M., respectively. The low pressure blade characteristics of this machine are shown in item 12, Table I.

Another, of 50,000 kW., being built by the Westinghouse Co., is of the general arrangement shown in Fig. 13. The high pressure and intermediate are arranged as a tandem compound, 1,800 R.P.M. machine, and shown in detail in Fig. 14. At full load, the high pressure expands to 132 lbs. abs., at which pressure it is reheated and returned to the intermediate turbine element where, at full load, it is expanded to 16½ lbs. abs., passing to the low pressure element driving its separate generator. The low pressure blade

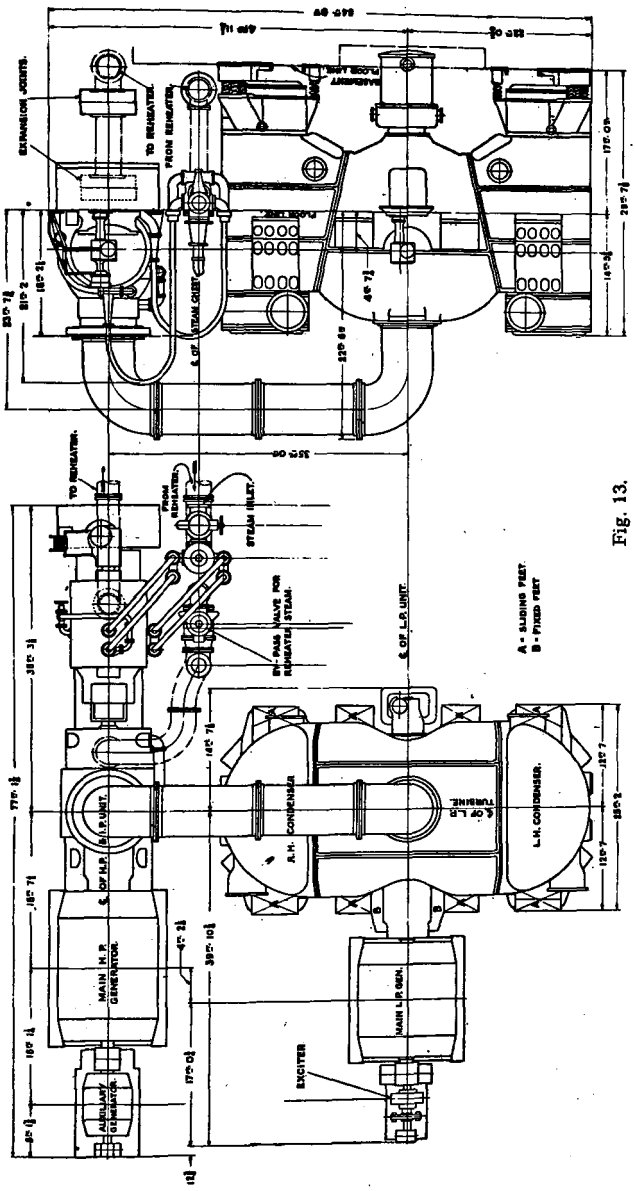

EXPANSION JOINTS.
TO REHEATER.
FROM REHEATER.
STEAM CHEST
TO REHEATER.
FROM REHEATER.
STEAM INLET.
BY-PASS VALVE FOR REHEATER STEAM.
A - SLIDING FEET.
B - FIXED FEET
MAIN H.P. GENERATOR.
AUXILIARY GENERATOR.
H.P. CONDENSER.
L.P. CONDENSER.
MAIN L.P. GEN.
EXCITER

Fig. 13.

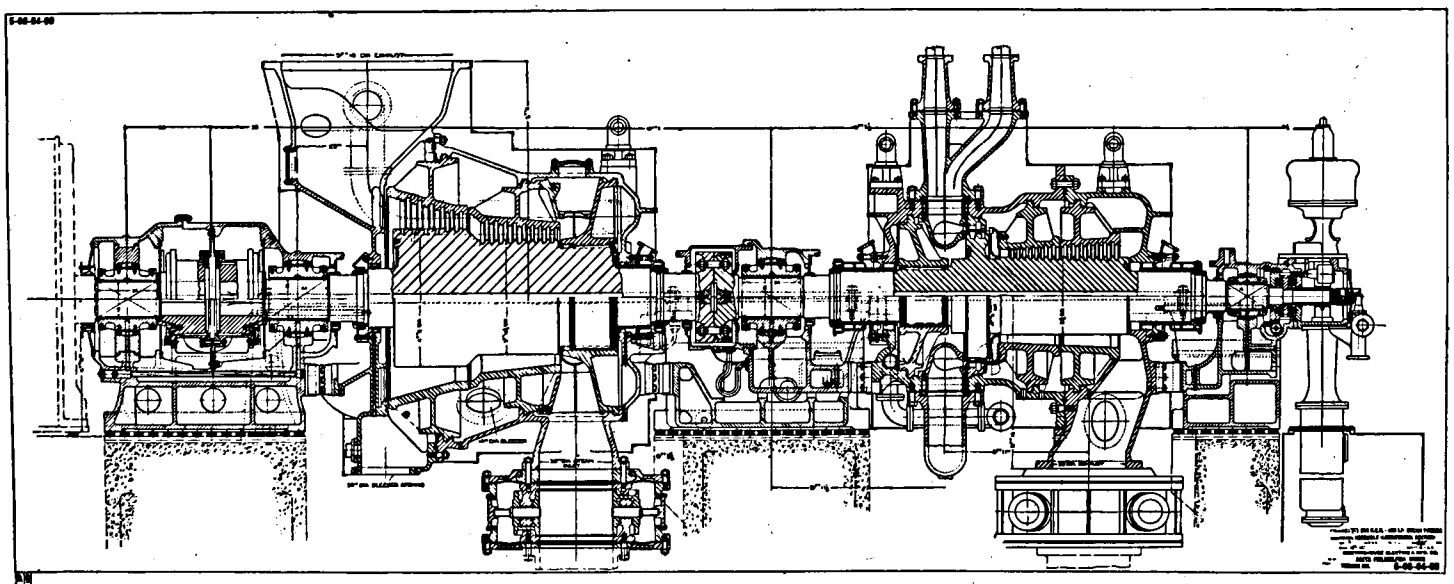


Fig. 14.

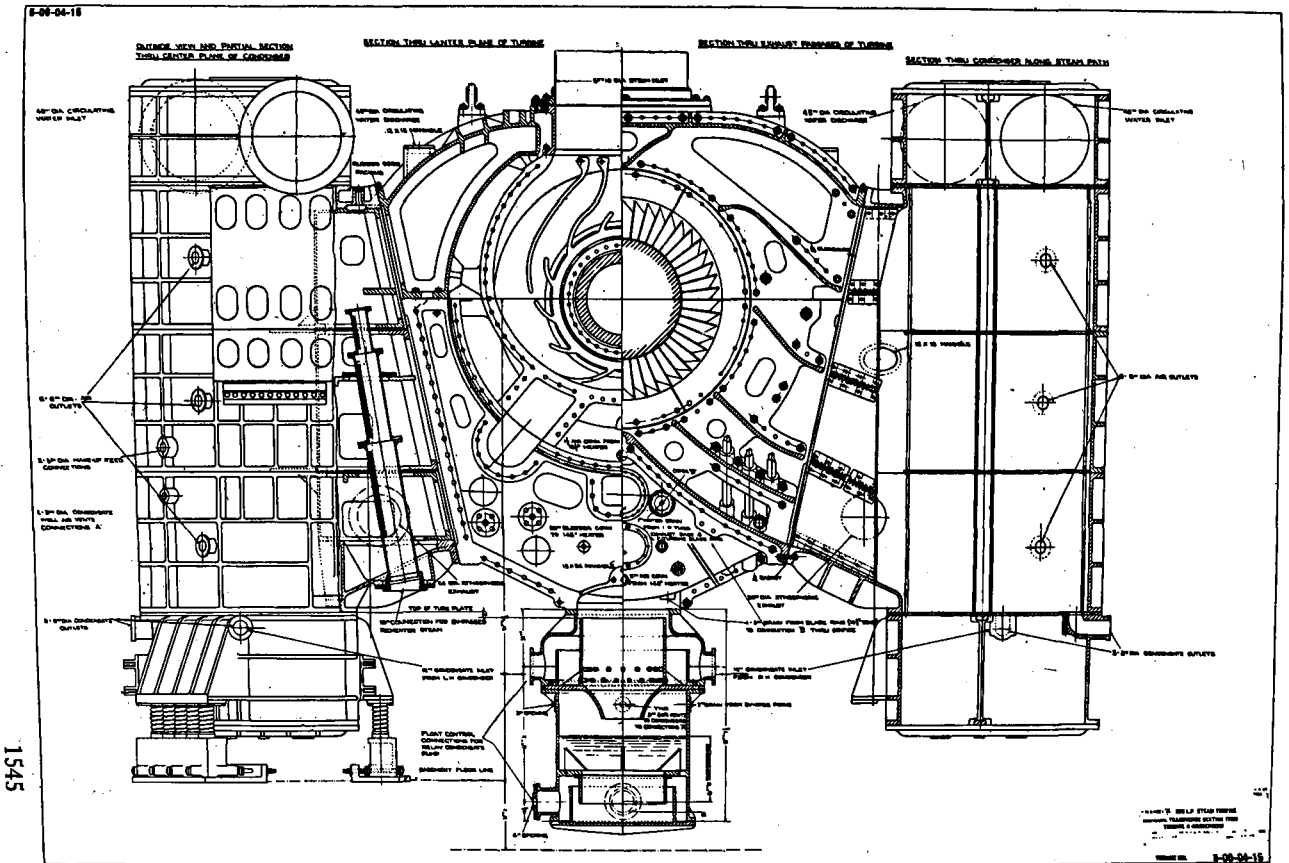

OUTSIDE VIEW AND PARTIAL SECTION THRU CENTER PLANE OF CONDENSER
SECTION THRU CENTER PLANE OF TURBINE
SECTION THRU EXHAUST MANIFOLD OF TURBINE
SECTION THRU CONDENSER ALONG STEAM PATH

Fig. 15.

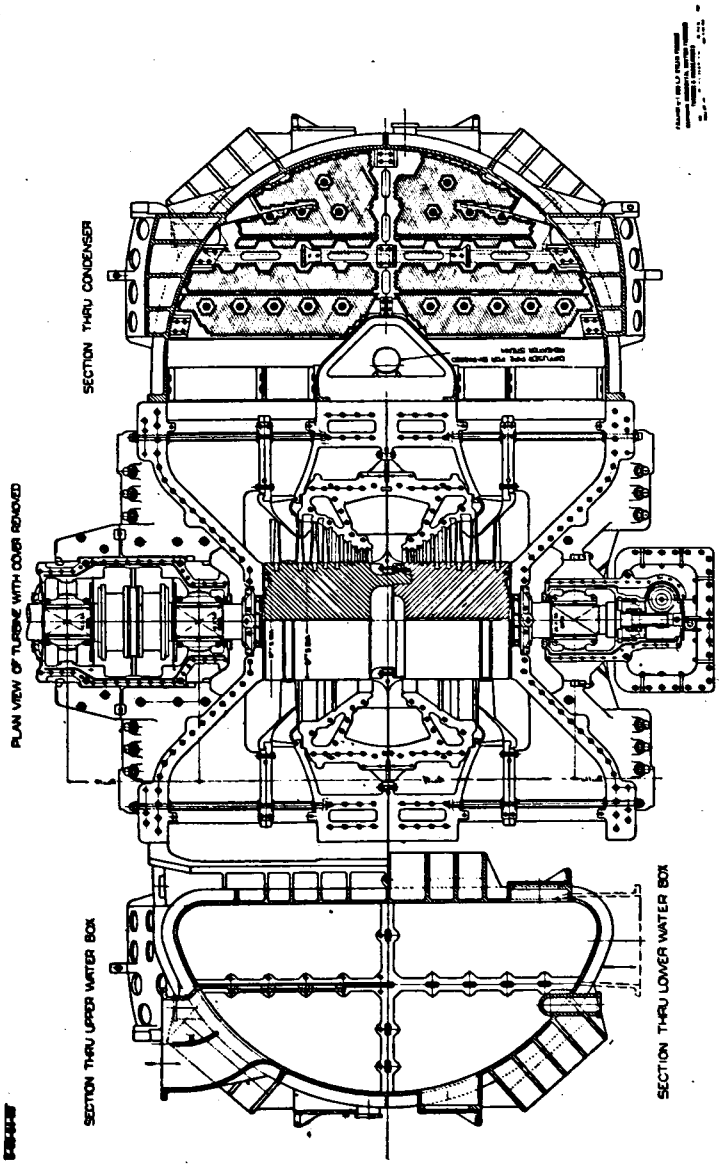

PLAN VIEW OF TURBINE WITH COVER REMOVED
SECTION THRU CONDENSER
SECTION THRU UPPER WATER BOX
SECTION THRU LOWER WATER BOX

Fig. 16.

characteristics are shown in item 37, Table I. Expectations of turbine performance of these machines have been based on a 10 lb. pressure drop through the reheater and its piping. It is important every precaution be taken to keep this at a minimum. Should this be as high as 25 lbs., practically all gain in economy from reheating would be lost.

The arrangement of the high and intermediate pressure turbines of the Westinghouse installation is shown in Fig. 14. They are arranged with steam flow opposed to each other so the one may neutralise the thrust of the other, eliminating the necessity of large dummies or balance pistons.

A characteristic of this installation is that all the condensers are vertical and furnished by three different manufacturers. The disposition of the condensing surface in the case of the Westinghouse installation is shown in the transverse section, Fig. 15, and the sectional plan, Fig. 16. In these views are shown the diffuser exhaust passages and the distribution of the steam to the entrance of the cooling surface. The flanges connecting the condensers to the turbine are inclined as shown in Fig. 15 to permit easy removal of the turbine cylinder cover. The joints in the upper portion are without bolts and gaskets, tightness being maintained by circular section rubber clamped over the joint.

The condenser being vertical, the condensate must pass over the cold tube plate with the objectionable feature that the condensate temperature would be depressed. To restore this, it is reheated in a hot-well of the form of a jet condenser receiving steam direct from the exhaust chamber of the turbine. The hot-well or jet condenser is provided with suitable vapour connections to a low pressure zone of the condenser.

A penalty of reheating is a complexity of regulating apparatus because the steam in the reheater and its piping would be sufficient to cause overspeeding in the event of the turbine being relieved of load. In the case of the Crawford Ave. installation, each of the three manufacturers has adopted a different method of handling this matter. That adopted by the Westinghouse Co. is shown in Fig. 17. The inner range of the speed responsive device operates the single valve controlling steam to the turbine and as the governor weights move out, this valve is closed. Further outward motion of the governor weights simultaneously opens a by-pass valve, by-passing steam from the reheating system direct to the condenser, and closes a butterfly valve in the inlet to the intermediate. A butterfly form

of valve was selected in order to introduce the least interruption to flow, and is carefully designed of stream line form.

Thought has been given to the effect of admitting highly superheated steam direct to the condenser, and in Figs. 15 and 16 is seen an internal steel pipe in the condenser through which this highly superheated steam will be admitted.

Some complexity is involved because the motions of the two sets of valves are reverse in direction. That is, the steam admission valve having reached its seat, the governor must have continued range of operation in order to open the reheater by-pass valve. Considering motion in the reverse direction, the governor weights swinging inwards must have continued motion after the reheater by-pass valve has reached its seat. This will explain the purpose of the collapsible and extensible links in connection with the relays of the two valve gears. These links have the powerful springs shown in the figure, which, if required to be extended and compressed by the governor, would interfere with its speed characteristic. Hence, the intervention of an additional relay between the governor and the relays of the valve mechanisms. These additional relays will require a greater rate of oil supply than the bearings if the valve gear is to respond quickly to speed changes, so an accumulator is installed, as shown in the diagram, which serves the double purpose of regulating the oil pressure in the governor system and supplying enough oil for one instantaneous complete swing of the valve gear without allowance for the quantity delivered by the oil pump. A feature of the system is that the charging or discharging of the accumulator does not affect the oil supply to the bearings, which are continually receiving the quantity delivered by the main pumps.

The additional relay in the governor mechanism and the collapsible and compressible links could have been avoided if relays had been employed having idle stroke corresponding to the whole travel of the governor. This would have increased their length excessively, so the plan adopted was preferred.

A further innovation of design is made because of the objection of carrying minor piping with 600 lbs. pressure about the turbine. Oil relays are therefore employed in connection with the automatic stop, automatic throttle, etc. This objection also applies to the auxiliary oil pump, which, for obvious reasons of availability must be steam driven, and no lower pressure steam than 600 lbs. is available in the neighbourhood. Hence, the automatic control of the two auxiliary oil pumps is oil relay operated in the manner

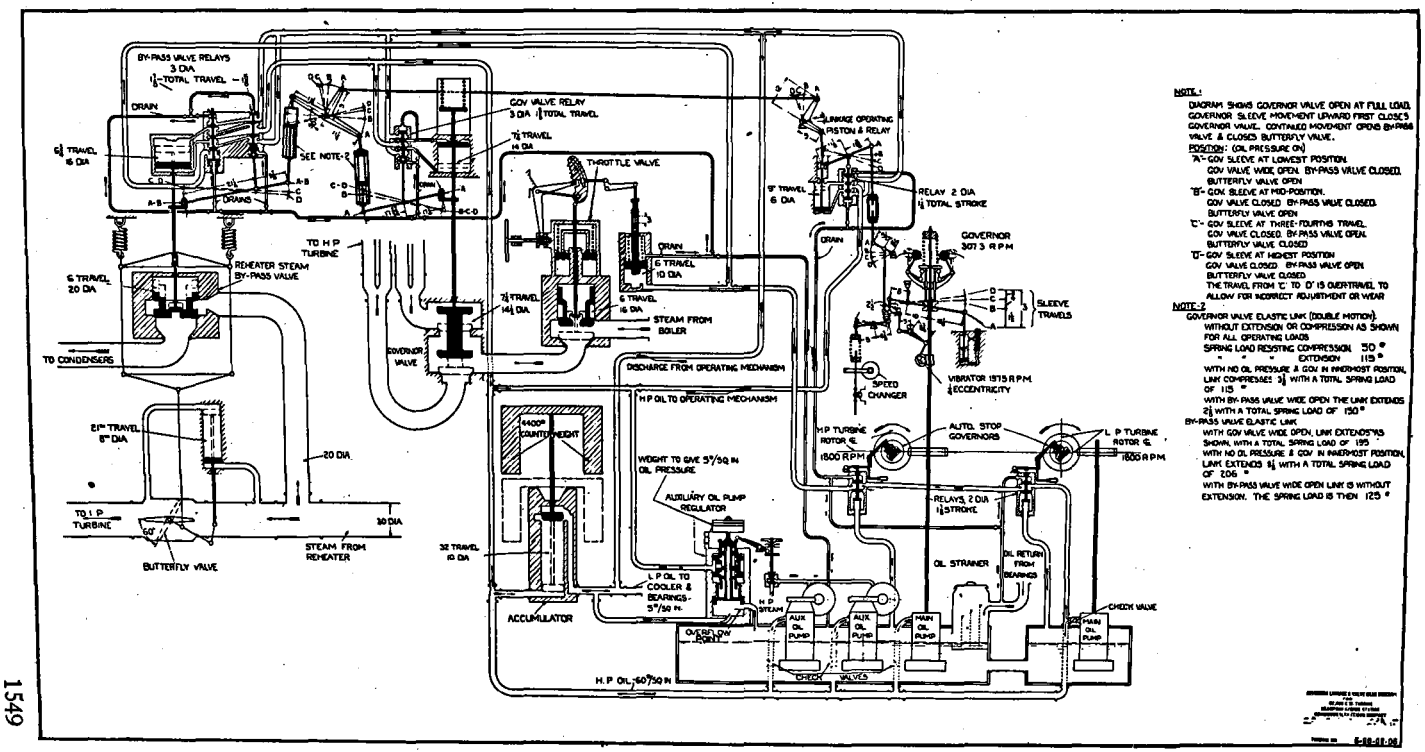

BY-PASS VALVE RELAYS
3 DIA
1½" TOTAL TRAVEL
DRAIN
GOV VALVE RELAY
3 DIA 1" TOTAL TRAVEL
LINKAGE OPERATING PISTON & RELAY
SEE NOTE-2
THROTTLE VALVE
RELAY 2 DIA
¼ TOTAL STROKE
GOVERNOR
307.3 R.P.M.
TO H.P. TURBINE
REHEATER STEAM BY-PASS VALVE
STEAM FROM BOILER
SLEEVE TRAVELS
TO CONDENSERS
GOVERNOR VALVE
DISCHARGE FROM OPERATING MECHANISM
H.P. OIL TO OPERATING MECHANISM
SPEED CHANGER
VIBRATOR 1815 R.P.M.
ECCENTRICITY
H.P. TURBINE ROTOR ⑥
1800 R.P.M.
AUTO. STOP GOVERNORS
L.P. TURBINE ROTOR ⑥
1805 R.P.M.
20 DIA
TO L.P. TURBINE
STEAM FROM REHEATER
BUTTERFLY VALVE
4400# COUNTER WEIGHT
WEIGHT TO GIVE 5"/SQ IN OIL PRESSURE
AUXILIARY OIL PUMP REGULATOR
RELAYS 2 DIA
1½ STROKE
OIL STRAINER
OIL RETURN FROM BEARINGS
L.P. OIL TO COOLER & BEARINGS - 5"/SQ IN.
ACCUMULATOR
CHECK VALVE
AUX. OIL PUMP
MAIN OIL PUMP
OVERFLOW PORT
CHECK VALVES
H.P. OIL 60"/SQ IN
NOTE-1
DIAGRAM SHOWS GOVERNOR VALVE OPEN AT FULL LOAD. GOVERNOR SLEEVE MOVEMENT UPWARD FIRST CLOSES GOVERNOR VALVE. CONTINUED MOVEMENT OPENS BY-PASS VALVE & CLOSES BUTTERFLY VALVE.
POSITION: OIL PRESSURE ON
'A'- GOV SLEEVE AT LOWEST POSITION.
GOV VALVE WIDE OPEN. BY-PASS VALVE CLOSED.
BUTTERFLY VALVE OPEN
'B'- GOV. SLEEVE AT MID-POSITION.
GOV VALVE CLOSED. BY-PASS VALVE CLOSED.
BUTTERFLY VALVE OPEN
'C'- GOV SLEEVE AT THREE-FOURTHS TRAVEL.
GOV VALVE CLOSED. BY-PASS VALVE OPEN.
BUTTERFLY VALVE CLOSED
'D'- GOV SLEEVE AT HIGHEST POSITION
GOV VALVE CLOSED. BY-PASS VALVE OPEN
BUTTERFLY VALVE CLOSED
THE TRAVEL FROM 'C' TO 'D' IS OVERTRAVEL TO ALLOW FOR INCORRECT ADJUSTMENT OR WEAR
NOTE-2
GOVERNOR VALVE ELASTIC LINK (DOUBLE MOTION).
WITHOUT EXTENSION OR COMPRESSION AS SHOWN FOR ALL OPERATING LOADS
SPRING LOAD RESISTING COMPRESSION 30 °
" " " EXTENSION 115 °
WITH NO OIL PRESSURE & GOV IN INNERMOST POSITION, LINK COMPRESSES 3/4 WITH A TOTAL SPRING LOAD OF 115 °
WITH BY-PASS VALVE WIDE OPEN THE LINK EXTENDS 2 3/4 WITH A TOTAL SPRING LOAD OF 150 °
BY-PASS VALVE ELASTIC LINK
WITH GOV VALVE WIDE OPEN, LINK EXTENDS 3/8 SHOWN, WITH A TOTAL SPRING LOAD OF 195 °
WITH NO OIL PRESSURE & GOV IN INNERMOST POSITION, LINK EXTENDS 9/16 WITH A TOTAL SPRING LOAD OF 206 °
WITH BY-PASS VALVE WIDE OPEN LINK IS WITHOUT EXTENSION. THE SPRING LOAD IS THEN 125 °

Fig. 17.

shown. The arrangement of all these mechanisms is made clear on the diagram, Fig. 17.

BALANCING.

The balancing of turbine rotors has received much attention. Most manufacturers have taken advantage of apparatus developed by N. W. Akimoff and sold by the Vibration Specialty Co. The Westinghouse Co. developed a balancing machine of their own similar to Akimoff's in the respect that the rotor is operated at slow speed on bearings carried on an inverted pendulum maintained vertical by opposing springs, observations of amplitude being made during resonance. A feature of difference is that the rotor is carried on pivotally supported bearing pads instead of rollers, thus reducing any error the result of departures of journals from true cylinders or errors of rollers. The use of rollers has not infrequently caused injury to journals by foreign particles being drawn between the surfaces. Furthermore, they are difficult to align so as not to produce a material end thrust of the rotor.

In Westinghouse practice, the rotor is speeded above the speed of resonance by means of an electric motor and magnetic clutch, the clutch separated and the rotor permitted to coast down in speed through resonance and the maximum amplitude observed, following which the clutch is connected, the current reversed and the rotor quickly brought to rest for adjustment of balance, The process of balancing as devised by the Westinghouse Co. involves only simple arithmetic. The sensitivity of the machine is such that almost any degree of accuracy of balance can be secured. The balancing operation is carried out at low speed approximately $\frac{1}{10}$ to $\frac{1}{4}$ the turbine speed, so it is necessary that the elements of the rotor be approximately in balance before being balanced in the machine so as to eliminate local couples of sufficient magnitude to cause a bending of the shaft when at speed, even though it be in perfect dynamic and static balance considered as a rigid body.

Generally, the effect of such balancing processes has been to elevate the plane of smooth running of turbines. It has, however, brought about a recognition of defects which were previously not known to exist. Slight vibrations at certain loads, due presumably to local distortions occurring under certain temperature and stress conditions, have brought about a practice lately developed by the Westinghouse Co. of seasoning turbine rotors. After the building of the turbine is complete, the rotor is first balanced, then placed in a casing in which it is slowly revolved by means of an appropriate

turbine and highly superheated low pressure steam admitted to the casing for several hours. Following this, the casing is opened to a condenser under vacuum and the rotor operated at 20 per cent. overspeed for 20 minutes. The rotor is then kept running slowly until it is sufficiently cooled to be removed, placed in the balancing machine and finally balanced. To secure complete seasoning, it is

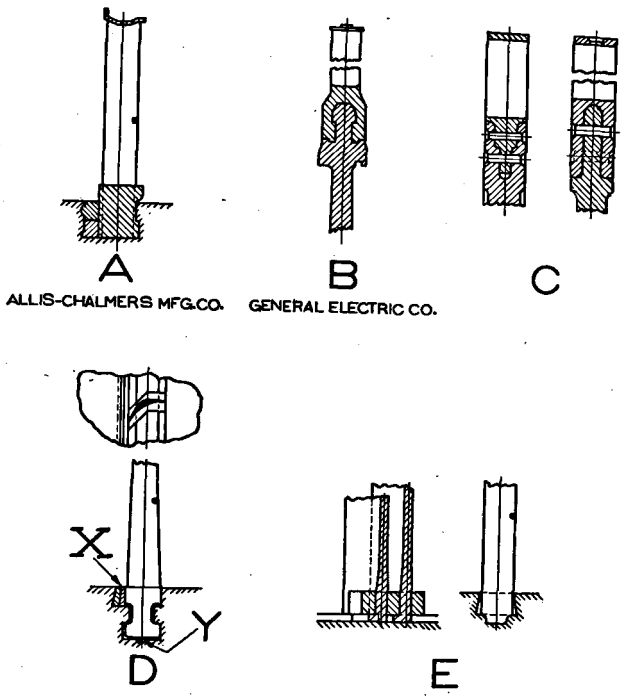


Fig. 18.

probable that the process must be carried out more than once with intervening cooling.

An incidental advantage of this process is to permit shipment of a large turbine following erection on the shop floor eliminating the cost and risk of erecting on a testing foundation, where if merely operated at overspeed with no load effects no seasoning and gives less assurance of smooth operation in service compared with the process described above.

The practice of the General Electric Co. is accurately to balance each completed wheel before assembly on the shaft. Following this, the complete rotor is dynamically balanced.

BLADING AND BLADE FASTENING.

The system of blade fastening employed by the three principal manufacturers is shown in Fig. 18. A method of fastening blades by means of cross pins, giving the maximum degree of strength, is employed by the Metropolitan-Vickers Co. and by the Westinghouse Co. for small size single disc turbines, and is shown at *C*, Fig. 18. It does not permit the ease of replacement as to blades interlocked in a circumferential groove.

The Allis-Chalmers Co.'s practice, shown at *A*, has the base shroud or foundation ring of bronze, which is cast on the blades. For temperatures higher than 600 degrees, the foundation ring is of cast steel.

The Westinghouse method, shown at *E*, with dovetail grooves whose walls have a small angle, has long been in successful use for low stresses, but is inappropriate for high stresses and wide operating temperature ranges where there are differing co-efficients of expansion of the material, because of an alternate crushing and loosening, which in instances have caused a progressive lifting of the blades in their holding slots.

A later development of method of attaching the higher stressed blades to drums, as employed by the Westinghouse Co., is shown in Fig. 8. This particular blade increases in section from the tip to the root, and like other forms, the section of the root is reduced at a point below the surface of the blade carrying element to form the holding means. Vibration is precluded from reaching down to this reduced section by the friction of the wedges at *X*, as in the case of *D*, Fig. 10. The method of forming the holding surfaces by means of rectangular undercut grooves recommends itself for ease of measurement. Ample clearances are provided, permitting blades to be readily slipped to place. They are held to their outer surfaces by means of short semi-circular caulking strips at *Y*, Fig. 8.

The drop forging art has been developed to a high degree by the Westinghouse Co., permitting the production of blades of tapered and warped section employed in the low pressure multiple exhaust blading. Examples of this are shown in Fig. 8, requiring no machine work beyond the fits at the base and the partitions when the latter are employed.

The blading of the first sixteen stages of the General Electric Co.'s turbine, illustrated in Fig. 6, is of monel metal machined from solid bar stock. The remainder is of nickel steel machined in a similar manner. The roots are formed integrally with the blades and are machined accurately to fit the grooves and each other.

Another feature of blade design enters in the case of large blades. A high ratio of blade height to mean diameter causes disparity of blade velocity between the tip and the root which is not easily satisfied with one steam velocity and constant inlet and discharge angles. The old practice of parallel section blading having a height of one-fifth the mean diameter has not been generally exceeded. The relative circumferential pitch between the tip and the base in the case of the above ratio, would be 1 to $1\frac{1}{2}$. This ratio of relative pitch becomes greater when a tapered form of blade is used. Tapering accomplished by thickening in a circumferential direction can be carried out only to a limited extent because of obstructing the blade passage at the base and otherwise interfering with the blade form, so additional tapering is usually carried out in an axial direction. This brings about a further effect of increasing the relative circumferential pitch in the proportion of the width at the base to the width at the tip. The actual ratio of the relative pitches at the tip and base of a rotor blade is, therefore, the product of the two.

$$\text{Relative Pitch} = \frac{\text{tip dia.}}{\text{base dia.}} \times \frac{\text{axial width at base}}{\text{axial width at tip}}$$

It is therefore desirable to make large blades with high ratios of relative pitch with warped sections as is practised in hydraulic turbines.

There is diversity of practice in inserting the last blade and locking it in its slot. In the case of higher stressed blades, it was customary to omit one blade and insert a locking means in its place. Lately a new locking means has been devised, as shown in Fig. 19, which permits a full complement of blades to be inserted in drum type rotors. The relative ease of blade attachment to a drum as compared with a disc is apparent.

No blade should have any reduction of moment of inertia of the section from the tip to the root because of the increased curvature at such points when vibrating, which may result in progressive fracture at that point. A point in design of higher stress blading to which sufficient attention is not always given is to avoid concentrated stresses, the result of eccentric loading. The blade forms, Fig. 8, have been carefully designed so the centres of gravity of

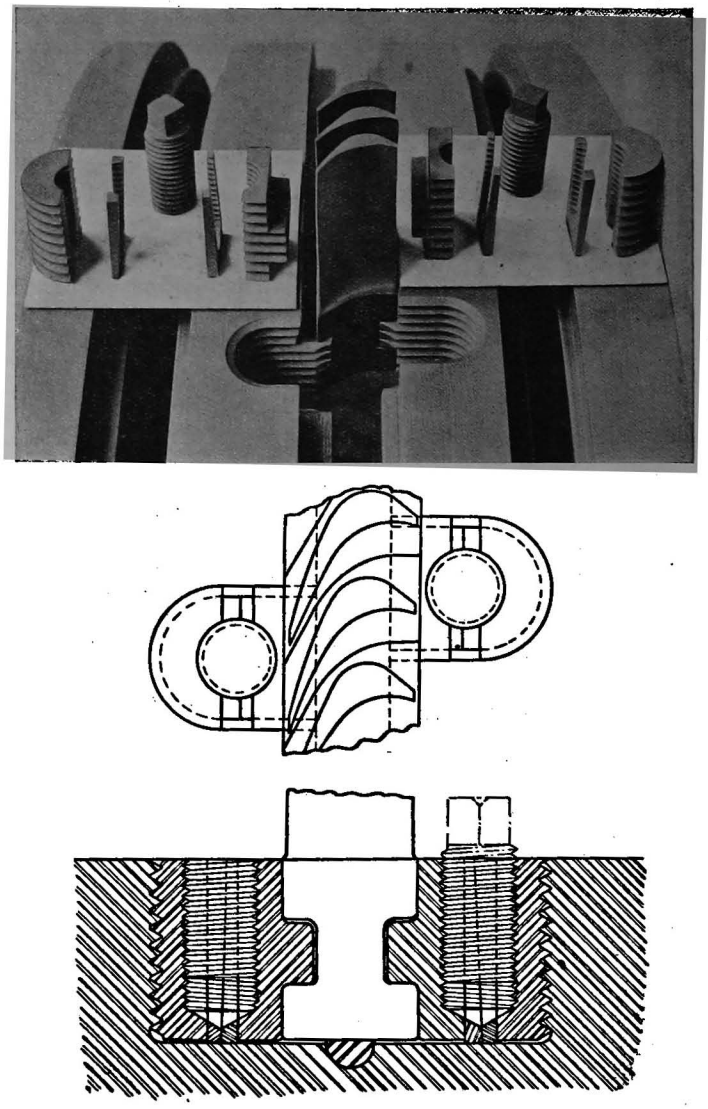


Fig. 19.

the various sections are all in a radial line with respect to the centre of support at the base.

The problem of the design of turbine blading, however, is not so much one to provide strength to resist centrifugal forces, but rather of sufficient knowledge of the subject to be able to eliminate the possibility of nodal vibrations.

All turbine blades are subjected to :

First : Bending moments because of the force causing rotation.

Second : Bending moments incidental to the contraction and expansion of shrouding or lashing wires, because of the blading heating and cooling at a different rate to the main blade carrying element.

Third : Vibratory stresses incidental to errors of balance, of frequency corresponding to the R.P.M.

Fourth : Probable vibratory stresses produced by high period vibrations in the steam current.

Fifth : Torsional vibrations incident to the character of the load with A.C. generators incidental to unbalanced phases, and a multiple of the R.P.M., are particularly manifest in geared turbines for marine propulsion and in the case of centrifugal pump drives.

To all the above are added the stresses incidental to centrifugal force in the case of the moving blades, and for this reason, breakage of moving blades is more common than of stationary ones. This fact suggested the later Westinghouse practice of making moving reaction blades of greater width of section than their complementary stationary blades.

The natural frequency of the turbine blading may be raised by the adoption of various forms of shroudings and lashings for the purpose of binding blades together, which, however, can be carried out only to a limited extent because of introducing bending stresses due to the blades heating and cooling when the expansion and contraction takes place at a different rate than in the blade carrying element.

A method proposed and practised by some manufacturers is to subject the completely bladed rotor removed from its casing to forced vibrations varying in frequency from zero to its normal R.P.M., concluding that the blading is safe so long as the natural frequency of any blades is less than the running speed inasmuch as their frequency would be higher when subjected to centrifugal force. This may be misleading, for the natural frequency is proportional to the square root of the modulus of elasticity, and

later research indicates that the elastic modulus is a variable quantity, depending upon temperature, stress and rate of application of stress. The stress due to centrifugal force is, of course, constant. The stress incidental to the vibration is applied at a variable rate depending upon the frequency and amplitude of the vibration. An important programme of research has been instituted by the Westinghouse Co., which will determine, first, the effect on the elastic modulus of temperature and stress for the various materials involved, and secondly, the maximum degree of resistance to vibratory stress, that can be secured by various forms of lashings for the different standard blades, the experiments to be carried out with as rapid heating and cooling as can be produced to the extremes of temperature ever likely to obtain in practice. Thirdly, determining the natural frequency of these blade groups, and correcting to the condition of stress and temperature incidental to their operating conditions. It is the author's regret that the result of this research is not available for presentation at this time.

The Allis-Chalmers Co. carried out experiments some years ago of subjecting groups of blades to hammer-like shocks causing them to vibrate at their natural period until breakage ensued. These experiments showed that greater resistance was secured with the middle lashing wire located nearer the base than the outer shroud and resulted in their modern practice in this regard.

BLADE MATERIALS.

Brass: Copper-zinc alloys are no longer employed for turbine blading by manufacturers of large turbines, because of the general deterioration and loss of strength at elevated temperatures. They are, however, still employed for the purpose by several manufacturers of smaller turbines operating at lower temperatures.

Bronze: Copper-tin alloys containing phosphorus are likewise no longer employed for turbine blading. With low tin content they are weak and rapidly lose their strength at high temperatures. Better physical properties may be secured with higher tin content, but tin in excess of 2 per cent. introduces a hot-shortness at temperatures at or below those required for any silver soldering or brazing process.

Nickel Steel: This is employed by the General Electric and Westinghouse Companies for impulse blading, and by the Westinghouse Company for the higher stressed reaction blading. That employed by the Westinghouse Co. is a high grade electric furnace

product, of low carbon content, the specifications as to chemical composition being :

Carbon	·05	..	·10 per cent.
Manganese	·30	..	·50 ,, ,,
Phosphorus	·02 per cent maximum.		
Sulphur	·03 ,, ,,		,,
Silicon	·10	..	·20 per cent.
Nickel	4·50	..	5·50 ,, ,,

In the hot rolled or forged condition, the minimum physical characteristics are as follows :—

Ultimate Tensile Strength	65,000 lbs.
Proportional Elastic Limit	35,000 lbs.
Elongation	30 per cent. in 2 in.
Reduction of area	60 per cent.

The heat treatment after forging consists of quenching in oil from 1,450 degrees Fahr., drawing at 1,200 degrees Fahr., and cooling in oil. In this heat treated condition, the minimum physical characteristics are as follows :—

Ultimate Tensile Strength	90,000 lbs.
Proportional Elastic Limit	50,000 lbs.
Elongation	25 per cent. in 2 in.
Reduction of Area ..	60 per cent.

The physical characteristics fall off at 500 degrees Fahr., approxi, mately 20 per cent. in Elastic Limit, 10 per cent. in Tensile Strength and 15 per cent. in Modulus of Elasticity.

There are instances where corrosion and erosion have been evident with this material where used in lower pressure stages.

Cupro-Nickel : This alloy is used considerably by the Allis-Chalmers Co. for turbine blading, and in some few instances by the Westinghouse Co. The Westinghouse specifications for this material are as follows :—

CHEMICAL COMPOSITION.

Copper	78·00	..	82·00 per cent.
Nickel ..	18·00	..	22·00 ,, ,,
Iron ..	·40 per cent. maximum.		
Lead ..	·05 ,, ,,		,,
Carbon ..	·05 ,, ,,		,,
Manganese	·60 ,, ,,		,,
Sulphur ..	·015 ,, ,,		,,
Silicon ..	·10 ,, ,,		,,

In the cold rolled or drawn condition, the following are the average physical characteristics :—

Proportional Elastic Limit	50,000 lbs.
Yield Point	65,000 ,,
Ultimate Tensile Strength ..	70,000 ,,
Elongation	20 per cent. in 2 in.
Reduction of Area	65 per cent.

The physical characteristics fall off at 700 degrees Fahr., approximately 27 per cent. in Elastic Limit, 22 per cent. in Tensile Strength.

Manganese Copper : This alloy is employed by the Westinghouse Company for low stressed reaction blades. The Westinghouse specifications are as follows :—

CHEMICAL COMPOSITION.

Manganese	4·00 ——	5·50 per cent.
Copper	94·50 per cent.	96·00 per cent.
Iron ..	·30 per cent. maximum	
Carbon ..	·08 ,, ,, ,,	
Lead ..	·08 ,, ,, ,,	

In the cold rolled or drawn condition, the following are the average physical characteristics :—

Proportional Elastic Limit	31,000 lbs.
Yield Point	48,000 ,,
Ultimate Tensile Strength ..	60,000 ,,
Elongation	20 per cent. in 2 in.
Reduction of Area	70 per cent.

The strength of this material falls off less with temperatures than any copper-tin or copper-zinc alloy. The physical characteristics fall off at 700 degrees Fahr., approximately 60 per cent. in Elastic Limit and 25 per cent in Tensile Strength.

Monel Metal : This material has been used to some extent by the Allis-Chalmers and General Electric Companies, and in a few instances where copper alloys have been troublesome, by the Westinghouse Company. The Westinghouse specifications are :—

CHEMICAL COMPOSITION.

Copper	23·00 per cent. minimum
Nickel	62·00 ,, ,, ,,
Iron	3·50 per cent. maximum
Aluminium ..	·50 ,, ,,
Manganese ..	1·50 — 3·50 per cent.
Silicon	·35 per cent. maximum
Sulphur	·04 ,, ,, ,,
Carbon	·15 ,, ,, ,,

It is regarded as important that the carbon content be carefully restricted.

In the cold rolled and annealed condition, the average physical properties of the material are as follows:

Proportional Elastic Limit	50,000 lbs.
Yield Point	60,000 ,,
Ultimate Tensile Strength ..	85,000 ,,
Elongation	25 per cent. in 2 in.
Reduction of Area	55 per cent.

The Westinghouse Company does not regard this, at the least in its present commercial development, as a desirable material because of non-uniformity and frequently the presence of carbon streaks and other imperfections which produce a greatly weakened and unreliable material. Its non-corrodibility is satisfactory. It is more or less hot-short between approximately 1,200 degrees Fahr. and 1,600 degrees Fahr.

Other materials not at present in general use are :—

Pure Nickel: The Westinghouse specifications are :—

CHEMICAL COMPOSITION.

Nickel, including Cobalt	99·00 per cent. minimum — Cobalt about ·40 per cent.
Manganese	·35 per cent maximum
Carbon	·15 ,, ,, ,,
Silicon	·10 ,, ,, ,,
Copper	·25 ,, ,, ,,
Iron	·50 ,, ,, ,,
Sulphur	·02 ,, ,, ,,

The physical characteristics are approximately as follows :—

	Forged.	Cold Rolled.
Proportional Elastic Limit	35,000 lbs.	
Yield Point	45,000 ,,	
Ultimate Tensile Strength	75000 ,,	80,000 lbs.
Elongation in 2 in.	30%	20%
Reduction of Area	55%..	

The material is very non-corrosive and lends itself well to forging, rolling and drawing operations. The physical characteristics fall off at 700 degrees Fahr., approximately 10 per cent. The present objection to the use of this material is cost.

Stainless Steel: The better known forms of stainless Steel are not regarded favourably by the Westinghouse Co. because they do not lend themselves well to drop forging operations. Blades of this material should be machined all over. A low carbon form of this material, beginning to be manufactured in the United States by the Firth-Sterling Steel Co., the Crucible Steel Co. of America, and the Allegheny Steel Co., is quite readily forged and believed to be as non-corrosive under normal blading service conditions as any other material although polishing is probably necessary to secure completely this non-corrodibility. The Westinghouse specifications for this material are as follows :—

CHEMICAL COMPOSITION.

Carbon	·07 — ·12 per cent.
Manganese	·80 per cent. maximum
Phosphorus	·03 „ „ „
Sulphur	·05 „ „ „
Silicon	·25 „ „ „
Chromium	11·50 — 13·00 per cent.
Nickel	·60 per cent. maximum

The heat treatment after forging consists of quenching in oil from 1,750 degrees Fahr., drawing at 1,200 degrees Fahr., and cooling in oil. In this heat treated condition, the minimum physical characteristics are as follows :—

Proportional Elastic Limit	60,000 lbs.
Ultimate Tensile Strength	90,000 „
Elongation	20 per cent. in 2 in.
Reduction of Area ..	60 per cent.
Izod Impact ..	50 ft. lbs.

The present objection to its use is cost.

Rustless Nickel Chromium Steel: A high nickel, medium chromium steel is used by the Allis-Chalmers Co., for their higher stressed reaction blading. The chemical composition is approximately as follows ·

Carbon	·35 — ·50 per cent.
Managnese	·50 — 1·50 „ „
Phosphorus	·04 per cent.
Sulphur	·05 „ „
Silicon	·75 — 1·50 per cent.
Nickel	19·00 — 25·00 „ „
Chromium	6·00 — 9·00 „ „

In the rolled condition, results have been secured approximately as follows :—

Proportional Elastic Limit	60,000 lbs.
Yield Point	80,000 ,,
Ultimate Tensile Strength ..	130,000 ,,
Elongation	26·0 per cent in 2 in.
Reduction of Area	50·0 per cent.

This material is quite non-corrosive, but is difficult to work, especially in machining. The cost is high.

The desiderata of turbine blading materials are :—

1. High fatigue limit.
2. A fine and uniform micro-structure, not subject to internal changes or growth under long periods at elevated temperatures.
3. Maintainance of physical strength and modulus at elevated temperatures.
4. Non-corrosiveness.

Consideration must be given to hot-shortness of material if any soldering or brazing is to be performed. If hot-shortness occurs at or below soldering temperature, fracture will result if any stresses exist during cooling of the parts.

LABYRINTHS.

Labyrinth packings, or, in re-action type turbines what are called "dummies," have been the subject of much concern to all turbine designers. The problem of producing a packing with minimum leakage, occupying small space, and strictly reliable is a difficult one. The conventional form employed for many years is that shown at *A*, Fig. 20, a later form of which is shown at *B*. This system is still employed by the Allis-Chalmers Co. The advent of what is known as the Kingsbury Thrust Bearing in the United States—the Michell Bearing in Great Britain—sensible of sustaining great thrust, made it seem obvious that a good thing to do would be to reduce the diameters of dummies in reaction turbines, and so diminish leakage, leaving as much as possible of the unbalanced axial thrust to be taken by the thrust bearing. It was found that the thickness of the oil film in the thrust bearing would vary materially with the amount of thrust, and with heavy loads the structural elements between the thrust bearing and the turbine cylinder proper would give under the load. This, together with distortion of the cylinder structure, gave unexpected changes of dummy clearance, so that it was difficult to maintain an adjustment

that would be at once safe and provide a fine clearance and low leakage loss.

This brought about the adoption of the two forms of labyrinth shown in *C* and *D*, Fig. 20. The former is employed where the labyrinth is adjacent to the thrust bearing. The bevelled outer surface provides for grinding and adjustment of clearance. The latter is employed where the labyrinth is remote from the thrust bearing, as in the case of semi-double flow turbines of types *A* and *B*, Fig. 1. These two types of labyrinths have been uniformly successful.

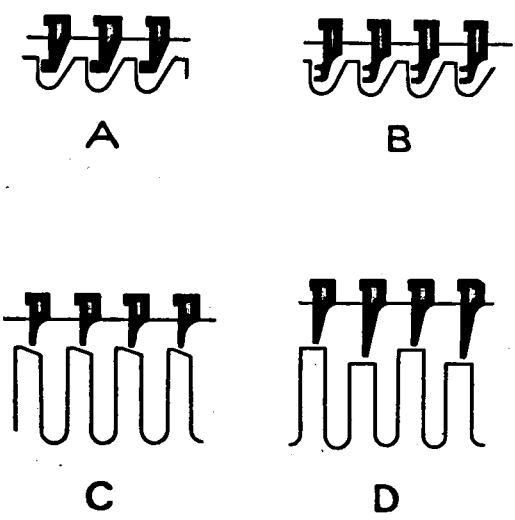


Fig. 20.

It would be supposed, generally, that types *C* and *D* have the advantage of reliability, but the disability of being more leaky than *A* and *B*. One particular instance, however, is that of one of the 35,000 kW. tandem machines at the Hellgate Station of the United Electric Light & Power Co., originally fitted with type *A*, where a clearance of ·032 in. at no load increased to ·089 in. at maximum load for the reasons quoted above. Substitution of the labyrinth of type *C*, in this case at least, gave both increased reliability and less leakage.

Desiderata in labyrinth packings are :

The providing of ample spaces between the successive points of fine clearance to form expansion chambers to render the packing

more effective. These also serve to provide space for torn off material in case of any breakage.

A further purpose of the deep grooves in types *C* and *D* is that any local heating will have a tendency to travel circumferentially before reaching the continuous longitudinal fibres of the rotor, thus causing smaller disturbance to the rotor.

The selection of the material which, in the case of contracting, will wear away without the generation of material heat.

For the latter characteristic, aluminium is ideal and has been employed to a great extent. However, it softens at high steam temperatures and dissolves in alkalies, and has, therefore, been abandoned. A 71 per cent. copper, 29 per cent. zinc mixture is in general use ; lead and iron limited to a maximum of ·07 per cent. and ·05 per cent., respectively. Nickel is being employed for conditions of high pressure drop and high temperature.

BEARINGS.

Some slight reduction of losses without affecting reliability may be secured by raising the unit pressures on bearings to at least three times present practice, which, however, may not necessarily effect a reduction of the total length of the turbine unit.

Some gyroscopic stabiliser rotors, for example, have been operated successfully with bearing pressures many times higher than customary with turbine practice. In one instance, a stabiliser rotor bearing 18½ in. × 28 in. operated successfully with a maximum pressure of 900 lbs. per square inch of projected area and an average pressure of 720 lbs. during one direction of precession. It, however, had the disadvantage of the journal moving over to the opposite side of the bearing at each precession.

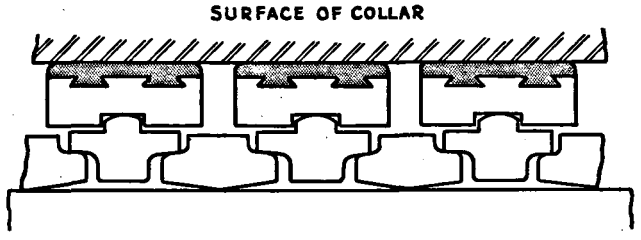
If present turbine practice of about 150 lbs. per square inch is increased materially, a means of establishing the oil film before the rotor is revolved is a necessity in order to avoid injury during the first fraction of a revolution. This has been readily accomplished in certain applications by the temporary application of high pressure oil in some appropriately disposed grooves in the bearing, establishing the oil film before motion is commenced.

A method adopted by the principal manufacturers in the United States is to provide for spherically formed keys with liners beneath them on the outer surfaces of the bearing shells, permitting the position of the rotor to be adjusted within the casing by interchange of liners. With reaction turbines, it is customary to perform what is known as " taking clearances," that is, centralising the rotor at

the extreme ends, then displacing it radially in four directions by interchanging liners until contacting at the blade tips is secured, after which adjustment of the liners places the rotor, beyond any doubt, in the desired position in the casing.

All turbine bearings comprise cast iron shells lined with a tin base mixture. The Westinghouse Co. employs a lead base mixture for most other purposes, including turbine generator bearings.

A function of the bearing lining is more than to provide a material which will not abrade the shaft in the event of failure. It is to provide a compressively elastic medium between the shell and the journal, which will be resilient under the concentrated journal loads incidental to errors of truth and flexure of the shaft. If bearing pressures are to be materially increased, consideration must be given to making the bearing material sufficiently thick to provide the



DEVELOPED SECTION ON MEAN DIAMETER OF BEARING

Fig. 21.

requisite elasticity. The bearing mixtures are taken as having the following moduli of elasticity under compression :

Tin Base Babbitt :		
Moulded in chilled form		2,000,000
Slow cooling	..	1,000,000
Lead Base Babbitt :		
Moulded in chilled form		900,000 to 1,050,000
Slow cooling	..	400,000 to 700,000

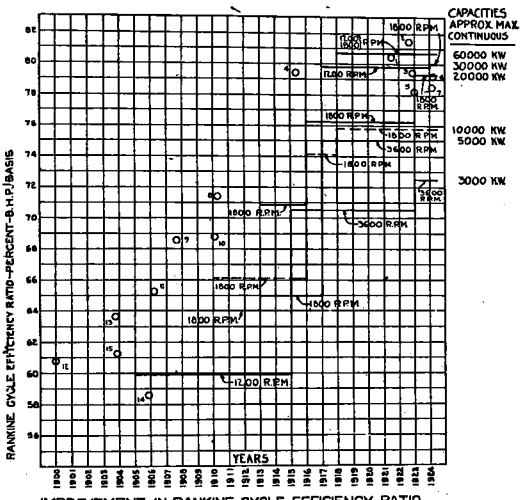
For this reason the babbitt in the stabiliser bearing mentioned above was made $\frac{7}{8}$ in. thick.

THRUST BEARINGS.

The later form of Kingsbury Thrust Bearing, in which the thrust segments are mounted on levelling blocks, as shown in Fig. 21, is an important improvement, as compared with the older practice of the segments mounted on a spherical self-aligning ring. It permits

of the insertion of any new segment though it be of different dimensions to the one it replaces. Any expansion of a segment due to local heating does not increase the loading of that segment because of the compensating effect of the levelling blocks.

While manufacturers of impulse type turbines have, as stated, progressed from turbines comprising few stages of multiple velocity



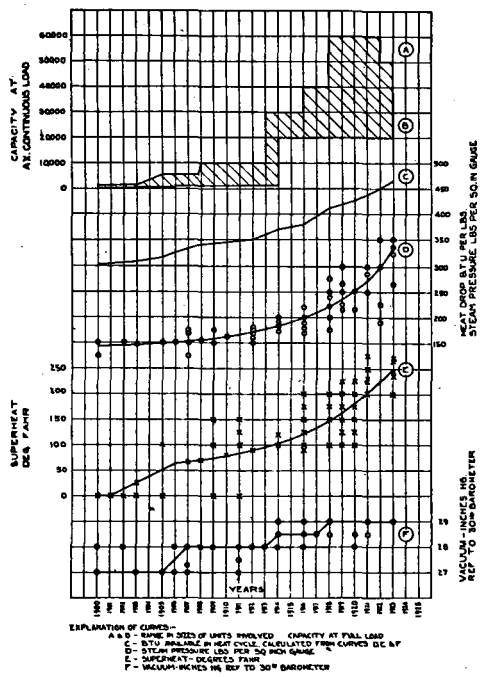
IMPROVEMENT IN RANKINE CYCLE EFFICIENCY RATIO OF WESTINGHOUSE 60 CYCLE TURBINE UNITS. BASED ON CONTRACT GUARANTEES AT BEST POINT LOAD GENERATOR LOSSES EXCLUDED.

NUMBERED POINTS INDICATE FIELD TESTS AS FOLLOWS:

		PRESSURE LBS. PER SQ. IN. GAUGE	SUPERHEAT DEGREES FAHR.	VACUUM INCHES MERCURY
1	60000 KW—3 CYLINDER-INTERBOROUGH RAPID TRANSIT CO.	205.5	15.6	28.91
2	35000 KW—TANDEM COMPOUND-UNITED ELEC. LIGHT & POWER CO.	180	100	29
3	35000 KW—TANDEM COMPOUND-COMMONWEALTH EDISON CO.	180	115	29
4	30000 KW—CROSS COMPOUND-INTERBOROUGH RAPID TRANSIT CO.	205	136.1	28.94
5	30000 KW—TANDEM COMPOUND-COMMONWEALTH EDISON CO.	210	200	29
6	30000 KW—TOLEDO EDISON CO.	228	184.4	28.61
7	20000 KW—CONSOLIDATED GAS, ELEC. LIGHT & POWER CO.	199	115	28.46
8	10000 KW—CITY ELECTRIC CO.	175	100	28
9	7500 KW—NEW YORK EDISON CO.	177.6	93.7	27.38
10	7500 KW—METROPOLITAN STREET RWY. CO.	175	110	28
11	5500 KW—INTERBOROUGH RAPID TRANSIT CO.	190.4	96.8	27.35
12	1500 KW—HARTFORD ELEC. LIGHT CO.	185	41.4	26.5
13	1250 KW—INTERBOROUGH RAPID TRANSIT CO.	145	0	27.02
14	500 KW—LUDWIG & CO-BRAKE TEST	153	99.5	27.39
15	400 KW—DEAN & MAIN-SHOP BRAKE TEST	180	104	27.95

Fig. 22.

elements to those with a greater number of stages of single velocity elements, with appropriately high velocity ratios, and so achieved great gains in performance, manufacturers of turbines employing reaction elements, beyond increasing the velocity ratios and the relative number of turbine elements to provide for changed operating conditions, have not particularly changed their thoughts of design. The advance in reduction of steam consumption in all types of



PROGRESS OF OPERATING CONDITIONS

Fig. 23.

turbines has been due more to development of generator design, permitting higher rotative speed, in turn resulting in reduction of leakage and permitting higher design constants such as velocity ratio without as much compromise for mechanical reasons. Improved condensing apparatus has made higher vacuum available, bringing about increased cost of the low pressure portion. Higher pressures and superheats have contributed greatly to better performance, but have added to intrinsic costs not only on account of the greater number of turbine elements to accommodate the increased heat drop, but also because of more costly materials due to the higher temperatures. Every step in performance has resulted in higher intrinsic value, except where an increase of R.P.M. has been possible.

Of course, turbine prices have not increased with intrinsic value because of improved manufacturing methods. Fig. 22 shows the progress in Westinghouse turbine efficiencies. The instances in which the gain in efficiency has been accomplished by greater rotative speeds is indicated. Curve, Fig. 23, shows in a general way

the increases of pressure, superheat and vacuum for the principal machines sold during each year, and calculated from these curves, the B.Th.U. heat drops. The curves of Fig. 24 show :—

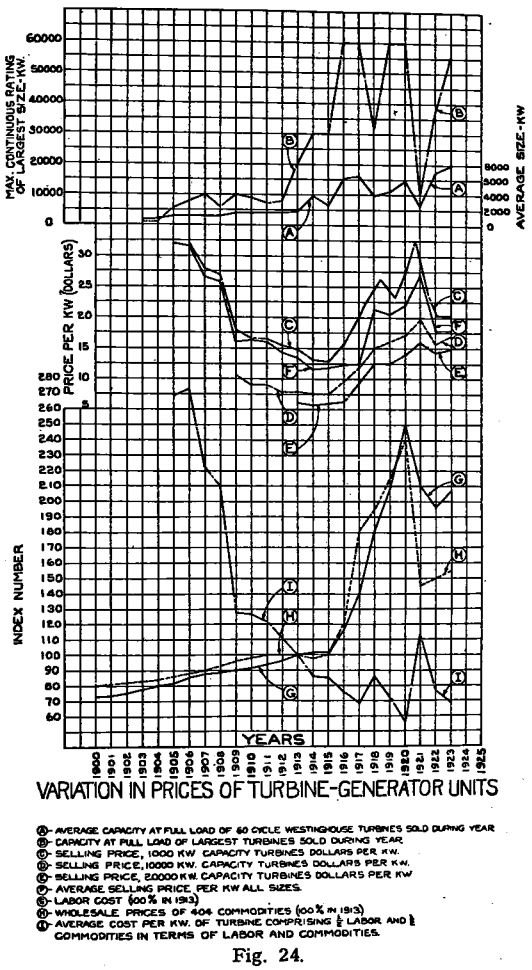


Fig. 24.

First: The average price per kilowatt, expressed in dollars, of maximum continuous capacity of turbines sold each year.

Second: The average cost of 404 wholesale commodities.

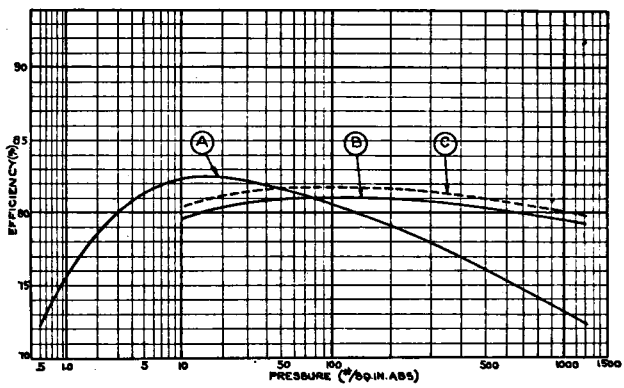
Third: Labour.

(The last two expressed as percentage).

Fourth: The variation of prices of turbines, expressed in a percentage on the basis that the turbine costs are made up of 50 per cent. wholesale commodity and 50 per cent. labour.

* * * * * *

Much thought is being given to the subject of higher steam pressures, and both the General Electric Company and the Westinghouse Company are building some, what might be called " exploratory " machines, for 1,200 lbs. pressure to exhaust against 300 lbs. back pressure. One being designed by the Westinghouse Co., of 3,200 kW. capacity, will be of impulse reaction type, to operate at



EXPECTED TURBINE EFFICIENCY RATIOS AT VARIOUS PRESSURES
(GENERATOR LOSSES NOT INCLUDED)

A- APPROXIMATE INDIVIDUAL STAGE EFFICIENCY CURVE FOR A TURBINE EXPANDING FROM 1200 # TO 29" VACUUM.- NO REHEATING.
B- AVERAGE EFFICIENCY FROM PRESSURES OF THE ABSCISSAE TO 29" VACUUM.- NO REHEATING
C- SAME AS 'B' EXCEPT REHEATING AT APPROXIMATELY ½ THE B.T.U. DROP TO 700° TOTAL TEMPERATURE.
ALL CURVES BASED ON 700° INITIAL TOTAL TEMPERATURE.

Fig. 25.

3,600 R.P.M. A feature of the design is that the cylinder, which is quite small, will be made of rectangular blocks of steel bored out for the rotor and blading. A particular feature of the design is the mounting of the small turbine cylinder in such manner that it, or the alignment, will not be disturbed by the expansion effects of the exhaust pipe, which is also a main steam line serving the lower pressure units in the power house.

It is not believed the designing of turbines for pressures up to 1,500 lbs. will present any insurmountable difficulties, although no practical experience has been had of the erosive action of steam

at such pressures. Low steam velocities will, however, be employed generally. It is believed that total temperatures of 750 degrees F. will not be exceeded.

Concerning turbine efficiencies with high pressure steam, the curves of Fig. 25 have been prepared. Curve *A* shows the approximate stage efficiencies to be expected of the turbine elements of a turbine of modern design with 1,200 lbs. per square inch initial steam pressure exhausting against 29 in. vacuum. Curve *B* shows the average efficiencies of turbines of modern design from the pressures in the abscissa to 29 in. vacuum. Curve *C* shows the effect of reheating to the initial temperature at one-third of the heat drop.

CONDENSERS.

Surface condensers containing 70,000 square feet of surface in a single shell have been constructed serving 50,000 kW. turbines. There are a few instances of jet condensers serving large turbines in locations where condensing water is so acid bearing that surface condensers were deemed impracticable. The largest single jet condenser is at the Warrior Station of the Alabama Power Co. and is of the low level Westinghouse Le Blanc type having a water capacity of 26,000 G.P.M., and serves a 30,000 kW. turbine. Two 45,000 kW. turbines at the Narragansett Electric Light Co., at Providence, R.I., are each served by a twin jet condenser of similar design having a water capacity of 36,000 G.P.M.

Two types of surface condensers are in general use as shown broadly in Fig. 26. These are known as the "down-flow" and "radial-flow" types, the latter having proprietary features. In older designs the relative weights and dimensions of radial-flow condensers exceeded those of down-flow condensers because of the dimensions of the belt around the condenser for the proper admission of steam to the surface.

The design of down-flow condensers has been improved to the extent of reducing steam pressure drop through the condenser. The practice of cutting steam lanes through the surface, as indicated in Fig. 26, has been largely discontinued and progressive tube spacing employed, so arranged as to obtain nearly equal steam velocities through the condenser. Steam lanes have a tendency to cause pressure differences, rendering portions of the surface remote from them relatively inactive. These improvements have resulted in an increase of weight of this type condenser of from 30 to 40 per cent., bringing the weights of the two types to an approximate parity.

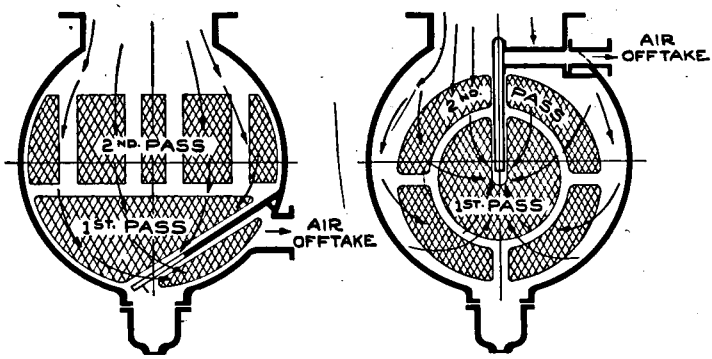


Fig. 26.

The radial flow type condenser is regarded as having advantages over the down-flow as follows :—

1. As the whole outer surface of the nest of tubes is available for the incoming steam, ample area is secured where the volume of steam is greatest, without material increase of tube pitch and approximately equal steam velocities obtained.

2. The distance travelled by the steam is easily made relatively shorter.

3. The condensate is nearer the temperature of the incoming steam and not depressed by the pressure drop through the condenser.

Improvements have been made to secure nearly equal distribution of steam to the entrance of the cooling surface as pointed out in discussion of Turbine Exhaust Chambers.

There has been a tendency on the part of all manufacturers to increase the amount of surface of the cooling area between the point at which the condensate is removed and the outlet to the air pump, this surface sometimes being termed the " air-cooling " surface.

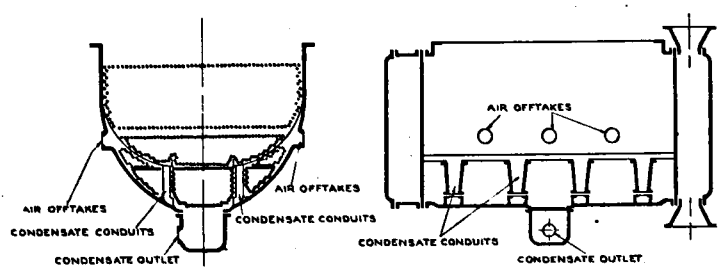


Fig. 27.

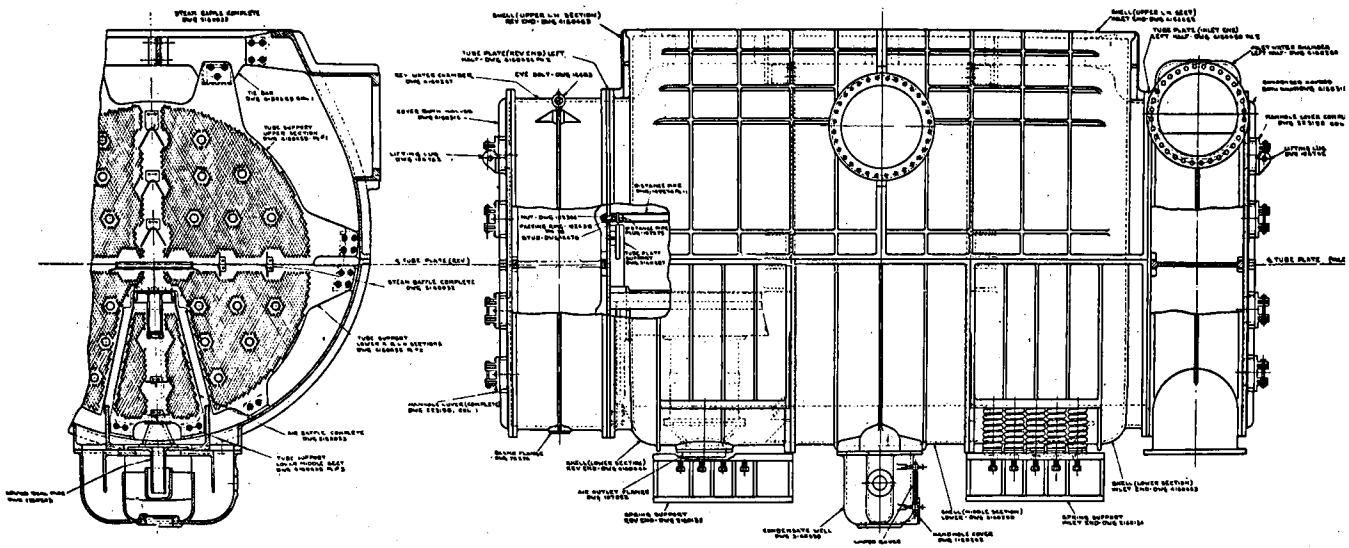
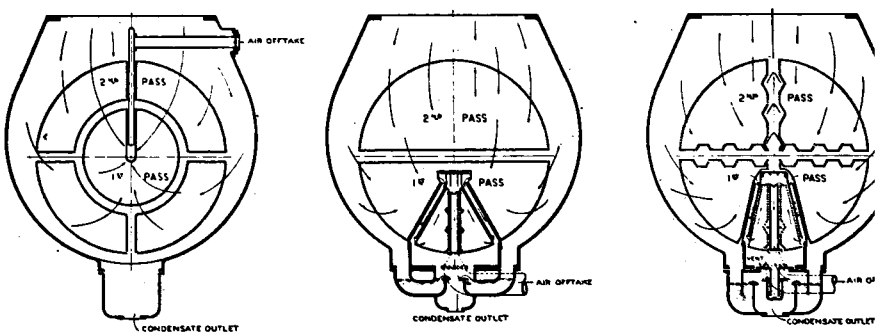


Fig. 28.

Westinghouse practice in this regard is to provide 8 to 10 per cent. of the total surface in this portion.

The arrangement applied to a Westinghouse down-flow condenser is shown in Fig. 27, where special provision is made to remove the constriction incidental to condensed steam cascading from the baffle. The condensate is caused to descend through enclosed conduits, permitting free flow of the vapours to the air-cooling surface.

Fig. 28 shows the arrangement of a modern radial flow condenser. The steam and vapour flows to the centre, thence, it descends to the bottom between plates, which extend the whole length of the condenser between the tube plates, the outer plates being jointed to the shell at the bottom. The vapours then ascend through the so-called " air-cooling " surface. The non-condensible vapours pass



Type A. Type B. Type C.

Fig. 29.

downwards through a narrow conduit in the middle of the air-cooling surface extending the whole length of the condenser, and are drawn to the air pump suction. The term " air-cooling surface " is a misnomer and is merely employed here to differentiate between the surface in the two locations. This surface is as effective condensing surface as any other in the condenser so long as air leakage is a minimum. It becomes air-cooling surface only when there is air leakage and is then effective in increasing the density of the non-condensible vapour and increasing the effectiveness of the air pump.

Condensate from the bottom of the shell outside of the partitions drains into the hot-well through hydraulic seals leaving the shell at the temperature of the steam entering the condenser. This water having passed the seal is exposed to the slightly lesser pressure

below the air-cooling surface. This produces some evaporation and no small degree of deæration.

The evolution of the design of hot-wells is not without interest. The types are shown in Fig. 29.

Type *A* was employed before the steam passages enclosed between plates of radial flow condensers were devised. Type *B* was evolved at the time the arrangement of baffles shown in Fig. 28 was adopted. In the case of type *B* the water in the hot-well is open to the air-cooling surface, and it was discovered that because of the slight reduction of pressure quite violent ebullition took place, so hot-wells of the same general design but with greater water surface were adopted, made large enough to provide a liberating velocity of about 30 ft. per second. This at once provided an effective means of deæration, which, however, slightly depressed the temperature of the condensate to that corresponding to the pressure between the baffles. Type *C* was then adopted, provided with a small vent to the air-cooling surface to prevent air binding. Of the two forms, *B* and *C*, *B* has the advantage of the maximum degree of deæration. *C* gives the maximum degree of condensate temperature. With type *C*, the degree of evaporation with relation to condensate temperature can be regulated to a limited extent by the adjustment of the size of the vent.

DEÆRATION.

The question of oxygen content in feed water has been receiving more attention. A number of deærators is being installed. Manufacturers advocating their sale state that in order to effect deæration, it is necessary to inject the heated water into a vessel in as finely divided spray as possible, the temperature corresponding to the pressure in this vessel being not less than 25 degrees F. below that of the injected water and that this, which might be called exploding of the particles, is necessary if complete deæration is to be secured.

In condensers with the older design hot-wells of type *A*, Fig. 29, at the Springdale plant of the West Penn Power Company and the Barbadoes Island plant of the Counties Gas & Electric Company, an oxygen content of between ·07 and ·1 cc. per litre is reported. In the Hell Gate installation of the United Electric Light & Power Company with hot-wells of type *B*, Fig. 29, tests are reported showing an oxygen content of ·045 cc. per litre, ·1 cc. per litre being considered a limit of good practice.

A recent test at the Windsor plant of the West Penn Power Company, where a hot-well of type *B* is employed, showed an oxygen content of ·28 cc. per litre in the water in the condenser before

entering the hot-well and ·041 cc. per litre in the condensate at the suction of the condensate pump.

A common cause of high oxygen content in condensate is frequently due to intermittent operation of the condensate pump which has excess pumping capacity, the pump alternately filling up and completely evacuating the condenser. During the latter interval, the condensate becomes ærated by air from the condenser. Tests in such installations have shown that by throttling the condensate discharge so that the pump has definite suction head, and the intermittent action stopped, the æration becomes less; hence, the desirability of always employing a hydraulic seal between the condenser shell and the pump suction.

VERTICAL CONDENSERS.

Vertical condensers are installed in a number of instances, particularly where there is great variation of level of condensing water. There are several installations on rivers subject to floods where the engine room floor is above high water, the vertical condensers being located at the bottom of a caisson in instances 70 ft. lower to be within reach of the condensing water, during low water stages. Vertical condensers are employed in these applications so that the tubes may be removed vertically—and no increase of diameter of caisson is provided for this purpose. The expansion of the long vertical exhaust pipe is taken by a slip type expansion joint. Most of these vertical condensers have been built by the Worthington Pump and Machinery Company.

SINGLE PASS CONDENSERS.

A number of single pass condensers for rather the smaller sizes has been installed, most of which have been built by the Ingersoll Rand Company, and it seems not improbable that this type will come into more general use in adaptable locations and where the pumping head is small, ranging from 10 to 15 ft. total head, and where condensing water is abundant, for approximately 40 per cent. more water is required than in the case of two pass condensers. Small diameter tubes are obviously to be preferred for single pass condensers, and those built have been equipped with $\frac{3}{4}$ or $\frac{7}{8}$ tubes which necessitate their location where the condensing water contains little debris.

The design of centrifugal circulating pumps for the low heads incidental to single pass condensers involves low rotative speeds and large dimensions if reasonable pump efficiency is to be secured.

With this in view, the Westinghouse Company has built an experimental propeller type pump of a special design, which, in actual test, with 14,000 G.P.M., 3 ft. suction, and 8 ft. total head, gave an efficiency of 80 per cent. ; the diameter of the propeller being 15 in., operating at 870 R.P.M.

DIVIDED WATER BOXES.

A number of two-pass condensers has been built with divided water boxes, by means of which the circulating water may be closed off from one-half of the condenser and those tubes cleaned while in operation. Actual experience with a 50,000 square feet condenser at the Windsor station of the West Penn Power Company, served with 50,000 G.P.M. of circulating water, with 25,000 kW. load, showed that the vacuum fell ·15 inches during the tube cleaning operation. Another instance is that of the Duquesne Light Company, where, with a 40,000 kW. installation, the turbine exhausting into two condenser shells, the drop in vacuum was ·2 inch. In this case, however, it was one-quarter of the surface which was out of service. The reason for the slight falling off in vacuum is because the heat transfer of the remaining tubes in operation is increased on account of nearly doubling the velocity through the tubes that remain in operation.

CONDENSER SHELLS.

Cast iron is generally employed for condenser shells. The use of steel plate is not regarded favourably for this purpose because of fears of corrosion. These are probably not misplaced, for there have been several instances of rapid corrosion of baffles, etc., even when the latter are made of ingot iron (a sheet steel made by the American Rolling Mill Company of Middletown, Ohio, with carbon limited to ·02 per cent.). One instance of a 40,000 square foot cast iron shell surface condenser with cast iron tube plates is that at the Gold Street Plant of the Brooklyn Edison Company. The ingot iron Baffles $\frac{3}{8}$ in. thick were found corroded with many holes after five years service, the remaining portions of the apparatus being in good condition. No doubt free oxygen in the condenser shell is the destructive agent.

HEAT TRANSFER RATE.

Condenser performances are judged by the average rate of heat transfer per square foot per degree Fahr. per hour mean temperature difference. Much may be learned from the study of individual tubes of a condenser while in actual service. For this purpose,

the Westinghouse Company devised the arrangement shown in Fig. 30, in which an individual tube is supplied with water from the water box by means of a small special pump. The other end of the tube discharges into a weighing tank. Temperatures are observed at each end of the tube and the speed of the pump is adjusted to give the desired water velocity. By this means, the effects of steam lanes have been studied and the discovery made of dead spots or air pockets in zones of badly designed condensers. The apparatus also lends itself to discovering the rate of heat transfer with varying degrees of fouling of tubes.

Some interesting tests of this character were made on a 26,000 square feet condenser at the Marion Plant of the Public Service

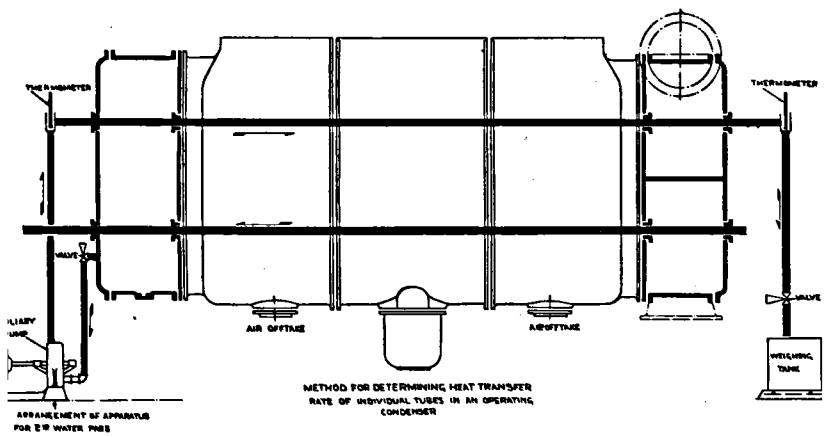


Fig. 30.

Electric Corporation of New Jersey, the condensing water for which is from the Hackensack River. The results of these experiments are shown on Curves, Fig. 31, one group being for the first pass, the other for the second pass. The first test—the lower line in the case of the first pass, is that of a fouled tube which had not been cleaned for the stated number of days. The next curve, No. 2, in each case gives the transfer rate of the same tube immediately following the tubes having been cleaned by means of a rubber plug. Curve No. 3 gives the transfer rate of the same tube, immediately following the tube having been scrubbed with a wire brush. Curve No. 4 shows the transfer rate following a new tube having been substituted for the old one. In this condenser investigation a more rapid falling off of transfer rate was always found in

the first water pass than in the second, which was no doubt due to it collecting more debris.

It will be noted from the curves that the heat transfer rate of a clean tube is closely proportional to the square root of the water velocity. Curve No. 1 with foul tubes shows the rate varying closely with the 3/10 power of the velocity.

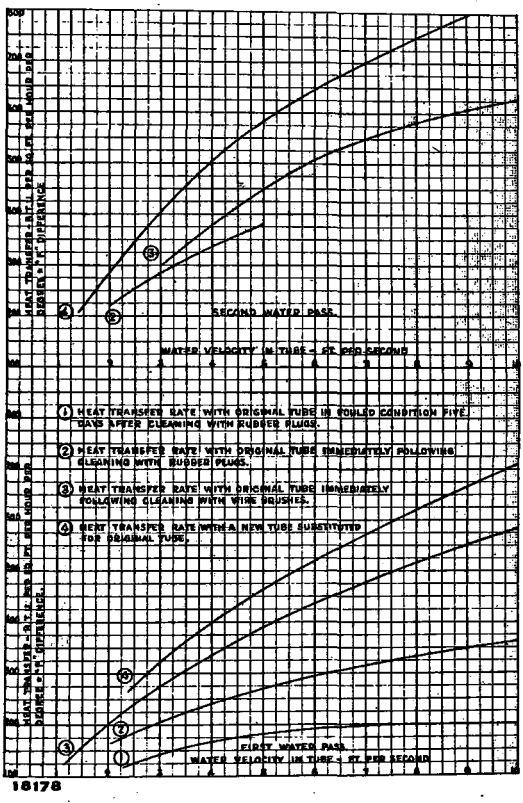


Fig. 31.

High rates of heat transfer are secured with clean tubes, and a few guarantees of condenser performance have been based on a heat transfer rate of 600 B.T.U. per square foot per degree per hour at 6 ft. per second circulating water velocity. To maintain such a performance, however, requires frequent cleaning, involving high cost

and interruption to service. It is customary nowadays to base condenser performance guarantees on a heat transfer rate of between 400 and 450 B.Th.U. per square foot per degree of mean temperature difference per hour at 6 ft. per second circulating water velocity and 70 deg. Fahr. temperature of ingoing circulating water. This permits the guaranteed performance to be maintained with a reasonable degree of foulness and, therefore, better serves the purchaser's interests.

SIPHON EFFECTS.

Depth of basement or elevation at which a condenser may be placed is determined by the elevation of the condensing water and the degree of siphon effect which can be satisfactorily employed. The maximum elevation between circulating water and the top of the discharge water nozzle of the condenser has frequently been limited to 20 ft. Experience, however, shows that this can be increased to 25 ft., providing the circulating water piping is free from air leaks and abrupt changes of direction of flow. The 40,000 square feet condensers at the Sherman Creek station of the United Electric Light & Power Company have frequently shown 27 in. vacuum by mercury column connected to the top of the circulating water outlet during periods of low tide, and no operating difficulties have ever occurred in consequence.

Table II. gives the principal characteristics and dimensions of a number of representative surface condenser installations. The table indicates where bleeding of the main turbine for feed water heating has been adopted. Generally, in such cases, the proportion of surface to steam flow is reduced. In two cases, *viz.*, West Penn Power Company and Colfax Power Company, larger amounts of surface are employed because the condensing water contains considerable debris.

Table III. shows a number of representative condenser tests.

CONDENSER TUBES.

One inch tubes, 18 b.w.g., are most commonly employed, both Muntz metal and Admiralty mixture being used, with a tendency towards the exclusive use of the latter. The principal features of Westinghouse specifications for Admiralty Mixture and Muntz Metal are as follows, which do not differ materially from specifications of other manufacturers and those of the American Society for Testing Materials :

COMPOSITION.

	Admiralty Tubes & Ferrule Stock.	Muntz Metal Tubes and Ferrule Stock.
Copper, Minimum	70·0 per cent.	59-63 per cent.
Zinc, Minimum	26·0 ,, ,,	37-41 ,, ,,
Tin	·90 to 1·20 per cent.	—
Lead Maximum·· ...	·075 per cent.	·25 per cent.
Iron Maximum	·06 ,, ,,	·08 ,, ,,
Other Impurities Maximum	·15 ,, ,,	·15 ,, ,,

The following tests are required on certain tubes selected in a prescribed manner.

That no fracture will show when hammered flat to three times the wall thickness.

That they may be expanded without fracture by means of a pin having a taper $1\frac{1}{2}$ in. to the foot until the internal diameter at the mouth is increased 20 per cent. for Admiralty Mixture and $16\frac{2}{3}$ per cent. for Muntz Metal.

Admiralty Mixture tubes are required to stand a season cracking test without fracture by immersion in an aqueous mercurous nitrate solution containing 100 grs. mercurous nitrate and 13 cc. nitric acid (specific gravity 1·42) per litre of solution for fifteen minutes.

Microscopic examination must show complete recrystallisation with uniform grain size and a requirement in the case of Admiralty Mixture that the average grain also shall not exceed ·035 mm.

CONDENSER TUBE PACKINGS.

Corset lacing is frequently employed and an ingenious device has been developed and used by some operating companies to apply this packing quickly by a simple compressed air machine.

In Westinghouse practice, a fibre packing has been used as much as any other, and when made to proper dimensions, leakage is not experienced. It is not believed that tubes readily slide in the fibre ferrules with expansion and contraction. Neither is it clear, on the other hand, that sliding is as necessary as sometimes supposed though there is more probability that corrosion of the tubes will be accelerated when they are subjected to stress.

A form of packing is available, comprising cylinders made up of wrapped lead base foil with graphite, and opinions as to its merit are strong, but equally divided.

Many modern installations have the tubes expanded at one end, being free to slide in the packing at the other. The Naval practice of employing bent tubes expanded and made rigid at both ends has not been employed in land service.

CLEANING OF CONDENSER TUBES.

1. Forcing of rubber plugs by water or air pressure cleans the tube satisfactorily, providing the debris is not of a nature that scales the tubes.

2. Wire brushes are satisfactory, but laborious.

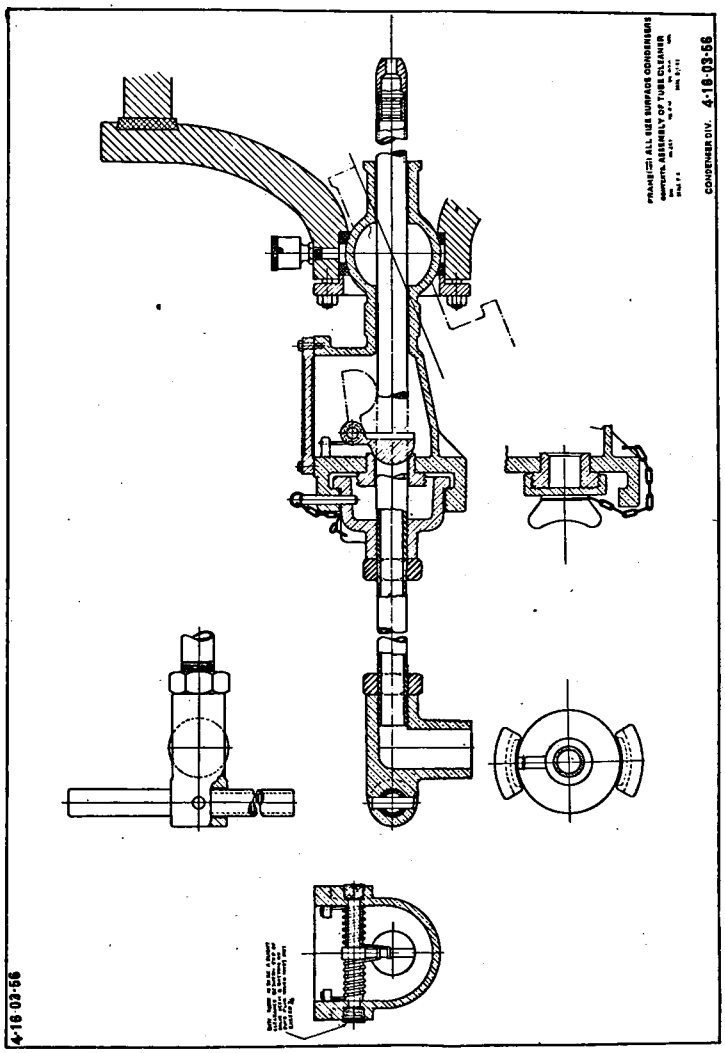


Fig. 32.

3. Baking a condenser with steam in the steam space. This causes the dirt to crack and loosen and is readily washed away.

4. A sand blasting process employing sand or ashes, shot through the tube with an ejector, employing water. This was common practice some years ago, but is seldom used to-day.

5. Condensers have been cleaned by soaking water spaces with mild acid solution.

6. A permanently installed method for washing leaves and such matter from the entrance to tubes has been introduced by the Worthington Company, and is shown on Fig. 32, 200 lbs. of water pressure are required. The method is found satisfactory for this limited purpose.

CONDENSER AUXILIARIES.

In old condenser practice, the auxiliaries were driven by non-condensing steam turbines, the opinion having been held that steam apparatus was more reliable and that so long as their exhaust steam was condensed in a feed water heater the efficiency was unimportant. To-day, nearly all condenser auxiliaries are arranged for motor drives and other arrangements made for heating feed water. Not the least reason for the change was the elimination of steam and exhaust piping with the attendant drains, etc., and the incidental heat, mess, and discomfort. Electrical energy for operating the auxiliaries is obtained from the following sources: (1) A house turbine operating in conjunction with a feed heater; (2) An auxiliary generator coupled to the main unit; (3) From the main bus, this source being augmented in cases with a small turbine unit floating on the auxiliary line automatically to pick up the load in the event of an electrical disturbance. The method of selection is made by means of a heat balance study and is beyond the scope of this paper.

CONDENSATE PUMPS.

Centrifugal pumps are employed almost exclusively.

The practice of providing 50 to 100 per cent. capacity in excess of normal requirements is generally observed. This is done to avoid flooding in case of broken tubes. It results in the pump operating at a low point of efficiency. A saving of roughly 3 per cent. for the total condenser auxiliary load could be secured if this excess capacity could be dispensed with.

CIRCULATING PUMPS.

Progress has been made in the design of pumps to secure higher efficiencies. In Westinghouse practice, the greatest gains have been secured by careful attention to the form of inlet passage, avoiding sudden changes of direction and maintaining equal water velocity from the inlet of the pump until it is within the impeller. An interesting case of this is in the comparison of an old and a new design as shown in Figs. 33 and 34, both designed for 60,000 G.P.M

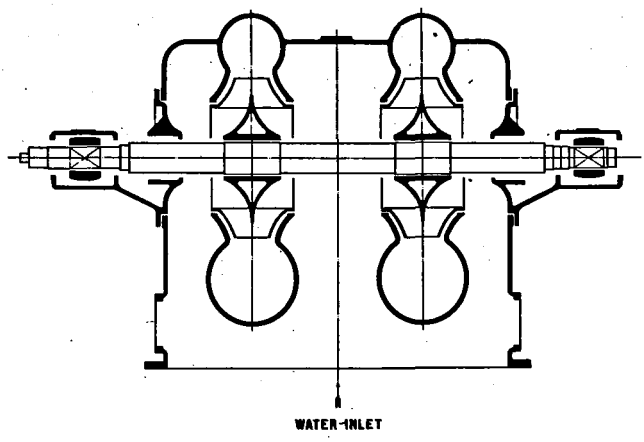


Fig. 33.

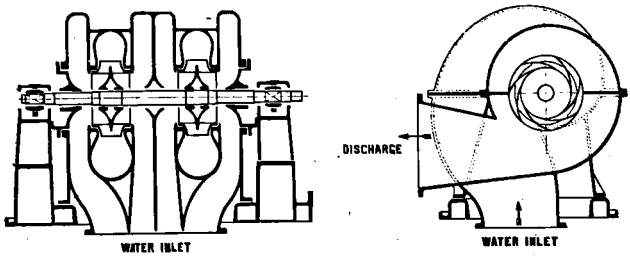


Fig. 34.

capacity, a suction head of 15 ft. maximum and a total head of 25 ft. The design of impellers is nearly the same the only difference being a change of inlet angle from 13 degrees to 10 degrees and the exit angle from 18 degrees to 19 degrees. The thickness and form remained unchanged. The principal difference is in the respect that a volute suction is employed with no obstruction or changes in velocity. Similar attention is given to the discharge passage providing a uniform reduction of velocity. Tests have shown the

efficiency of the one to be 70 to 71 per cent., the other 81 per cent. A marked difference is the almost silent operation of the higher efficiency pump.

Eighty-six per cent efficiency has been secured with double runner pumps of 30,000 G.P.M. capacity with similar characteristics of design but for relatively lower rotative speed, but actually the same R.P.M.

In many of the recent plants, two circulating pumps are being installed, each of half the required total capacity with that incidental

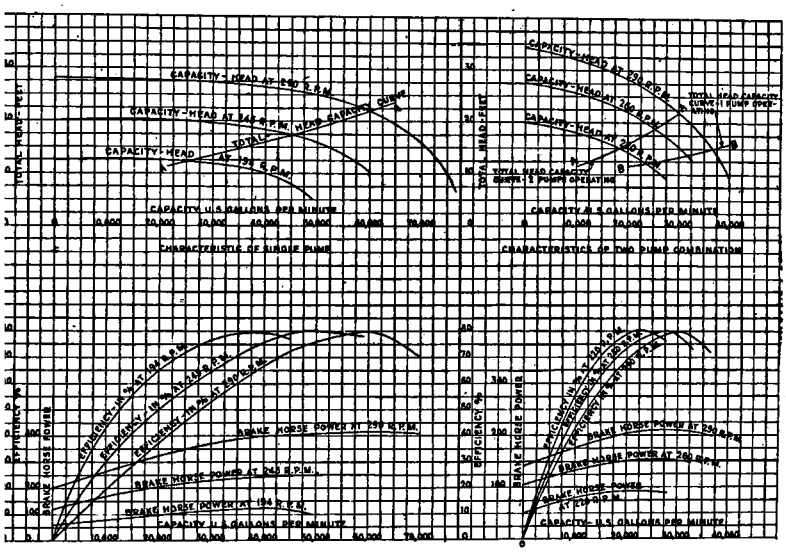


Fig. 35.

advantage of reliability. Two speed motors are sometimes employed, both arrangements permitting reduction in power input to be secured during times of low temperature water. The curves of Fig. 35 show the performance of various combinations of circulating pumps for supplying a 50,000 sq. ft. condenser for 28·7 in. vacuum, serving a 30,000 kW. turbine having a water rate of 10 lbs. per kWh., the maximum pumping requirements being 60,000 G.P.M., the normal condenser water temperature 70 degrees F. In the one set of curves the condenser is equipped with a single circulating pump and a two-speed motor. In the other, with two circulating pumps each driven by a two-speed motor.

From the curves may be determined the following power inputs to the circulating pumps with varying condensing water temperature with various operating combinations and the vacuum secured:

SINGLE CIRCULATING PUMP.

Inlet Water Temp.	Vacuum	G.P.M. Circulated	R.P.M.	B.H.P. Input	Saving in power input by varying pumping capacity
70	28·70	60,000	290	417	
50	29·16	46,000	245	250	167
40	29·00	24,000	194	103	314

TWO CIRCULATING PUMPS.

	Inlet Water Temp.	Vacuum	G.P.M. Circulated	R.P.M.	B.H.P. Input	Saving in power input by varying pumping capacity
Both operating	70	28·7	60,000	290	417	
Ditto.	50	29·10	36,000	220	182	235
One pump operating	50	29·10	36,000	290	200	217

In these calculations, due allowance of heat transfer rate has been made for the varying water velocities.

AIR PUMPS.

Air removal pumps of hurling water type and of steam ejector type are in general use. In new installations the steam ejector appears to be predominant. The reciprocating form of air pump is seldom used. Table IV. gives the performance of the two types as built by the Westinghouse Company. No real comparison, however, can be made of the performance between the two on the basis of tests of a measured quantity of free air displaced. In actual performance, the air pump must displace a mixture of steam and air with steam predominating. The air removal capacity of the air ejector is exercised in removing both the steam and air of the mixture, whereas, on the other hand, the steam in the mixture is promptly condensed in the hurling water form of pump, and its whole capacity then exercised in the removal of air. An ejector and hurling water pump might both have equal capacities so far as a test of measured air being admitted to an otherwise closed inlet. When these two

pumps come to be set to serve condensers with similar duty it may be found for this reason that the hurling water pump is adequate and the ejector wanting. This is brought out in Table IV. in the comparisons of mixture pumping capacity and dry air capacity.

The comparisons in the table do not include the heat contained in the discharge from the ejectors.

Some operating companies make a practice of carefully observing air leakage by actual measurement, some of them permanently installing a rotative dry vacuum pump piped up so as to connect to any condenser. The air discharge is measured by means of an air bell, the regular air pump being closed off and the unit operated at reduced vacuum during the brief time of the observation.

Certain companies with advanced methods consider that installations of about 30,000 kW. capacity should not have air leakage in excess of 4 to 6 cubic feet free air per minute (referred to 70 degrees). Regular observations are made and the source of leakage discovered and corrected whenever it reaches a prescribed limit. The 100,000 sq. ft. condenser in four shells serving the 70,000 kW. turbine at the plant of the Interborough Rapid Transit Co., in a test made shortly after installation, showed a leakage of 6·75 cubic feet per minute.

The author desires to express his thanks to the General Electric Co., of Schenectady, and the Allis-Chalmers Co., of Milwaukee, for drawings and data concerning the steam turbines of their manufacture, also to the Westinghouse Electric & Manufacturing Co. for having placed their records at his disposal. His thanks are due also to those members of the South Philadelphia Works of the Westinghouse Electric & Manufacturing Co. who have aided in the preparation of this paper, *viz.*, Messrs. R. C. Allen, Assistant to Chief Engineer, D. W. R. Morgan, Engineer of the Condenser Department, H. F. Schmidt, Consulting Engineer and others of the Engineering staff who assisted in preparing and checking the data.

ITEM	MANUFACTURER	FIRST UNIT INSTALLED AT		LIFE OF DESIGN						ROW OF LONGEST BLADES				AREA OF ANNULUS								QUALITY INDEX		TOTAL LOAD			REMARKS REFERENCES	NOTES
			FROM	TO																								NOTE NUMBERS REFER TO COLUMN NUMBERS.
	I	II	III		IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII	XXIII	XXIV	XXV	XXVI	XXVII	XXVIII	
	LAND INSTALLATIONS																													
1	GENERAL ELECTRIC CO	DETROIT-EDISON CO.	1915	—	35,000	40,000	750 R		1200		22	154	4-75	765	818	2.34	1.92	38.4	38.4		21,700	—	054	056	—	—	—	W. BRUNDAHL - J. ELECTR. ENG. JUNE 1924	NOTE XIV TOTAL AREA OF ALL ANNULI DISCHARGING TO CONDENSER
2	" " "	2ND TURB	1916	—	—	—	750 R		1200		22	117	6-18	765	745	—	—	40.6	40.6		20,700	—	—	—	—	—	—	" "	
3	" " "		1918	—	25,000	30,000	750 R		1500		22	120	6-88	765	793	2.93	2.49	38.9	38.9		24,000	—	052	041	—	—	—	" "	
4	" " "		1918	—	25,000	30,000	750 R		1500		24	126	6-17	784	823	2.32	1.74	42.3	42.3		24,100	—	044	033	—	—	—	" "	
5	" " "	(ANSONIA 2500 KW)	1923	—	45,000	50,000	750 R		1200		20½	134½	4-48	715	820	2.27	1.82	46.4	46.4		26,100	—	029	024	—	797,000	19.8	8710	GENERAL ELECTRIC CO
6	ALLIS - CHALMERS CO	WHEELOCK	1913	—	—	30,000	750 / 1-C		1800		19½	87½	5-15	804	604	—	2.66	46.2	30.8		13,200	—	—	108	—	—	—	ALLIS CHALMERS CO.	
7	" " "	—	1913	—	—	30,000	750 / 1-C		1800		15	70	4-23	697	69.7	—	1.90	69.7	23.2		11,600	—	—	097	—	—	—	" "	
8																														
9																														
10																														
11	C.A. PARSONS	BRUNSWICK-WOLFF POWER STA. ELEC. CO.	1915	—	20,000	22,500	SCHULZ 7-STAR		750		19	102	5-83	346	371	4.86	3.45	18.1	7.6		4,520	4000 48.1	873	643	—	617,000	34.3	7210	"PARSONS" NOV 4 1922
12	" "	BRUNSWICK-WOLFF ELECTRIC ASSOC.	1923	—	24,000	—	PAR. L.		720		4.0	160	4-89	695	730.5	2.78	—	22.3	22.3		13,360	—	125	—	—	—	—	W. BRUNDAHL - J. ELECTR. ENG. JUNE 1924	
13	METROPOLITAN - VICKERS	SIDNEY CORPORATION	1921	—	12,000	15,000	ROVERS EXHAUST		1800		13	49	5-21	364	361	5.01	1.83	67.0	33.9		20,200	—	089	064	—	—	—	" "	
14	ALKALI & ELECTROLYSE ASSOCIATION	THOMSON - HOUSTON ELECTRICAL CO.	1912	—	45,000	50,000	—		1000		30	134	8-7	695	695	3.46	1.73	19.1	19.1		10,000	—	081	065	—	—	—	" "	
15																														
16																														
17	ESCHER - WYSS	SCHWEIZERHALLE - PARIS	1921	—	20,000	22,000	—		1200		22½	110	4-88	709	914	1.89	1.36	37.9	27.5		23,600	—	048	036	—	—	—	"PARSONS" AND L. FREE	
18	BRITISH THOMSON - HOUSTON	BUTTERSTEAM CORPORATION	1913	—	20,000	22,000	—		1500		22	113	5-56	778	814	1.90	1.90	30.5	30.5		23,800	—	049	048	—	—	—	"LONDON ENGINEERING" JUNE 15 1934	
19																														
20																														
21																														
22	W.E.B.M.CO.	—	1911	1923	2,000	2,000	—		3600		8	46	5-00	628	648	3-48	2-93	27.0	27.0		16,700	29.4	125	084	—	97,840	29.2	9230	W.E.B.M.CO
23	" "	2,500 K.W.	1924	—	3,000	3,600	—		3600		10	48	4-59	644	816	3.05	2.44	38.4	24.5		21,500	30.7	098	067	—	97,000	15.0	6130	" " "
24	" " "		1918	—	4,000	5,000	—		3600		8	46	5.00	628	15.98	3.49	2.79	27.0	27.0		16,700	29.2	125	082	—	97,500	29.0	8240	" " "
25	" " "	WESTWOOD PUBLIC SERVICE CO.	1918	—	5,000	10,000	—		1500		16	77	5.13	602	29.2	3.15	2.52	29.4	29.2		17,100	61.5	125	100	—	104,000	34.9	7700	" " "
26	" " "	15,000 K.W.	1924	—	15,000	15,000	—		1800		20	83	4-15	648	36.2	3.42	2.41	34.5	34.5		21,000	49.3	083	047	—	103,000	29.4	3500	" " "
27	" " "	WEST POINT REACTION	1916	—	12,000	20,000	750 / 1-A		1800		12	86	5.69	708	34.6	3.16	1.71	34.6	17.9		14,300	39.1	118	100	—	100,000	24.0	8670	" " "
28	" " "	BRIDGEPORT HYDRAULIC CO.	1917	1921	10,000	20,000	750 / 1-A		1500		15	82	5.67	697	29.6	2.78	2.22	30.6	19.3		11,500	49.3	144	118	—	103,000	31.2	11500	" " "
29	" " "	ELECTRIC LIGHT & POWER CO. OF BUFFALO, N.Y.	1910	1923	10,000	25,000	750 / 1-B		1200		15	77	5.13	605	30.4	2.82	2.08	30.4	20.3		11,100	49.3	180	088	—	100,000	24.5	7730	" " "
30	" " "	25,000 K.W.	1923	—	0,000	25,000	750 / 1-C		1500		23½	88½	3-96	679	36.2	2.61	2.28	38.5	44.3		28,500	80.0	073	051	—	106,000	31.0	8850	" " "
31	" " "	TRANSMISSION 33-mm PWR. PL. STATION	1918	—	25,000	30,000	750 / 1-F		1500		15	88	4.89	679	69.1	2.75	2.20	46.0	34.0		14,200	86.2	115	086	—	89,000	27.7	10020	" " "
32	" " "	HYDE PARK ELEC. & STEAM TRANSM. STA. 27	1914	—	25,000	30,000	750 / 1-G		750		18	154	6.88	466	87.4	3.75	3.04	46.2	8.5		2,860	95.0	441	385	—	1057,700	38.6	10644	" " "
33	" " "	50,000 K.W.	1923	—	25,000	30,000	750 / 1-G		1200		22½	96½	3.86	679	83.25	3.23	2.40	83.25	44.3		28,500	791	073	054	—	118,000	27.6	8480	" " "
34	" " "	SCHENECTADY - RAILWAY COMPANY STATION	1917	—	20,000	30,000	750 / 1-B		1500		21	101	4.61	628	82.5	3.06	2.67	41.1	20.6		12,300	67.0	170	126	—	834,000	29.5	7310	" " "
35	" " "	ELECTRIC POWER & LIGHT CORP.	1923	—	30,000	40,000	750 / 1-E		1500		21	101	4.61	628	82.5	2.67	2.00	41.1	30.8		18,400	67.0	125	098	—	830,000	34.4	9210	" " "
36	" " "	UNITED ELECTRIC OF NJ. MAIN STATION	1924	—	40,000	60,000	750 / 1-H		1800		23½	86½	3.96	679	109.3	3.21	2.67	109.3	44.3		28,500	79.0	073	055	—	1081,000	29.5	8280	" " "
37	" " "	ELECTRIC POWER & LIGHT CORP.	1924	—	25,000	30,000	750 / 1-D		1800		23½	86½	3.96	679	109.3	2.67	2.67	109.3	44.3		28,500	79.0	073	055	—	1029,000	34.5	9720	" " "
38	" " "	SOUTHERN LIGHT & POWER CO. SOUTH STATIONS	1918	1923	20,000	30,000	750 / 1-J		1500		15	98	5.44	613	109.3	3.06	2.55	66.4	17.1		10,500	86.5	190	128	—	1093,000	29.0	10770	" " "
39	" " "	INTERBOROUGH RAPID TRANSIT CO. 10TH ST. STATION	1917	1917	40,000	60,000	750 / 1-J		1500		15	88	5.67	687	111.8	2.79	1.85	77.8	19.3		11,500	61.0	144	096	—	1498,000	27.8	10400	" " "
40	" " "	BROOKLYN - EDISON CO. - NORTH WEST STATION	1917	—	25,000	30,000	750 / 1-E		1200		15	88	5.44	613	76.9	1.85	2.18	54.5	17.1		8,300	64.5	180	156	—	782,000	31.5	10360	" " "
41																														
42																														
43	MARINE INSTALLATIONS																													
44	WALLSEND SLIPWAY	R.S. MAURETANIA	1907	—	—	70,000 Ind. 68,000 Exp.	—		180		82	142	7.36	127	77.8	—	3.67	78	78		408	—	—	266	—	—	—	LONDON ENGINEERING - MAR 8 1907	
45	HARLAND & WOLFF	R.S. BRITANNIC	1913	—	—	45,000 Ind. 42,000 Exp.	—		170		88½	176½	8-00	131	103.1	—	5.51	81	81		844	—	—	520	—	1958000	—	10780	LONDON ENGINEERING - FEB 27 1914
46	" "	R.S. OLYMPIC	1910	—	—	45,000 Ind. 42,000 Exp.	—		165		88½	168½	8.46	122	86.4	—	5.14	78	78		674	—	—	578	—	913000	—	9740	LONDON ENGINEERING - OCT 15 1910
47	SLOMN & VOSS	U.S.S. LEVIATHAN	1914	—	—	70,000 Ind. 68,000 Exp.	FESSEL SYSTEM		170		86	177½	7.49	186	184.8	—	3.83	106	23		496	—	—	442	—	—	—	E.S.B. (UNDER GOVERNMENT CONTROL) NAVAL ARCHITECT JAN 31 1920	
48	W.E.B.M.CO.	FIRST SUBMARINE LEADER - DOUBLE HULL	1918	—	12,000 Ind. 10,000 Exp.	—	—		3,000		8	46	5.00	628	17.7	1.70	1.70	69.2	24.6		14670	87.7	085	068	—	—	—	W.E.B.M.CO.	
49																														
50																														

NOTE XVII:-
$A_2 = A_1 \left(\frac{N}{1800}\right)^2$

NOTE XXI
BLADING CONSTANT
$K = \Sigma\left[\left(\frac{D}{100}\right)^n\right] \times \left(\frac{N}{1000}\right)^2$
WHERE D = MEAN DIA. INCHES
N = RPM
n = TOTAL NUMBER OF REACTION ROWS INCLUDING BOTH MOVING AND STATIONARY BLADES.
ONE IMPULSE WHEEL WITH A SINGLE ROW OF MOVING BLADES IS TAKEN AS EQUIVALENT TO 4 TOTAL ROWS OF REACTION BLADES
ONE IMPULSE WHEEL WITH TWO ROWS OF MOVING BLADES IS TAKEN AS EQUIVALENT TO 16 TOTAL ROWS OF REACTION BLADES
THIS CONSTANT IS BASED ON THE NUMBER OF TURBINE ELEMENTS IN SERIES. IN THE CASE OF MULTIPLE EXHAUST BLADING, A MEAN CONSTANT IS DETERMINED BASED ON THE STEAM FLOW THRU EACH PATH.
THE B.T.U. HANDLING CAPACITY AT CONSTANT EFFICIENCY IS APPROXIMATELY PROPORTIONAL TO THIS CONSTANT

LAST BLADE CHARACTERISTICS

Table 1.

ITEM NUMBER	CONDENSER MANUFACTURER	STATION * STAGE BLEEDING ** STAGE EMPLOYED	SIZE, TURBINE K.W. MAX CONT RATING	SIZE OF CONDENSER SQ. FT. SURFACE	NO. OF SHELLS	NO. OF PASSES	TYPE OF CONDENSER	U.S.G.P.M. CIRCULATED	SQ. FT. PER K.W.	U.S.G.P.M. PER K.W.	U.S.G.P.M. PER SQ. FT. SURFACE	DIA. OF TUBES	ACTIVE LENGTH OF TUBES	NO. OF CIRCULATING PUMPS	CAPACITY OF EACH CIRC. PUMP U.S.G.P.M.	VAC. RECEIVED 30" BAROM.	STEAM CONDENSED PER HOUR	BASIS OF GUARANTEES: TEMP. CIRC. WATER	BASIS OF GUARANTEES: HOURS PER WEEK	BASIS OF GUARANTEES: TOTAL CONDENSER SURFACE	TYPE OF DRIVE FOR CIRC. PUMP	CAPACITY OF AIR PUMPS CU. FT. AIR PER MIN	TYPE OF TUBE PACKING USED	WEIGHT OF CONDENSER INCLUDING WATER	TYPE OF AIR PUMP	REMARKS
I	II		III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII	XXIII	XXIV	XXV
1	ALLIS-CHALMERS	PUBLIC SERVICE CO NO. ILL WAUKEGAN, ILL.	30,000	52,000	1	2	DOWN FLOW	50,000	1.73	1.67	0.962	1"	20'	1	50,000	28.5	330,000	70	6.35	MOTOR	—	—	—	STEAM JET	—
2	ALLIS-CHALMERS	* COMMONWEALTH EDISON CO., CALUMET STATION	35,000	62,000	1	2	DOWN FLOW	65,000	1.77	1.86	1.05	1"	20	2	32,500	28.5	400,000	70	6.45	MOTOR	—	—	—	STEAM JET	—
3	INGERSOLL-RAND	NEW YORK EDISON CO., WATERSIDE STATION	35,000	30,000	1	1	DOWN FLOW	70,000	0.86	2.00	2.33	3/4" O	22'	2	35,000	28.79	370,000	60	12.32	TURBINE	24 CU FT @ 29"	CORSET LACE	275,000*	STEAM JETS	NORMAL OPERATION 1 EJECTOR - 17 CU. FT. - 29 in. WEIGHT CON. 103 EXCLUSIVE OF TUBES
4	INGERSOLL-RAND	** CONSUMERS POWER CO.	20,000	17,700	1	1	DOWN FLOW	35,000	0.885	1.75	1.98	3/4" O	20'	1	35,000	28.45	190,000	70	10.75	TURBINE MOTOR	—	—	180,000*.	STEAM JET AND R.D.V. PUMP IN SERIES	SURFACE EXCLUSIVE OF EXTERNAL AIR COOLER
5	WHEELER COND. & ENG. CO.	* OHIO POWER CO., PHILO STATION	35,000	45,000	1	2	DOWN FLOW	45,000	1.29	1.29	1.00	1"	18'	—	—	28.73	300,000	60	6.66	MOTOR	—	EXPANDED ONE END FIBRE PACKED THE OTHER	700,000*	STEAM JETS	WEIGHT COL. INCLUDES EXHAUST CONN. & AUXILIARIES
6	WHEELER COND & ENG. CO.	LOS ANGELES GAS & ELECTRIC CORP SEAL BRANCH	30,000	45,000	1	2	DOWN FLOW	50,000	1.50	1.67	1.11	1"	21'	—	—	29.00	264,200	60	6.88	—	56 CU FT @ 26"	EXPANDED ONE END, CRANE METALLIC THE OTHER	394,000*	STEAM JETS	NORMAL OPERATION - 1 EJECTOR 28 CU. FT. @ 29"
7	WHEELER COND & ENG. CO	** PUBLIC SERVICE PROD. CO KEARNEY	30,000	50,000	1	2	DOWN FLOW	—	(.67	—	—	1"	—	—	—	—	—	—	—	—	—	—	—	—	—
8	WHEELER COND & ENG. CO.	NEW YORK EDISON CO., WATERSIDE STATION	35,000	30,000	1	1	DOWN FLOW	60,000	0.86	1.72	2.00	3/4" O	23'-3½"	2	30,000	28.62	370,000	60	12.32	TURBINE	31 CU FT @ 28.5"	CORSET LACE	285,000*	STEAM JETS	NORMAL OPERATION - 1 EJECTOR 15.2 CU. FT. - 29.2"
9	WHEELER COND & ENG. CO.	CONSOLIDATED GAS CO., BALTIMORE, MD	20,000	30,000	1	2	DOWN FLOW	40,000	1.50	2.00	1.34	1"	19'	2	20,000	28.65	199,000	60	6.64	MOTOR	—	—	—	—	—
10	WHEELER COND & ENG. CO.	NEW YORK EDISON CO., WATERSIDE STATION	35,000	50,000	1	2	DOWN FLOW	70,000	1.43	2.00	1.40	1"	—	—	—	28.79	300,000	65	6.00	MOTOR TURBINE	—	—	—	A. E. G. PUMP	—
11	WHEELER COND & ENG. CO.	MEMPHIS POWER & LIGHT CO., TENN.	20,000	35,000	1	2	DOWN FLOW	35,000	1.75	1.75	1.00	1"	21'	1	35,000	28.90	230,000	60	6.57	—	70 CU FT @ 28.5"	CORSET LACE	313,000*	STEAM JETS	NORMAL OPERATION - 1 EJECTOR 35 CU. FT. @ 28"
12	C. H. WHEELER CO.	* UNION ELEC. LT. & PR. CO., CAHOKIA STATION	35,000	54,000	1	2	DOWN FLOW	61,000	1.545	1.745	1.13	1"	19'	2	30,500	28.88	350,000	60	6.47	MOTOR	—	CORSET LACE	—	2 R.D.V. PUMPS 33"×24	NORMAL OPERATION 1 - AIR PUMP
13	WORTHINGTON CO.	COLUMBIA GAS & ELECTRIC CO., CINCINNATI - FORT HILL STATION	40,000	50,000	1	2	DOWN FLOW	80,000	1.25	1.50	1.20	1"	18'	2	30,000	28.97	320,000	60	6.41	MOTOR	—	—	—	—	VERTICAL CONDENSER
14	WORTHINGTON CO.	* UNION ELEC. LT. & PR CO., CAHOKIA STATION	30,000	53,000	1	2	DOWN FLOW	54,000	1.77	1.80	1.02	1"	20'	2	27,000	28.91	330,000	60	6.23	MOTOR	—	CORSET LACE	—	2 R.D.V. PUMPS 33"×24	NORMAL OPERATION 1 AIR PUMP
15	WORTHINGTON CO.	* OHIO RIVER EDISON CO., TORONTO, OHIO	30,000	50,000	1	2	DOWN FLOW	60,000	1.67	2.00	1.20	1"	20'	2	30,000	28.59	300,000	70	6.00	MOTOR	70 CU FT @ 29.5"	EXPANDED ONE END, METALLIC PACKING THE OTHER	544,500	STEAM JETS	NORMAL OPERATION - 1 PUMP 30 CU. FT. - 29IN
16	WESTINGHOUSE-ELEC. & MFG. CO.	* COMMONWEALTH EDISON CO. FISK ST. STATION	35,000	58,000	1	2	RADIAL FLOW	60,000	1.60	1.72	1.075	1"	20'	1	60,000	28.45	385,000	70	6.88	MOTOR	30 CU FT @ 28.5	CORSET LACE	388,000*	LEBLANC HYDRAULIC	—
17	WESTINGHOUSE ELEC. & MFG. CO.	UNITED ELEC. LT. & PR. CO., HELL GATE STATION	35,000	50,000	1	2	RADIAL FLOW	70,000	1.43	2.00	1.40	1"	19'	2	35,000	28.78 28.65	350,000 400,000	85 65	7.00 6.00	MOTOR	12 CU FT @ 29"	CORSET LACE	388,000*	LEBLANC HYDRAULIC	—
18	WESTINGHOUSE ELEC. & MFG. CO.	* DUQUESNE LIGHT CO., COLFAX STATION	60,000	100,000	4	2	DOWN FLOW	132,000	1.67	2.20	1.32	1"	19'	3	44,000	28.03	600,000	60	6.00	MOTOR	30 CU FT @ 28.50	EXPANDED ONE END, FIBRE PACKED THE OTHER	EACH COND 141,700*	STEAM JET LE BLANC HYDRAULIC	2 CONDENSERS SERVE EACH LOW PRESSURE TURBINE
19	WESTINGHOUSE ELEC. & MFG. CO.	* DUQUESNE LIGHT CO., COLFAX STATION	30,000	55,000	1	2	RADIAL FLOW	70,000	1.833	2.34	1.27	1"	20'	2	35,000	28.70 28.48	283,000 400,000	70 70	5.16 7.38	MOTOR	50.5 CU FT @ 28.50	EXPANDED ONE END, FIBRE PACKED THE OTHER	502,000*	STEAM JET	NORMAL OPERATION - 1 BANK OF EJECTORS 26.8 CU. FT. @ 28.5
20	WESTINGHOUSE ELEC. & MFG CO.	** COMMONWEALTH EDISON CO, CRAWFORD AVE.	50,000	85,000	2	2	DOWN FLOW	70,000	1.30	1.4	1.08	1"	19'	2	35,000	28.6	374,000	70	5.75	MOTOR	18.3 CU FT @ 28.5	EXPANDED ONE END, METALLIC PACKING THE OTHER	TWO COND. 387,800*	STEAM JET LEBLANC HYDRAULIC	TUBE PLATES DRILLED FOR 70,000 SQ. FT
21	WESTINGHOUSE ELEC. & MFG. CO.	* PHILADELPHIA ELEC. CO.	30,000	50,000	1	2	RADIAL FLOW	75,000	1.67	2.50	1.50	1"	21'	2	37,500	28.98	300,000	60	6.00	MOTOR TURBINE	30 CU FT @ 28.5	PACKED BOTH ENDS, METALLIC PACKING	430,100*	LEBLANC HYDRAULIC	1 CIRC. PUMP USED NORMALLY - 46,000 G.P.M.
22	WESTINGHOUSE ELEC. & MFG. CO.	* WEST PENN POWER CO., SPRINGDALE STATION	20,000	32,000	1	2	RADIAL FLOW	32,000	1.60	1.60	1.00	1"	19'	2	16,000	28.35	235,000	70	7.34	MOTOR	18.3 CU FT @ 28.5	FIBRE PACKING	220,000*	STEAM JET LEBLANC HYDRAULIC	—
23	WESTINGHOUSE ELEC. & MFG CO.	** WEST PENN POWER CO., SPRINGDALE STATION	30,000	55,000	1	2	RADIAL FLOW	70,000	1.835	2.34	1.275	1"	20'	2	35,000	28.77	358,000	65	6.91	MOTOR	48 CU FT @ 28.5	EXPANDED ONE END, FIBRE PACKED THE OTHER	486,000*	STEAM JET	NORMAL OPERATION - 1 EJECTOR 34 CU. FT. @ 28.5
24	WESTINGHOUSE ELEC. & MFG. CO.	** SOUTHERN CALIFORNIA EDISON CO.	30,000	55,000	1	2	RADIAL FLOW	70,000	1.835	2.34	1.275	1"	20'	2	35,000	29.0	350,000	67	6.38	MOTOR	48 CU FT @ 28.5	—	505,000*	STEAM JET	NORMAL OPERATION - 1 EJECTOR 34 CU. FT. @ 28.5
25	WESTINGHOUSE ELEC. & MFG. CO.	** BROOKLYN EDISON CO., HUDSON AVE. STATION	50,000	70,000	1	2	RADIAL FLOW	100,000	1.4	2.00	1.43	1"	20	2	50,000	28.89	500,000	60	7.14	MOTOR	31.2 CU FT @ 28.5	CORSET LACE	537,000*	STEAM JET LEBLANC HYDRAULIC	NORMAL OPERATION - 1 EJECTOR 23.5 CU. FT. @ 28.5
26	WESTINGHOUSE ELEC. & MFG. CO.	** CONNECTICUT LIGHT & POWER CO., DEVON	20,000	40,000	1	2	RADIAL FLOW	43,000	2.00	2.15	1.075	1"	20'	2	21,500	28.83	280,000	60	8.56	MOTOR	20 CU FT @ 28.5	CORSET LACE	318,500*	LEBLANC HYDRAULIC	NORMAL OPERATION - TAIR PUMP 10 CU. FT. @ 28.5
27	WESTINGHOUSE ELEC. & MFG. CO.	** UNITED ELEC. LT. & PR. CO., HELL GATE STATION	30,000	63,000	1	2	RADIAL FLOW	90,000	1.76	1.80	1.43	1"	19'	2	45,000	28.79	530,000	60	8.42	MOTOR	34 CU FT @ 29.0	FIBRE PACKING	535,500*	STEAM JET LEBLANC HYDRAULIC	NORMAL OPERATION - 1 EJECTOR 17 CU. FT. @ 29"
28	WESTINGHOUSE ELEC. & MFG. CO.	** PUBLIC SERVICE PROD. CO., KEARNEY STATION	30,000	50,000	1	2	RADIAL FLOW	76,000	1.67	2.54	1.52	1"	19'	2	38,000	28.98	300,000	60	6.00	TURBINE MOTOR	10 CU FT @ 29.0	CORSET LACE	369,000*	STEAM JET LEBLANC HYDRAULIC	—

U.S.G.P.M. = UNITED STATES GALLONS PER MINUTE.
°F. = DEGREES FAHRENHEIT
SQ. FT. = SQUARE FEET
CU. FT. = CUBIC FEET.

DESIGN DATA OF REPRESENTATIVE CONDENSER INSTALLATIONS

Table 2.

ITEM NUMBER	PURCHASER	NAME OF STATION	SPEC. CONDENSER SQ.FT. OF SURFACE	DATE OF TEST	DURATION OF TEST IN HOURS	LOAD IN K.W.	QUANTITY STEAM CONDENSED LBS. PER HOUR	METHOD USED FOR DETERMINING STEAM QUANTITY	BAROMETER	VACUUM PRESSURE AT CONDENSER INLET	WATER TEMP. AT CONDENSER INLET °F.	AIR TEMP. OF COND. ROOM AT BEGINNING OF TEST °F.	AIR TEMP. OF COND. ROOM AT END OF TEST °F.	TEMP. RISE OF COOLING WATER °F.	TEMPERATURE OF CONDENSATE °F.	CONDENSATE DEPRESSION °F.	CIRC. WATER INLET °F.	CIRC. WATER TEMP. END OF 1ST PASS °F.	CIRC. WATER DISCHARGE °F.	TEMP. RISE IN TOP PASS °F.	TEMP. RISE IN 1ST PASS °F.	TEMP. RISE IN BOTTOM PASS °F.	QUANTITY CIRC. WATER G.P.M.	WATER VEL. THRU TUBES FT. PER SEC.	DESIGN REFERENCE
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII	XXIII	XXIV
1	DUQUESNE LIGHT	BRUNOTS ISLAND	52,800	11-OCT-23	2	39,700	418,783	V-NOTCH METER	30	28·90	29·16	81	82	79·1	1·9	62·7	69·5	73·9	6·8	4·4	560	77,400	8·55	2 CONDENSERS EACH 26400 SQ FT
2	WEST PENN POWER	WINDSOR	50,000	31-JUL-23	1	28,000	283,570	VENTURI METER	30	28·40	28·56	93	95	86	5	77	81	86	4	5	463	59,200	6·15	FIG. 32 TYPE B
3	UNITED ELEC. LIGHT	HELL GATE	50,000	13-SEPT-23	1	30,604	326,145	WEIGHED	30	28·54	28·76	—	91	85·8	5·2	72·4	78	81·1	5·6	3·1	429	69,300	6·93	FIG. 32 TYPE B
4	UNITED ELEC LIGHT	201ST STREET	37,300	10-AUG-20	2	22,430	288,547	WEIGHED	30	28·47	28·60	92·5	92·5	91·9	0·6	72·3	75·5	82·5	3·2	7	475	52,200	6·26	FIG. 32 TYPE A
5	CLEVELAND ELEC. ILLUMINATING CO.	———	45,000	3-OCT-19 16-MAY-21	—	25,000 20,000	284,000 245,000	WATER RATE CALCULATED FROM GUAR.	30 30	28·74 28·81	—— 28·91	89·6 83·5	86·2 84·4	88·7 84	0·9 0·4	69·8 62	75·2	80·8 73·5	5·4 —	5·4 —	418 479	50,000 39,400	5·85 6·5	FIG. 32 TYPE A
6	CLEVELAND ELEC. ILLUMINATING CO.	———	45,000	28-DEC-22 6-JUL-21	—	25,000 20,500	287,500 234,000	WATER RATE CALCULATED FROM GUAR.	30 30	29·19 28·50	29·47 28·55	73 94	72·8 92	73·5 94	+0·5 0	62 82	68 86	53 90	6 4	5 4	235 595	48,500 52,400	5·65 6·42	FIG. 32 TYPE A
7	BOSTON ELEVATED	———	25,000	11-JUL-19 11-JUL-19	—	16,000 15,000	206,000 195,000	WATER RATE CALCULATED FROM GUAR.	30 30	28·68 28·78	28·88 28·98	81 85	81·7 85·3	81 85	0 0	66 66	74 74	78 78	8 8	4 4	517 565	32,200 30,500	6·4 6	FIG. 32 TYPE A
8	BROOKLYN EDISON	GOLD STREET	32,000	21-AUG-22	—	25,000	343,000	WATER RATE CALCULATED FROM GUAR.	30	27·54	——	103·5	108·1	109·5	0	77·5	85·5	95·0	8	9·5	450	37,000	6·05	FIG. 32 TYPE A
9	PHOENIX UTILITY	PARSONS, KANS.	27,000	4-FEB-24	—	7,500	85,000	WATER RATE CALCULATED FROM GUAR.	30	29·6	29·63	52	52	52	0	38	42·5	48	4·5	5·5	312	16,000	2·95	FIG. 32 TYPE C
10	COUNTIES GAS & ELEC.	BARBADOES	40,000	4-MAR-24	—	14,557	165,000	WATER RATE CALCULATED FROM GUAR.	30	29·27	29·38	69·82	69·5	69·76	0.06	40·78	47·84	53·80	7·06	5·96	175	24,100	2·88	FIG. 32 TYPE A
11	DAYTON POWER & LIGHT	MILLERS FORD	30,000	7-JAN-22	—	20,600	235,500	WEIGHED	30	29·09	29·19	76	77·5	76	0	35	40·2	48	5·2	8·8	201	30,700	5·07	FIG. 32 TYPE A

BAROMETER = INCHES Hg.
G.P.M. = U.S. GALLONS PER MINUTE
B.T.U. = BRITISH THERMAL UNIT
°F = DEGREES FAHRENHEIT

CONDENSER PERFORMANCES

Table 3.

	LEBLANC HYDRAULIC AIR PUMP														STEAM JET AIR PUMP									
ITEM NUMBER	AIR REMOVAL CAPACITY BY ORIFICE TEST. LBS. PER HOUR FREE AIR AT 23" INCHES MERCURY AND TEMPERATURE OF WATER 60°	AIR REMOVAL CAPACITY BY ORIFICE TEST. LBS. PER HOUR FREE AIR AT 26.5" INCHES MERCURY AND TEMPERATURE OF WATER 80°	AIR REMOVAL CAPACITY BY ORIFICE TEST. LBS. PER HOUR FREE AIR AT 28.5" INCHES MERCURY AND TEMPERATURE OF WATER 80°	B.H.P. INPUT	TOTAL STEAM RECORDED BY MOTOR ORIFICE ON BASIS OF 150 LBS. PUMP PRESSURE	POUNDS STEAM PER HR. PUMPED FREE AIR AT 23" H.g. COLUMN	POUNDS STEAM PER HR. PUMPED FREE AIR AT 26.5" H.g. COLUMN	POUNDS STEAM PER HR. PUMPED FREE AIR AT 28.5" H.g. COLUMN	POUNDS MIXTURE PER HR. PUMPED AT 23" H.g. TEMP OF MIXTURE 65°F	POUNDS MIXTURE PER HR. PUMPED AT 26.5" H.g. TEMP OF MIXTURE 65°F	POUNDS MIXTURE PER HR. PUMPED AT 28.5" H.g. TEMP OF MIXTURE 65°F	LBS. STEAM RECORDED AT 23" H.g. COLUMN TO PRODUCE 1 LB. MIXTURE AT 65°F	LBS. STEAM RECORDED AT 26.5" H.g. COLUMN TO PRODUCE 1 LB. MIXTURE AT 65°F	LBS. STEAM RECORDED AT 28.5" H.g. COLUMN TO PRODUCE 1 LB. MIXTURE AT 65°F	23" VAC.	26.5" VAC.	28" VAC.	TOTAL STEAM TO EJECTOR 150 LBS. GAUGE	EJECTOR CAPACITY OF MIXTURE 65°F	EJECTOR CAPACITY AT 23" H.g. COLUMN OF MIXTURE 65°F	EJECTOR CAPACITY AT 26.5" H.g. COLUMN OF MIXTURE 65°F	EJECTOR CAPACITY AT 28.5" H.g. COLUMN OF MIXTURE 65°F	POUNDS STEAM PER LB. OF MIXTURE AT 23" H.g. COLUMN	POUNDS STEAM PER LB. OF MIXTURE AT 26.5" H.g. COLUMN	POUNDS STEAM PER LB. OF MIXTURE AT 28.5" H.g. COLUMN
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII	XXIII	XXIV
1	99	135	158	95	950	9·6	7·04	6·01	226	262	286	4·2	3·62	3·32	225	265	285	2085	225	265	285	9·25	7·86	7·31
2	74·1	108	130	80	800	10·8	7·4	6·15	169	210	235	4·74	3·81	3·40	170	216	240	1562	170	216	240	9·2	7·23	6·51
3	49	67·5	78·1	56	560	11·4	8·3	7·11	112	131	142	5·0	4·27	3·94	114	135	150	1050	114	136	150	9·21	7·78	7·00
4	36	47·6	57·1	44	440	12·2	9·24	7·7	82·2	92·5	103	5·35	4·76	4·27	85	108	120	781	85	108	120	9·2	7·23	6·51
5	22·2	31·1	36	32	320	14·4	10·3	8·8	50·7	60·4	65	6·3	5·3	4·92	45	60	72	480	45	60	72	10·7	8·0	6·45

H_g = MERCURY
F = DEGREES FAHRENHEIT
B.H.P. = BRAKE HORSE POWER

COMPARISON OF WESTINGHOUSE HURLING WATER AIR PUMP & STEAM EJECTORS

Table 4.

RÉSUMÉ.

En ce qui concerne la question des tuyères, celles-ci ont été modifiées d'une part pour avoir un rendement admissible dans les turbines à faible vitesse de rotation, d'autre part pour obtenir une section de passage suffisante pour les dernières roues. Ce changement a été principalement obtenu par la modification de la disposition de l'amenée de vapeur du générateur. On donne la description de différentes méthodes pour alimenter les dernières roues, soit en employant des tuyères multiples à basse pression, soit en montant les turbines en compound. On trouvera également un exposé des diverses raisons qui ont amené à l'emploi de turbines montées en compound. On donne un tableau des dimensions des dernières aubes dans les principales machines construites, par les plus importants fabricants. Tous les exemples sont ramenés à une turbine géométriquement équivalente de 1800 tours par minute, ainsi que les autres facteurs qui découlent de ce sujet.

La position des aubes dans l'arrivée de vapeur dans des cas différents de celui des turbines à très basse pression est discutée ; les mérites et inconvénients relatifs des deux types principaux à impulsion ou à répulsion sont exposés. On fait remarquer les principaux facteurs qui contribuent au haut rendement des machines à impulsion.

Les derniers types des turbines de la G.E.Co. et de la Westinghouse sont décrits et on donne une description très détaillée des turbines destinées à la " Crawford Avenue Plant " de la " Commonwealth Edison Company " qui doivent fonctionner sous une pression de 550 lbs., une surchauffe de 725 degrés, avec un dispositif de réchauffage.

On donne le dispositif de fixation des aubes employées par les différents fabricants et on discute la question de la forme donnée aux aubes.

Les caractéristiques physiques des matériaux employés pour diverses aubes sont décrites.

On fait ressortir que toutes les améliorations dans les turbines, à l'exception de l'augmentation de la vitesse, ont amené d'une façon générale une augmentation intrinsèque du prix de revient. Néanmoins on peut dire que les prix des turbines ont diminué si on considère l'augmentation du prix de la main d'œuvre et des matières premières.

On donne une description des grandes installations de condenseurs, ainsi qu'un tableau de leurs principales dimensions et caractéristiques. Un autre tableau indique les conditions d'exploitation d'un certain nombre d'entre elles. Suit une description générale des divers types de condenseurs à surface et de l'emploi des condenseurs auxiliaires.

STEAM UTILISATION

DISCUSSION

Chairman: MR. JOHN W. LIEB (U.S.A.)

Friday, July 4th. *Morning Session*

THE CHAIRMAN, in opening the session, said that the steam turbine had certainly produced an enormous revolution in the art of power generation. With the early work of de Laval in Sweden they were all familiar, but that early work had laid the foundation for subsequent very large developments. Confined at first to smaller units by the limitations imposed by the design, it had been taken up later by Sir Charles Parsons and then had been really initiated the enormous development that had been followed up by Zoelly and other workers, some of whom proceeded upon thermo-dynamic lines and others with a larger idea, towards the practical application.

In the old engines which were fast disappearing, they had had some rather useful and valuable features. One had been their considerable flexibility and the lesser necessity of an accurate gauging as to load. A turbine was more apt to plough through with the load that was put upon it. The ability to start up quickly in the case of old steam engines had certainly been a valuable feature.

Two or three years ago, when the expansion of the larger operating units had made it necessary to have a particular eye to the economy of investment in real estate, and the effort to get larger and larger capacities within the existing power station walls, the steam engine had become doomed, and in a number of cases the very finest types of triple and quadruple expansion engines which had been running a very minimum number of hours in the years past, hardly enough to get them down into a satisfactory working bearing—units of 3,000, 4,000 and 5,000 H.P.—had been removed and put on the scrap heap, and had not brought in even as much as the cost of their removal. That was a very striking example of the part which obsolescence had played in the industry of power generation.

One of the fundamental elements in all power plant operation and power production was reliability in service. That was a fundamental to which any design of turbine must conform if it were to have a large measure of success in commercial application, because, after all, those immense power generating aggregations were able to serve the public, and the public must first of all be well served, so that the faith and confidence which they reposed in the reliability and continuity of a service might not be misplaced. Power production had come to be such an integral part of our daily life and so contributory to health and happiness and convenience, that a reliability of service took the very first place. He thought it should be stated broadly that this question must be considered of paramount importance, not secondary even to efficiency.

It might be stated that, as a whole, there seemed to be manifest a tendency to seek more or less common ground, something perhaps akin to a compromise in the design of impulse and reaction turbines. These units played a very important part as units in larger and still larger power aggregates, and in the United States for instance most of the new stations were built on designs providing for a station aggregate of 300,000, 400,000 or 500,000 kilowatts. Their more or less standard units for these aggregates ran from 30,000 to 50,000 and 60,000 kW. units, and even so large a unit as 100,000 kW. was in the minds of designers at the present moment.

SIR CHARLES A. PARSONS (*Great Britain*), in presenting his paper on *Steam Turbines*, reminded the audience of a slight omission in the Chairman's speech, which might be attributed to his excessive modesty. Before 1884, there had been lying at the Patent Office 100 patents for turbines. He had not personally examined them till some five years later. He had often said that in those 100 patents would be found outlined nearly all the chief principles that were at present used in steam turbines. What the old inventors had lacked had been a due perspective view of the conditions which had to be encountered, and therefore they had met with failure. Though this had been the chief reason for their failure, a contributory reason had been the absence of demand for a very high speed engine until recent years. All the real advances since 1884 had embodied the principles enunciated before 1884, and one of the chief workers in this field had been Mr. Curtis of America. He had been the first to apply in practice the sinuous treatment of steam at high velocity, which had been foreshadowed many years before by Pilbrow just as the compound turbine had been foreshadowed by Dr. Wilson, a clergyman and Master of Arts of Glasgow University, a Scotsman of Greenock. To Mr. Curtis and to de Laval, who had introduced the expanding steam jet which mathematicians had said was impossible of realisation, they owed much.

MR. O. JUNGGREN (*U.S.A.*), said that Mr. Hodgkinson in his admirable paper on steam turbines and condensers had indicated the growth and present tendencies of the turbine industry in the United States, based primarily on the development of the turbine manufactured by the Westinghouse Co. In order to indicate more completely the situation in the turbine industry as a whole in the United States, he was taking the liberty of supplementing this paper with a brief statement of what The General Electric Co. of America, as manufacturers of the Curtis type of turbine had done, and was doing, to promote the cheap and reliable generation of electric power.

The development of large turbines by The General Electric Co. might be briefly summed up in three classes :—

(1) Turbines made with Curtis combined velocity stages throughout.

(2) Turbines having one combined velocity stage with a varying number of single wheels.

(3) Turbines with single wheels throughout and the characteristic of a conical construction of the rotor.

The underlying idea in the general development of the General Electric turbine units had been reliability through simplicity, and to develop the turbine as the generator had developed, thereby securing a balanced combination giving the highest efficiency.

The development of the steam turbine had now reached such a point that any great advance in the efficiency could not reasonably be expected, although they might expect some further advance by study and persistent research regarding the behaviour and action of steam in buckets and nozzles. The greatest advance would be found in increasing the temperature and pressure in conjunction with bleeding, for heating the feed water and reheating the steam after it had done a certain percentage of the total work.

The General Electric Company had built and had on order for the electrical industry in the United States at the present time, a total of 460,000 kW. turbine generating capacity at steam pressures ranging from 530 lbs. to 600 lbs., a total temperature of steam of 725° F. and reheated to 725° F. at a pressure of about 110 lbs. In addition, such units were arranged for multi-stage extraction for heating feed-water. Among these installations might be mentioned :—

One 60,000 kW. unit for the Commonwealth Edison, Chicago. This consisted of two separate turbines and generators. High pressure unit operated at 1,800 r.p.m., developing 17,000 kW. ; the low pressure at 1,200 r.p.m., developing 43,000 kW.

Eight 35,000 kW. to 40,000 kW. units for the American Gas & Electric Co. These units operated at a speed of 1,800 r.p.m., and had the repeat feature in one complete turbine casing, making a simple and robust construction.

Two 40,000 kW. units for the Columbia Gas & Electric Co. These units were of the tandem type, operating at 1,800 r.p.m.

The efficiency guarantees for these turbine units ranged from 10,450 to 10,300 B.Th.U.'s per kilowatt hour, at the above stated steam conditions and 29 ins. of vacuum, with two and three stage bleeding for heating feed water up to 245° F.

One 2,600 kW. 3,600 r.p.m. unit for the Boston Edison Co., to operate at 1,000 lbs. steam pressure—total temperature 700 °F., discharging the steam at 360 lbs. pressure for use in the regular steam turbines. This unit would be in operation before the end of 1924.

When various turbine constructions were discussed, the writers usually placed great stress upon what was termed the leaving losses of a turbine; the loss in the last blade. In order to reduce these, numerous devices had been proposed, and they had double flow, parallel double flow and multiple flow, but in so doing other losses were assumed, such as increased leakage losses, losses due to eddies and carry-over losses. A much simpler arrangement was to avoid such constructions, giving attention to substantial bucket fastening and non-vibrating buckets, which would produce a moderate leaving loss. It was more than likely that no bucket failure had ever occurred in any turbine due to centrifugal force alone. It was always combined with vibratory and heat stresses. Vibrations of any kind must be avoided in turbines, especially in the wheels and buckets. This subject had been dealt with in a most thorough and complete manner by the late Mr. Wilfred Campbell in his paper on "The Protection of Steam-Turbine Disk Wheels from Axial Vibration," presented at the spring meeting of the American Society of Mechanical Engineers at Cleveland, Ohio, May 28th, 1924.

If this were any indication of what would happen in the near future, there would be still further insistence upon increase in economy in the production of power. There appeared to be two ways in which this might be accomplished. The first was by using Mr. Emmet's mercury process in combination with the steam cycle at comparatively moderate pressure, and on top of this superimposing the mercury cycle. The other was by increasing the pressure and temperature of the steam, both having the object of increasing the economy through an increase of temperature range. The steam turbine was perfectly capable of utilising as high steam pressures and temperatures as could be generated, and in the near future they might see large turbine units operating on pressures as high as 1,500 lbs. in as satisfactory a manner as present day results.

The trend in the power field in the United States was toward consolidation and concentration, resulting in a demand for larger and larger turbine units, and sizes of 100,000 kW. and over might be considered in the near future. The design of such sizes would, of course, vary from present day construction, but there did not seem to be any limitation to the size of turbine units that could be produced, except the demand.

DR. S. Z. DE FERRANTI (*Great Britain*), said that he had for a long time been very much interested in turbines, although he had not for a considerable period done anything from a business point of view in the way of building for the market. In 1902-3 he had come to the conclusion that the right thing to do was to build a re-superheating turbine, to get as nearly as possible to isothermal expansion. This had been based upon the idea that in a heat engine the great thing was not simply a high temperature dropping to a low temperature, but that they should have a cycle in which they did as nearly as possible the whole of the work at the top temperature. Theoretically, this meant exhausting at very nearly as high a temperature as they started with, transferring the heat in the regenerator to the incoming fluid and working on what was—when the air could be used as a fluid—a very perfect cycle. His object had been to get as nearly as possible commercially to that type of cycle with steam. He had therefore come to the conclusion that the thing to do was to use a moderate pressure—in those days 200 lbs. only—and to reheat the steam at as many points as possible on its way to the condenser. This had involved under certain conditions of load—in fact under all loads, but more so with light loads—a considerable transfer of heat from the steam at the low pressure end, by means of a regenerator placed before the condenser. This was a development which had taken place rather later on.

After making a great many experiments, about the year 1910 he had built a turbine of 3,000 kW. capacity running at 3,000 r.p.m. This turbine had had no dummies. The blading had been on the Parsons' principle. The blading system had been very carefully designed, with the path as regular as possible and increasing most smoothly. It had been a two stage turbine. The idea of the isothermal expansion at that time had got watered down to doing it in two stages. It had had a regenerator in the circuit between the exhaust and the condenser, and later on it had been fitted with an arrangement for bleeding at four stages.

The turbine had been a peculiar one in this sense. There had been an outer casing of wrought steel. Inside the casing, there had been another barrel or drum of wrought steel into which the blades had been welded. The running drum which was in two diameters also had had the blades welded in. This turbine had run a great many experimental trials. It had supplied a great deal of power to Vickers' Works at Sheffield, and generally the performance had been satisfactory.

They had superheated the steam regularly, and without any undue difficulty, to 750° F. They had exhausted the steam still superheated, and they had then re-superheated the steam in another superheater alongside the high pressure one and returned it to the turbine. The two superheaters had been separately fired. They were small tubes and stood alongside the boilers very closely adjoining the turbine. This had been a small installation complete in itself. They had had a very interesting experience in the attempt to use an alloy steel for the superheater tubes, the deterioration of which they had greatly feared in those days. He had had tubes drawn of 25 per cent. nickel steel, and this had proved a great difficulty. They had eventually got the tubes and put them into superheaters, and they had done quite well; but they had afterwards found that with ordinary steel they could do just as well with that temperature.

Four years ago, he had come back to the idea of doing the work at a high pressure. Where compression was required with an air cycle, that is to say a negative work, they must do it at the lowest temperature for the cycle. He had made a small engine in which the cylinder and the regenerator which was within the cylinder, and the piston, had been red-hot, and this had worked quite well. But, what was more to the point, they had made several small turbine wheels of 10 ins. diameter, which they had run at 26,000 revolutions. There had been nothing wonderful in that. They had been supplied with a comparatively low pressure high temperature air from a combustion chamber fed from a separate air pump. The casing and the turbine wheel had run at that speed at a bright red heat, and the temperature had been about 900° C.

SIR CHARLES PARSONS, said that he fully endorsed everything Dr. Ferranti had said. He attributed the non-success of that period of re-heating to the growth of cast-iron, such as was got in the fire-bars of boilers. At that period it had not been known that cast iron would grow at the ordinary temperatures of steam, and they had all looked upon it as a new phenomenon. They had had something to do with one of Dr. Ferranti's cylinders, and had helped him a little in the design. When that cylinder had been put to work, it had grown so much that the guide blades had fouled the rotating blades. That meant a growth of $\frac{3}{8}$ or $\frac{1}{4}$ in.

MR. J. P. CHITTENDEN (*Great Britain*), said that Mr. Hodgkinson was rather hard on impulse turbines; he had made his main point on the question of disc vibration. Many years ago, the speaker had encountered this with one machine, and since then they had been fortunate enough to avoid it. As far as he knew, in Great Britain there had only been two cases where it had been definitely proved that the trouble with impulse turbines had been due to disc vibration.

Mr. Hodgkinson had also said that it was correct to have the impulse stage at the high temperature end of the turbine. That he agreed was in very many cases desirable, but it was controlled to a very large extent by the relative output and speed. On the same page, Mr. Hodgkinson had referred to

end-tightened reaction blading. Whilst in no way attempting to advocate such a method of reducing leakage, he would suggest that if clearances were at the high pressure end, where it was a very easy matter to control them due to the fact that they occurred near to the thrust block, they were far less dangerous there than having them at the low pressure end, where such devices as a split flow were employed.

Mr. Hodgkinson had given a large number of curves which were based on different velocities of flow at the blade edge. He thought it was rather a pity that instead of giving the relative losses, he should have given some idea of the actual losses in efficiency. Supposing that the total loss here was 1 per cent., it mattered very little whether the blades were wide or whether they were not wide.

There was also one remark at the end of the paper to which he would like to draw attention. The author had stated that the method of fastening the blades by means of cross-pins gave the maximum strength. He urged that the outside fixing, as they called it, was undoubtedly the strongest possible form of fastening a blade on to a disc. It was not only the strongest, but it was the lightest form of fastening, and gave the least stress to the hub of the disc, and that was the point where the maximum stress of the disc occurred

MR. KARL BAUMANN (*Great Britain*), said that, with regard to the development of the multiple exhaust turbines, no test results had been given, but tests had recently been made by the Metropolitan-Vickers Electrical Co. on a 7,000 kW. turbine, which was installed at Bristol, and the results which they had obtained would shortly be published. One way of judging the multi-exhaust blading, was to ascertain the increase in vacuum, which could be utilised without decrease in efficiency by the addition of the multiple exhaust stage. They had found that with the multiple exhaust stage, a vacuum of 28·63 ins. could be utilised with the same efficiency as a vacuum of 27·8 ins. was utilised with the same turbine, but without the multi-exhaust stage. That meant that the multiple exhaust stage was able to deal with a 60 per cent. larger volume of steam at the exhaust end, with the same thermo-dynamic efficiency of the turbine.

One speaker had referred to the development which had taken place in connection with the two-cylinder machine. There was nothing novel in that machine, as in order to utilise high steam pressures efficiently, most designers had realised that an extra high pressure cylinder was necessary.

MR. B. POCHOBRADSKY (*Great Britain*), said that the recent research of the Institution of Mechanical Engineers and the British Electrical and Allied Manufacturers Association had led to the discovery of a new law, governing the steam flow in nozzles ; it showed that the efficiency was highest at a very low velocity, somewhere in the neighbourhood of 300 ft. per second, and that a second maximum existed at a high velocity, *viz.*, in the neighbourhood of 1,800 ft. per second. These results suggested a new line of design, *viz.*, that in a turbine only the very low velocities and the very high velocities in the neighbourhood of the two maxima should be used if highest efficiencies were required, and that no medium velocities should be applied. This meant a turbine which contained stages of small diameters and stages of large diameters, no intermediate diameters being applied.

On account of friction losses and leakage losses in the high pressure portion being serious, only small diameters would be used in the high pressure portion. On the other hand, the low pressure portion must of necessity be large in diameter, because they required large areas to pass the steam through. The new turbine would, therefore, have in the high pressure portion small diameter stages, and in the rest of the turbine large diameter stages would be used. The small diameter in the high pressure portion of the turbine resulted in high steam pressures inside the casing of that portion and as they increased the boiler pressure, at the same time they must search for a new solution of the high pressure end, capable of dealing satisfactorily with the high pressures and high temperatures.

He believed he had succeeded in arriving at such a solution by the provision of an internal casing in the high pressure end. This internal casing was

attached to the external casing in a flexible manner, and in such a way that it remained co-axial with the external casing under all conditions of operation. Longitudinally, the internal casing would be fixed in one plane to the external casing. The internal casing designed in such a manner could expand freely in all directions, although it remained always co-axial and longitudinally fixed at one point. Between the internal casing and the external casing, the steam pressure was held at some medium figure between the pressure inside the internal casing and outside the external casing.

The pressure drop was, so to speak, split into two portions, one for each casing, so that the pressure forces were easy to deal with, even with very high boiler pressures. Similarly the temperature drop was also split into two portions : the internal casing would be hot, the external casing at its hottest place being subjected to steam which had already given up some of its heat, while working in the internal casing. In this manner, however, every individual part of the turbine casing was subjected only to moderate temperature gradient.

This solution offered no mechanical difficulties in design, and he thought it quite capable of easily overcoming the difficulties which the designer was likely to have to face, in the case of very high steam pressures and temperatures being applied.

MR. M. K. KÖNIG (*Switzerland*), said that with regard to reheating and maximum steam temperature, the results of the Nozzle Research Committee which had showed a decrease in efficiency at higher temperatures should be borne in mind. With regard to hydraulic efficiency, the most economical initial temperature in any stage would be that which ensured just a small superheat after expansion and utilisation of heat. Any surplus temperature might improve matters in the next lower stages, but brought about a decrease in efficiency in the stage in question. The expansion line of the ideal turbine in this respect should run parallel to the saturation line of steam. The reheating could be done by live steam of maximum superheat in contraflow to the steam flow in the turbine affecting an approach to isothermal expansion. Such a cycle involved, however—for the time being anyhow—a practically impossible complication of the design.

Mr. Stork, in his paper *Steam Turbines for High Pressures*, had explained at some length the importance of what he had called the quality figure, and said that investigations had shown that all present turbines were defective in so far as this quality figure for the high pressure part was concerned. He had claimed that it had been proved necessary (between the lines was to be read that the Erste Brunner Co. had proved it), to raise the quality figure of the existing construction to a very considerable extent, so that the values of the low pressure part were reached. It would be simpler to say, as Sir Charles Parsons in his paper had said, " throughout the stages of a turbine the criterion of efficiency is the velocity ratio "—then it would with the same clearness be understood that the company in question, relying on very effective design and high degree of workmanship, was successfully running small multi-stage multi-cylinder turbines with the maximum velocity ratio in every stage even of the high pressure part, securing at the same time the advantage of full admission, increased reheat, carry-over, etc.

It was also claimed that this design was characterised by flat course of the top of the efficiency curve, as compared with the efficiency of an ordinary impulse wheel. If the author would compare Stodola's curves for the single wheel of a single stage turbine with that of a single wheel in multiple stage turbines, where a certain amount of carry-over was effected, he would find the simple reason for the difference of the curves. The comparison of these two curves was totally wrong.

MR. GEORGE A. ORROK (*U.S.A.*), said that what the central station man wanted to-day was a turbine which would run 8,760 hours in the year, if necessary. He wanted a turbine that could be started up from cold at two minutes' notice, and he wanted a turbine in which the blading and the other portions of the machinery would not deteriorate. He hoped that the turbine designers would give them that turbine some day.

DISCUSSION

MR. S. J. WATSON (*Great Britain*), said that in considering the matter of cost, they had to look at the two, three, or even four casing machines as compared with the single casing machines. There was no doubt that with a multiple casing machine they could get an improved economy, but the point they had to take into consideration from the operating point of view was how much did it cost. The latest and most economical machine of to-day was not going to be in that same position three, four or five years hence. Therefore it seemed to him that they had to obtain, over a period of three or four years, the equivalent in fuel saving which was represented by the additional capital which they expended. It was a matter of some small moment, and was well worth consideration.

Another point was the design of large machines at high speed. He paid tribute to the alternator designers, particularly of Great Britain, for the way in which they had followed speeds up to the 3,000 revolution range. Whatever the turbine maker had required in the way of speeds, the alternator maker had promptly met. There was one thing for which they were profoundly thankful in Great Britain, and that was the standard periodicity of 60, and therefore they could not exceed a speed of 3,000 revolutions per minute. He would like to know whether, in America, where apparently the standard periodicity was 60, any considerable progress had been made in the design of comparatively large machines of 20,000 of 30,000 kW. with a speed of 3,600 r.p.m.

MR. IRVING E. MOULTROP (*U.S.A.*), said that he would say a word on what they were doing with their 1,200 lbs. installation. His job was to build a station which would enable his company to put a kilowatt on the bus bars at the lowest possible cost. That made him start with the load curve. In New England, they unfortunately had not the same manufacturing business as they had in other centres, such as round about Chicago, Pittsburgh, etc., and consequently they had to start with the business they had in hand. 550 lbs. re-heating worked out beautifully for those manufacturing centres with a fine load curve, but it did not fit Boston conditions. What they were doing was to build a standard reliable and fairly simple station, and superimpose on that a unit of higher pressure. In their light load period they did not need to run the high pressure machine if it were not practicable. Furthermore, all the various schemes that had been described cost more money per unit of capacity than the standard station, because they spent money for extra efficiency but did not get any extra capacity. With their scheme they got extra capacity, and as near as they could determine that extra capacity was just balanced by the extra cost. In other words, the unit cost of their station, they expected, was going to be the same as that of a standard station, so that they hoped to gain increased efficiency without any increased overheads. That was one point that was rather important for them.

MR. BERNARD PRICE (*Union of South Africa*), said that when considering efficiency it was necessary to bear in mind the cost of fuel, which varied very much in different places, and when considering capital cost it must be remembered that the cost of installation varied for different parts of the world. But there was a third factor which was independent of fuel, but which varied, according to the cost of labour and transport, namely, the cost of maintenance. Ease and cheapness in effecting routine overhauls, inspections, maintenance and repairs became a very important factor when the plant was situated far from manufacturing districts and factories, and he urged designers to give careful attention to this aspect of the problem when developing towards higher pressures.

MR. STANLEY COOK (*Great Britain*), who replied in the discussion in place of Sir Charles Parsons, said that the engineers of the present generation would, he thought, find it difficult to acquit themselves of the charge of extravagance, with regard to the use they had made of the sources of energy which lay in nature in coal and oil, but at any rate it would be seen from the papers that had been presented that morning, that they were now keenly alive to the situation and were doing their best to redeem their characters.

There was sufficient mechanical skill and sufficient scientific knowledge at the present day to enable them to size up all such proposals as were being put forward for increased efficiency. Mr. Pochobradsky had proposed an internal casing for a high pressure turbine. That surely was not necessary. Even with the higher pressures that had been mentioned, it did not appear that there should be any difficulty in making a satisfactory design of a high pressure turbine, provided the turbine was made small enough, and of course that implied using high revolutions. He thought the most generally favoured proposal for a high pressure turbine of that sort was to have it geared to the rest of the turbine or turbines.

Mr. Hodgkinson had referred to precautions which were necessary in controlling the speed of the turbines, when a system was fitted with a re-heater. He would like to mention that this was a matter that was fully dealt with in Sir Charles Parsons' paper.

Mr. König had said that a difficulty with re-heating was that the recent Nozzle Research Committee had found a decrease of efficiency with increased velocity; but it was difficult to see how that had any real connection with re-heat, because the velocity of the blades of the turbine and of the steam were all a matter of design and could be chosen at will at their most efficient value.

He would like to add one word in reference to what Mr. Watson and Mr. Moultrop had said with regard to extra cost. These gentlemen were filled with the laudable desire of getting something for nothing. They wanted to have the increased efficiency and to pay nothing for it. If they would study Sir Charles Parsons' paper carefully, he thought they would find that the proposals put forward almost gave them that, for what was done by the proposals in the paper was to reduce the amount of heat that had to be put into the steam by the boilers for a given output. That meant reduced heating surface, and that in itself should compensate very largely for any increase in cost that might be incurred by the increased pressures and any mechanical difficulties that had to be overcome. The heating surface and the weight of the boiler plant, as expressed in terms of output, would really be reduced, whilst for the turbines, the output per lb. or the weight of the turbines in lbs. per horse-power, should not be increased, in spite of the fact that they had this increased efficiency.

MR. FRANCIS HODGKINSON (*U.S.A.*), said that with reference to Mr. Stork's paper and concerning turbines designed with multiple cylinders, the real advantage of this construction, as he saw it, was the ability to operate the separate compounded elements at different speeds, thereby obtaining the benefit that had been referred to many times, of a small diameter high pressure element and ample areas in the low pressure element, which might be secured with the lower speed of the low pressure. In that connection, it must not be forgotten that losses were incurred when steam was taken from one turbine cylinder and put into another. This, however, had been largely overcome by the very admirable arrangement proposed for the Crawford Avenue Station of the Commonwealth Edison Co. by Sir Charles Parsons.

Concerning Mr. Chittenden's comments as to the effect of vibrations of discs on impulse turbines, which had been the cause of many serious difficulties—though these were believed now to be well overcome, he referred him to the paper read before the American Society of Mechanical Engineers a month before by Mr. Wilfred Campbell, where this subject had been very ably treated.

So far as the so-called end-tightening was concerned, of course any close axial clearances were reasonably safe when adjacent to the thrust bearing. They were, as he said, to be avoided at parts removed from that, *viz.*, at the low pressure end. When a split exhaust, as Mr. Chittenden called it, was employed, ample clearances obtained in that region.

His purpose in referring in his paper to cross pins for securing blades to discs had been to show a method of construction. Of course, cross pin constructions were used with the blade enveloping the edge of the disc, as well as with the blade set in a groove in the disc. What he wanted to bring out was that an equally strong construction could be secured by that means as by any other. He himself preferred to set the blades in grooves as being the simpler construction.

DISCUSSION

Mr. Watson had asked a question concerning multiple cylinders and had inquired what would be the relative cost of two 20,000 kW. single cylinder plants, as compared with one 40,000 kW. cross compound plant (two cylinder). He was not in a position to answer that question beyond saying that the one 40,000 kW. plant would be a little more costly, but that there was an obvious degree of reliability to be secured by the two-cylinder construction.

THE CHAIRMAN, said that he wanted to say just one word as a user of turbines. He doubted whether any of the larger undertakings, on the question of reliability of service, could say that the availability of the machine 8,760 hours a year was the answer. The question of price was not going to stand in the way when that requirement was completely filled. He doubted whether any of the Utility Companies wished them to squeeze the dollar or the pound so hard that they wanted even approximately to get something for nothing, but they did want that something good, and they wanted it to remain reliable.

THE CHAIRMAN then closed the session.