

Ministry of Fuel and Power

# FUEL

## and the Future

VOLUME ONE



LONDON  
ESTY'S STATIONERY OFFICE

Price 6s. 0d. net

# FUEL AND THE FUTURE

*The Report of the Proceedings of the Conference  
is completed in the following volumes:*

## VOLUME II

*Section D—High Temperature Processes.*

*Section E—The Carbonisation and  
Chemical Industries.*

*Section F—Special Industrial Sessions.*

*Joint Session I—The Sizing and Grading  
of Coal.*

PRICE 6s. By post 6s. 6d.

## VOLUME III

Relevant parts of the Opening Session,  
followed by—

*Section G—Modern Heating and the  
Architect.*

*Section H—The Home and its Fuel Services.*

*Joint Session II—District Heating. Con-  
cluding with a summary of the closing  
session.*

PRICE 3s. 6d. By post 3s. 10d.

---

OBTAINABLE FROM

H.M. STATIONERY OFFICE

AT THE ADDRESSES ON COVER PAGE 4

OR THROUGH ANY BOOKSELLER

**MINISTRY OF FUEL AND POWER**

# **FUEL**

## **and the Future**

**The Proceedings of a Conference held in London  
on October 8th, 9th and 10th, 1946, under the  
Auspices of the Fuel Efficiency Committee**

**VOLUME ONE**

**LONDON**  
**HIS MAJESTY'S STATIONERY OFFICE**  
**1948**

# CONTENTS

	Page
PREFACE . . . . .	vi
<b>OPENING SESSION</b>	
Dr. E. S. Grumell . . . . .	1
The Rt. Hon. Emanuel Shinwell, M.P. . . . .	2
Alderman C. W. Key, M.P. . . . .	7
'Sir Clive Baillieu . . . . .	8
Lord Citrine . . . . .	12
<b>CLOSING SESSION</b>	
The Rt. Hon. Emanuel Shinwell, M.P. . . . .	16
Dr. E. S. Grumell . . . . .	17
The Rt. Hon. Sir Stafford Cripps, K.C., M.P. . . . .	18
<b>SECTION A—THE GENERATION OF STEAM</b>	
<b>SESSION I. THE AVAILABILITY OF WATER-TUBE BOILERS</b>	
1. M. H. Adams : Remarks on boiler availability . . . . .	26
2. W. G. Marskell : Investigations and recommendations regarding cleaning . . . . .	33
3. Dr. H. E. Crossley : Research work at the Fuel Research Station on boiler deposits . . . . .	36
4. Dr. G. Whittingham : Research work on deposits by British Coal Utilisation Research Association . . . . .	40
5. R. Llewellyn Rees : Research work by the Boiler Availability Committee . . . . .	45
6. J. Mayer : Boiler design . . . . .	49
<i>Discussion</i> . . . . .	53
<b>SESSION II. DESIGN AND OPERATION OF SMALLER BOILERS</b>	
1. Dr. E. G. Ritchie : Considerations affecting the efficiency of the heating surface of shell boilers . . . . .	54
2. A. S. Peacock : Water-tube boilers for industrial purposes in Great Britain . . . . .	60
3. H. E. Pearsall : Mechanical stokers for shell boilers . . . . .	62
4. C. H. G. Hayward : The chain-grate stoker as applied to shell boilers . . . . .	73
5. E. L. Tinley : Underfeed stokers for firing steam boilers . . . . .	77
6. P. G. Ryder : The firing of shell boilers with pulverised fuel . . . . .	90
7. P. A. Evans : The installation of steam boilers . . . . .	96
8. H. C. Oughton and R. W. Towers : Automatic control of solid-fuel fired steam-raising plants . . . . .	98
9. H. D. Watson : Industrial steam-raising plant . . . . .	104
<i>Discussion</i> . . . . .	116



SECTION A—THE GENERATION OF STEAM—*continued*SESSION III*a.* SHUNTING LOCOMOTIVES

	Page
1. R. E. Ketley : Trends in the development of design of the direct-fired steam locomotive . . . . .	124
2. F. A. Harper : Notes on Diesel-electric shunting locomotives . . . . .	127
3. John Alcock : Straight Diesel shunting locomotives . . . . .	131
4. C. D. Hanna : Fireless or steam-storage locomotives . . . . .	132
5. A. C. Thirtle : Experience in the operation of shunting locomotives . . . . .	135
6. E. L. Diamond : Shunting locomotives for iron and steel works . . . . .	137
7. J. Stafford : Shunting locomotives for colliery requirements . . . . .	141
8. G. J. Davis : Shunting locomotives on cement works . . . . .	142
<i>Discussion</i> . . . . .	143

SESSION III*b.* THE TRAINING OF BOILERHOUSE AND FURNACE OPERATORS

1. Dr. R. J. Sarjant : War-time training of personnel . . . . .	148
2. Dr. W. Abbott : Standard courses . . . . .	149
3. E. W. Bussey : Education as viewed by the T.U.C. . . . .	150
4. R. H. Brennan : Education as viewed by the employer . . . . .	151
5. S. N. Duguid : Aids for training . . . . .	152
6. T. M. Ashford : The practical aspect of classes for stokers . . . . .	153
7. W. Bates : Standard methods of firing locomotives . . . . .	153
8. W. Caudle : The Ministry Stoker-demonstrator's point of view . . . . .	154
9. P. B. Silk : Duties of personnel . . . . .	155
10. L. G. Northcroft : The status of the works engineer . . . . .	155
<i>Discussion</i> . . . . .	156

## SUMMARY OF THE MAJOR CONCLUSIONS FROM SECTION A

By Sir Johnstone Wright . . . . .	158
-----------------------------------	-----

## SECTION B—STEAM UTILISATION

## SESSION I. WHERE EVERYTHING DEPENDS ON STEAM

1. "Beer and Coal"—Bulletin for the brewing industry . . . . .	161
Ralph Worssam : Introduction . . . . .	162
Oliver Lyle : The utilisation of low-grade heat . . . . .	163
F. E. B. Moritz : Discussion . . . . .	164
The Hon. John F. Gretton : Discussion . . . . .	166
2. Fred Walker : Steam for the rubber industry . . . . .	167
3. R. Bunting : The efficient utilisation of steam in the chemical industry . . . . .	170
4. L. G. Northcroft : Steam research and education . . . . .	172
<i>Discussion</i> . . . . .	174

SECTION B—STEAM UTILISATION—*continued*

SESSION II. WHERE POWER AND STEAM NEEDS NEARLY BALANCE		Page
1. R. G. Sands : The paper and board makers' view of fuel and the future . . . . .		178
T. R. Young : Discussion . . . . .		184
R. H. Brennan : Discussion . . . . .		186
2. F. Courtney Harwood : Immediate and future aims of the laundry industry . . . . .		187
3. W. O. Goldthorpe : "Laundering and coal"— Bulletin for the laundry industry—introduction . . . . .		190
G. A. Crosland : Discussion . . . . .		191
I. R. Brown : Discussion . . . . .		192
4. J. J. Tomlinson : Steam and the hospital engineer . . . . .		192
R. G. Rogers : Discussion . . . . .		193
J. C. Chynoweth : Discussion . . . . .		195
5. D. L. Copp : The use of back-pressure steam . . . . .		195
<i>Discussion</i> . . . . .		198

## SESSION III. WHERE POWER OUTBALANCES PROCESS STEAM

1. F. Buckingham : Where power outbalances process steam . . . . .		207
2. E. E. Stimson and R. Bunting : Heat conservation in the dyeing and finishing trades . . . . .		213
3. C. T. Wade : Steam utilisation in the dyeing and finishing trades . . . . .		225
4. H. W. Perkins : Heat and power in the hosiery industry . . . . .		230
5. R. H. Harral : Power for cotton mills . . . . .		231
6. T. H. Carr : Public electricity supply in the woollen industry and ancillary trades . . . . .		234
7. T. W. Evans : Power saving in textile mills . . . . .		238
8. H. R. Lupton : Power for pumping . . . . .		241
9. W. R. M. Belcher : Mechanical power transmission in engineering works . . . . .		241
<i>Discussion</i> . . . . .		243

## SUMMARY OF THE MAJOR CONCLUSIONS FROM SECTION B

By J. G. Bennett . . . . .	244
----------------------------	-----

## SECTION C—HEAT FOR DRYING

## SESSION I. DRYING, CONDITIONING AND STORING

1. J. C. Lowson : The electric infra-red process . . . . .	246
2. R. F. Hayman : Town gas for drying by radiant heat . . . . .	254
3. A. M. Lehmann : Efficiency of conveyor drying and enamelling plants . . . . .	263
4. Dr. A. W. Scott : The drying of foodstuffs and waste products . . . . .	267

v

SECTION C—HEAT FOR DRYING—*continued* Page

SESSION I. DRYING, CONDITIONING AND STORING—*continued*

5. E. H. Farmer and C. G. Six : Spray and roller drying	277
6. A. S. White : The drying of chemical products by the atmospheric tray dryer . . . . .	288
7. C. R. Love : The drying of china clay . . . . .	290
8. Charles Stevens : Leather drying . . . . .	292
9. A. C. Hutt : Drying, conditioning and storing . . . . .	294
10. K. H. Sambrook : Use of oil fuel for drying . . . . .	295
<i>Discussion</i> . . . . .	296

SESSION II. FACTORY HEATING AND AIR CONDITIONING

1. Dr. Oscar Faber : Factory heating and fuel savings . . . . .	301
2. J. W. Cooling : Air conditioning . . . . .	310
3. H. H. Bruce : Temperature gradients . . . . .	312
4. J. L. Musgrave : Radiant heating . . . . .	315
5. L. Copeland Watts : Insulation and heat loss (air and structure losses) . . . . .	317
6. F. R. L. White : Application of instruments to boiler plant . . . . .	319
7. J. R. Kell : Thermostatic control . . . . .	320
8. G. P. Barnett : Fuel economy in its relation to atmospheric conditions in factories . . . . .	322
<i>Discussion</i> . . . . .	325

SESSION III. HEAT FOR AGRICULTURE AND HORTICULTURE

1. F. E. Bulletin No. 46, introduced by W. H. Gamble : "How glasshouse growers can save fuel" . . . . .	330
2. C. B. Chartres : Grain drying and the combine harvester . . . . .	332
3. David Fairclough : Grass and herb drying . . . . .	337
4. Dr. A. W. Scott : Engineering aspects of grass drying . . . . .	340
5. Dr. A. H. Burgess : Hop drying . . . . .	345
6. H. J. Hamblin : Power saving with special reference to tractors . . . . .	347
7. H. S. Hall : Dairying—fuel economy in sterilisation . . . . .	350
8. C. A. Cameron-Brown : Electric heat for agriculture and horticulture . . . . .	353
9. D. Stewart : Glasshouse heating, with special reference to tomato growing . . . . .	358
10. L. Kinnell : Artificial rain . . . . .	360
<i>Discussion</i> . . . . .	363

SUMMARY OF THE MAJOR CONCLUSIONS FROM SECTION C

By W. L. Boon . . . . .	368
-------------------------	-----

## PREFACE

The general need for efficiency in British industry has never been greater than it is today. Fuel efficiency is an integral part of production efficiency, and correct fuel utilisation is now, and will be in the future, essential in every factory, establishment and home. For this reason, the Fuel Efficiency Committee of the Ministry decided in March, 1946, to convene a conference at which both the present state of development of fuel utilisation and its future trends could be freely discussed by experts in each individual field in an informative manner for the general guidance of all fuel users, industrial and domestic.

Nearly five thousand industrialists and members of domestic organisations interested in fuel usage attended the conference on 8th, 9th and 10th October, 1946.

After a joint opening session at which those assembled were addressed by prominent members of the Government, Industry and Trade Unions, the conference divided into eight sections meeting simultaneously in different places, each section holding three sessions consecutively. The sections dealt with the following subjects :—

- Section " A "—The Generation of Steam.
- Section " B "—Steam Utilisation.
- Section " C "—Heat for Drying.
- Section " D "—High Temperature Processes.
- Section " E "—The Carbonisation and Chemical Industries.
- Section " F "—Special Industrial Sessions.
- Section " G "—Modern Heating and the Architect.
- Section " H "—The Home and its Fuel Services.

Two joint sessions were then held simultaneously, one dealing with the Sizing and Grading of Coal, and the other with District Heating, after which there was a closing session presided over by the Rt. Hon. Emanuel Shinwell, M.P., Minister of Fuel and Power, and addressed by the Rt. Hon. Sir Stafford Cripps, K.C., M.P., President of the Board of Trade, at which also the sectional chairmen summarised the conclusions of their meetings.

The proceedings of the conference have been printed in three volumes, of which this book comprises the first. It is devoted to the opening and closing sessions together with the first three technical sections dealing with the generation of steam, steam utilisation, and heat for drying.

Considerations of space have made it necessary to curtail most of the communications to a greater or lesser extent by abridgement, summarisation or condensation as best fitted the subject. Every care has been taken to avoid the omission or distortion of any essential matter, and the authors are thanked for submitting to this unfortunately necessary operation.

Where requested, acknowledgments have been formally made in the text of this publication. In addition, the Ministry wish to express their thanks to all those who have contributed to the success of this conference and without whose aid it could not have been held.

Finally, it should be pointed out that the fact of publication of these proceedings must not be held to imply that all the views expressed therein are necessarily in every respect those of the Ministry of Fuel and Power.

# FUEL AND THE FUTURE

## OPENING SESSION

*Chairman: Dr. E. S. GRUMELL, C.B.E.*

CHAIRMAN OF THE FUEL EFFICIENCY COMMITTEE

THE CHAIRMAN welcomed all those who for the last four or five years had been working so energetically and so successfully in conserving fuel during a period of great stress, and without whose assistance this country would now be in an even more serious position. He added that while it was impossible to say precisely how much fuel had been saved, it was the opinion of the Committee that, had it not been for the nation-wide campaign, requirements today would most certainly be greater by not less than five million tons. Many members of the Committee would prefer to put that figure at ten million tons.

He welcomed also newcomers who perhaps had not been actively associated with the work of the Committee before, but whose presence at the Conference might be taken as evidence that they were about to join in the campaign. A special welcome was accorded to distinguished visitors from the Continent, from the Dominions, from America and from other countries. Some 30 of these visitors from a dozen different countries were representatives of the National Committees of the World Power Conference. The Executive Committee of that Conference had decided that the subject of its first public conference since 1938 should be "Fuel Economy". That conference would be held at the Hague in September 1947 by invitation of the Netherlands National Committee.

Referring to the speakers at the opening session, the CHAIRMAN said: The first speaker will be the Rt. Hon. Emanuel Shinwell, Minister of Fuel and Power. One of the very many duties of our Minister is to promote efficiency and economy in the use of fuel and power, and we hope to hear him speak today on that subject. In the execution of that duty, we are here to help him and I trust that the Minister will feel encouraged and inspired by this great gathering. More than 4,500 individuals are attending this Conference, and I think that discloses the great and growing interest which is being shown in this vitally important subject. At the same time, the Conference reveals the extraordinary diversity of the fuel problem. This diversity alone raises considerable difficulties in dealing with the subject, but I think you will agree that these difficulties must be overcome, and fuel must not be allowed to become a limiting factor in manufacture when ingenuity, resource and enthusiasm in tackling problems of fuel conservation and wastage can prevent it.

The second speaker was to have been Mr. Aneurin Bevan, Minister of Health, but he is unfortunately not able to attend. In his place we welcome Alderman Key, Parliamentary Secretary to the Ministry of Health, who will have something to say about domestic consumers. I think I am right in saying that this is the first joint industrial-domestic conference to be held, and it is, I think, interesting to note that there is no longer any hard and fast dividing line between industrial and domestic utilisation. The fundamental principles of fuel technology are common to both. Alderman Key will be followed by

Sir Clive Baillieu, the President of the Federation of British Industries, who will speak from the industrialist's point of view on the importance of planning production for a maximum output with the least possible use of fuel and power. I also hope that Sir Clive will give us some indication of the attitude of management towards this problem. Thus far we certainly have had a magnificent response in most quarters, but not in all, and we want more. It must be realised by everyone that unless the problem of efficient utilisation is tackled energetically and continuously the industry of Great Britain will not be in a position to face competition.

Finally, in the absence of Mr. Jack Tanner we welcome Lord Citrine. Lord Citrine is a member of the National Coal Board, but I think he would be better known to you as the General Secretary of the T.U.C., and he will be speaking today in that capacity. You will have seen posters of his fellow trades unionists in the Lobby, and I hope you all have a copy of that excellent little document, "Fuel Facts", which has been issued by the T.U.C. That document refers to the fuel watcher, and I want to make it clear now that he or she is a very important person; we must have people who will save fuel in every factory, in every office and in every home. I welcome the support of the T.U.C. We want all the assistance and all the enthusiasm we can get. The demand for coal is increasing, the position is somewhat better, but we must all get together—and after all this is everybody's job—and really put our backs into it as we did during the war when we were producing munitions of war. If we do that, Ladies and Gentlemen, I believe that "Britain Will Make It."

**The Rt. Hon. Emanuel Shinwell, M.P.:** Ladies and Gentlemen, on behalf of the Ministry of Fuel and Power I extend to all the assembled delegates a cordial welcome. Many of you have travelled a long way to attend this Conference, no doubt at some inconvenience to yourselves, and are now to consider and report upon the various aspects of fuel efficiency. In so doing you are rendering the whole nation a considerable service.

No subject is so far-reaching, nor indeed so beneficial, in its ultimate consequences, as that of how to promote the efficient use of fuel. It is, of course, directly associated with the present fuel shortage, but it is more than a short-term problem; it concerns the industrial and, therefore, the social future, not only of this country, but of people all over the world. Unless we can promote the highest efficiency in the use of our fuel resources and make the necessary changes in the technique of industry, we shall not be able in the coming years to maintain our prestige in the industrial field, nor can we provide a high standard of living.

We are at the beginning of another industrial revolution with far greater opportunities than those that faced the people 150 years ago. There is more technical skill and general knowledge at our command; our industrial organisation, while in many respects defective, is vastly superior, and I am glad to inform the representatives of other nations that the ability of our scientists and technicians will bear favourable comparison.

But if the opportunities are greater so is the need. We must conform to modern standards of living and even improve upon them. The needs of the people in the aftermath of a devastating war, the risks associated with international competition, our dependence on imports of raw material and food-stuffs are a sharp and constant challenge to us all—whether we are technicians or politicians, or for that matter, just ordinary people. Therefore, we must

not any longer misuse our resources, rather should we exercise our ingenuity and skill in removing all forms of waste—using our raw materials and reduced manpower in the most effective fashion.

In this matter we must promote the utmost co-operation between the politicians and the technicians. I suspect that in the past the fuel engineers have been regarded as “back-room boys”, doing important jobs, no doubt, but never seen and rarely heard. Perhaps they have been far too bashful to speak of their capabilities, much less of their needs. As I have a strong conviction that politicians cannot succeed without the assistance of the technicians, I am glad that this Conference has attracted the attention it deserves, and may thus serve the purpose of bringing our fuel engineers out of the back-rooms and into the Board-rooms where their opinions can, and should, be adequately ventilated.

Now there is one politician who will be grateful for your assistance ; it is, as you may expect, the Minister of Fuel and Power.

One of your number recently startled me by contradicting a statement that has been made everywhere since I became Minister. He said, “We do not want more coal”. However, he added this important qualification—“we want more efficiency in its utilisation.” The search for that higher efficiency is the purpose of this Conference.

Most people in the country, for one reason or another, misuse the coal they get. I regret it should be so and we must endeavour to break down prejudices before we succeed in applying those splendid ideas about fuel efficiency which you have evolved and which you wish to apply with speed.

In a period of improvisation, it is not easy to determine the right policy. We are now in this phase of improvisation. Although we are about to embark on a plan for the coal industry we must also adapt ourselves to existing needs. There is a shortage of manpower and material. We must plan for the future but not all our plans are capable of immediate application. Therefore, while the short-term position is acute, we must improvise. Our problem is to harmonise that improvisation with the plans and policy which are essential in the long run.

I shall not dwell on the matter of improvisation for long this morning, for the title of this Conference is “Fuel and the Future” and you are met to consider plans for a period of five or seven years ahead. How long the period of improvisation will last I cannot say, but we can surely be optimistic enough to place its duration at much less than seven years.

Meanwhile, we cannot escape the difficulties of transition from war to peace, so that what I must say on the period on improvisation, though brief, is of the utmost importance. We have to address ourselves to the problem of how we can get through the coming winter without dislocation of our national life—how we are to avoid a shortage of domestic fuel and the curtailment of industrial production.

This is not the occasion to deal with the efforts that have been made on the production side—the improvement in mineworkers’ conditions, the stimulus to recruitment, or the development of open-cast mining. Without those efforts the position would undoubtedly be graver than it is. We can claim to have arrested the rot and that is all to our advantage.

Nevertheless, we must recognise that the manpower in the coalmining industry is declining. Without emergency measures to repair the wastage and

secure recruitment from new sources, this decline must continue. Mechanisation in the form of power loading is on the increase but it is still in its infancy and affects only about 1 per cent. of the annual output. It must be some years before intensive mechanisation of this type can play any large part in increasing production. Therefore, the crucial problem at the moment is how to make the most efficient use of the manpower below ground that is at present available to the industry.

Meanwhile, in order to assist in meeting the gap between production and consumption, we have improvised by arranging to bring substantial quantities of heavy fuel oil into this country. And I should like to pay tribute to those who have agreed to change over from coal to oil. I am sure that they will follow with special attention the addresses to be given at the Session of the Conference on "Oil Firing". It is regrettable that with our vast coal resources conversion from coal to oil, even on a limited scale, should be necessary, but this is almost entirely attributable to the process of deterioration that has characterised the industry in recent years.

However, there are limits to the relief to be found from importing and using oil. These limits, to quote only two, are set by shipping space and the availability of oil-burning equipment. I take this opportunity of saying publicly that the limits of the present conversion programme have been reached. The new commitments already undertaken, added to our existing requirements, will absorb all the heavy oil for which equipment can be guaranteed within a reasonable period of time. All commitments undertaken will, of course, be honoured, but in considering further applications we should, I think, give priority to those processes where there is special advantage to be gained from oil firing, where the maximum quantity of coal can be replaced by the minimum of oil. So that if any industrialist is hesitating today about bringing his coal-burning equipment to the peak of efficiency, in case he may later be called upon to convert to oil firing, I suggest that he owes it to himself, no less than to the nation, to hesitate no longer.

Making every allowance for possible increases in production, and after arranging to reduce our distributed stocks to the lowest limit that we dare, we run a very grave danger of breakdown. In the public utilities, there is one additional danger, arising from lack of plant. Neither the gas nor the electricity industry has had sufficient opportunity to overtake their wartime arrears of maintenance, let alone make adequate provision for the increased loads that are being thrust upon them.

We have already experienced the consequences. There have been periods when power stations have shed their load and when gasworks have reduced pressure. Fortunately, up to now, those periods have been of short duration. But when I tell you that, in the case of electricity, the normal load is expected to be 8 per cent. greater this winter than it was last, and the peak demand, even at the present time, is 15-20 per cent. higher, you can appreciate the situation that we face.

Therefore, we must seek for a reduction in consumption. The alternatives are to step up at once our efforts to economise, or to face, in the depths of the coming winter, a breakdown in supplies. I know you will agree with me there is but one choice between these alternatives.

I am obliged to set a target for this effort, and to ask for an all-round voluntary saving in consumption of at least 10 per cent. I believe I am not asking the impossible, for I know how dramatic have been the results of your



previous efforts. I recall how great were the savings made in 1944 and 1945, when it became essential to impose economies by Direction.

This saving of 10 per cent. is needed in coal, gas and electricity, and must apply to all consumers, not only in industry, but also in the home and in public and commercial undertakings.

Lest there be any misunderstanding, let me say at once, I am not proposing to reduce the allocations of coal to domestic consumers. I look to them for savings in the form of gas and electricity. And since domestic consumption of gas was 26 per cent. higher in 1945 than it was in 1938, while with electricity the increase was 65 per cent., I feel sure the domestic consumer can and will respond.

However, I must remember that I am addressing an audience that is thoroughly fuel-conscious. I must avoid preaching too much to the converted. And, while the situation demands the maximum effort by everyone to save more fuel, it would obviously be unwise to expect additional savings from those who have already co-operated fully in the fuel efficiency campaign.

I turn from the short-term prospects to the long-term, from the period of improvisation to that of planning. I doubt whether, as a long-term policy, fuel efficiency requires either explanation or justification. It is an end in itself, for waste in any form is an evil thing.

Until 1914 the availability of good quality coal at low prices in the United Kingdom had resulted in little attention being paid to its efficient use, and judged by present standards there was a great waste of fuel. But with the war of 1914-1918 there came a fundamental change in the position.

Inland coal consumption (exclusive of colliery fuel and miners' coal) reached its peak in 1916 with 179 million tons. The drive for fuel efficiency then began to tell and its effects continued to be felt throughout the inter-war period. As a result, the consumption in the inter-war years barely exceeded that in 1913, and the peak consumption in 1937 was only 171 million tons as compared with 167 million tons in 1913.

During this period the population increased by 10 per cent., the use of power and heat in manufacturing processes was widely extended to secure increased production, new industries came into being and the standard of domestic comfort was raised considerably. In spite of all these developments the inland consumption of coal had not increased.

In many industries there was a clear trend of a decrease in the amount of fuel required per unit of industrial output as shown by the following figures :

In 1920 coal consumption per unit of electricity generated was 3.74 lb.

By 1929 this had decreased to 1.5 lb. per unit, and by 1937/38 only 1.43 lb. per unit was required. In the White Paper on the Iron and Steel Industry the following figures for fuel consumption per ton of pig iron are given :

1913	..	..	..	..	41 cwt. per ton pig iron
1937	..	..	..	..	33 cwt. per ton pig iron

In 1939 Sir Harold Hartley, in addressing the British Commercial Gas Association on "The Conservation of the Nation's Resources", said that he had made a rough calculation of the savings effected by the technical improvements in the case of gas, electricity, railways, iron and steel, and collieries. If the efficiencies of these industries had remained at the 1920 levels, in 1937

they would have required about 47 million tons more coal, or 58 per cent. of their 1937 consumption.

Subsequent analyses of the inter-war years indicate that the fuel economies were mainly the result of the installation of new plant and equipment which was considerably more efficient in its use of fuel. But the replacement of capital equipment is usually slow (boilers, for example, have lives of 25 to 50 years) and in industries where fuel costs are a small proportion of their total costs, there was little incentive to replace equipment on grounds of fuel economy alone, particularly with the low price of coal in the inter-war period.

On the outbreak of war a Committee was set up under the chairmanship of Sir William Bragg to review the fuel position in the light of war conditions. The Committee was doubtful as to the scope for further economies in view of the progress made in recent years. In 1941, however, when the fuel position became critical owing to the increased demand for coal for the munition factories and the falling output from the mines, a second Committee was appointed under the chairmanship of our present Chairman, Dr. E. S. Grumell, to review the recommendations of the 1940 Committee and to report on immediate measures of economy with a view to alleviating the now serious shortage in supplies.

The investigations carried out by the Committee showed that in general, the standard of fuel efficiency in industry was still low in spite of the economies effected since 1914. This was due to inefficient practice and to the existence of much old-fashioned and inefficient plant. Even in the best managed works it was possible to suggest ways in which fuel could be saved by improved methods, and it was estimated that the visits to factories resulted in an average increase of efficiency of 10 per cent.

During the war it was not possible to replace obsolete plant on any large scale, but 2,490 licences were granted by the Government to firms for the purchase of such fuel-saving plant and appliances as were estimated to save the capital cost of installation by the fuel saving obtained within two-and-a-half years. In many cases this economy was obtained in an even shorter period, and it is estimated that nearly three-quarters of a million tons of coal were saved in this way.

Thus in the inter-war years two conflicting tendencies were at work. The growth of new industries, like the motor-car industry, and the development of new uses for fuel and power increased the demand for coal. On the other hand, there grew up an appreciation of the importance of using coal properly which the wartime work of the Fuel Efficiency Committees has hastened so much.

Up to now these two tendencies have roughly balanced one another. At the moment it is clear that, although production is rising, consumption is outstripping it by far. It will be interesting to see whether this balance is regained. Reference has been made to the diversity of the uses of fuel, and the Programme of this Conference shows that new demands are already appearing. Who, for example, would have expected, a few years ago, that farming would be found among the major fuel-consuming industries? Yet that is now its position. Moreover it is clear that the heat and power needs of the ordinary household are going to rise very rapidly. The fascinating report of the Fuel and Power Advisory Council, which two sections of this Conference will discuss, describes the British home, in cold weather, as the "smallest in the civilised world". All the functions of family life are confined to "a narrow

half circle of warmth" in front of the sitting-room fire. Shall we remain content with this condition of affairs ?

In industry, the policy of full employment, the drive for greater mechanisation, the demands for better standards of lighting, heating, and ventilating the factory all require more fuel.

It is clear that there will be full employment for the fuel technologists also. Indeed, they will have to work overtime to increase efficiency if all these new benefits are to be secured. There will be no room for absenteeism. I can assure you that they will have the full support of the Ministry of Fuel and Power, not merely as a statutory duty but as a matter of firm conviction. I shall do everything to promote co-operation and happy relations between fuel consumers and the Ministry, which have been built up on the magnificent voluntary work so many of you have performed on Fuel Efficiency Committees, and which I am sure you will continue.

But the fuel engineer will need other help besides mine. In industry he must have the support of management and labour. On the domestic side, he must carry with him the architects, the housing authorities, and most of all, the housewives.

The success of fuel efficiency is conditioned by the measure of co-operation we receive. It calls for the active support and encouragement of all sorts and conditions of men—and I hasten to add of women—who, at any rate in the domestic sphere, can do much to mitigate the harshness of the short-term problem. Much depends on this Conference ; on its vigour, its capacity for direction, and above all on its courage in departing from the bad old ways.

There will be many speakers of repute who will address the Conference. I wish I could stay and hear them all, but that is impossible in present circumstances. However, I shall have the opportunity of attending the final session when the reports of the respective chairmen will be heard.

I shall, therefore, be able to leave you this morning with the deep conviction that you are ready to proceed with your discussions with enthusiasm, and that your sole desire is to place your skill and knowledge at the service of the nation.

**Alderman C.W. Key, M.P.,\*** spoke of fuel requirements in connection with the housing programme, with particular reference to space heating, cooking and the provision of hot water. The fuel now expended in providing for these services represented over one-third of the total consumption—a clear indication of the importance of efficient domestic utilisation of fuel. Notwithstanding this heavy consumption, domestic heating services in this country were lamentably inadequate. The new housing programme had presented an opportunity of remedying past defects. To this end, ways and means of implementing the recommendations of the report on Domestic Fuel Policy made by the Fuel and Power Advisory Council were already under active consideration.

While gas and electric appliances were reasonably efficient and priced within the reach of the lower income groups, much required to be done to improve appliances for burning solid fuel. Even though efficient appliances might be more costly than those hitherto in use, the difference would be recouped many times over by the resulting economy in fuel. Alderman Key added : " Much as we are concerned to keep housing costs down, we would not dream of cutting out an improved appliance from Local Authorities' plans merely on account of the additional cost." The chief difficulty at the moment

\* The verbatim text of Alderman Key's speech will be found in Vol. III.

was that of quick production, particularly in cast iron, and on that account Local Authorities were being asked to instal only one space-heating, solid-fuel appliance in each house, until sufficient new appliances were available.

Alderman Key referred also to the need for smoke abatement, to the importance of considering appliance design from the housewife's angle, and to the need for good thermal design of buildings, including thermal insulation. There was also much to be learned regarding district heating, to which a Joint Session of the Conference was to be devoted. Experiments in district heating were to be encouraged.

**Sir Clive Baillieu :** The purpose of this Conference is to stimulate interest and to promote a higher standard of efficiency in the use of all forms of fuel and in every field of utilisation. Such a purpose will attract the general support and co-operation of everyone. It is a mere truism to point out that our continued national prosperity rests on a basis which is predominantly industrial, and that our industry depends on the economic supply and the efficient use of our fuel resources. In this country we have no extensive water-power resources, though such as are available are being usefully developed ; nor have we succeeded in discovering any substantial supply of oil. It is therefore on the economic and efficient use of coal, and all forms of energy derived from coal, that we should concentrate as a vital factor in our programme of industrial expansion.

A relatively short time ago Lord Cherwell reminded us that in using our coal resources we are living on capital as distinct from income, and are banking on science to provide a substitute form of energy before these resources are exhausted. As a result of the subsequent and somewhat spectacular development in the field of atomic energy the production of such a substitute source seems more probable and measurably nearer than when Lord Cherwell's warning was given. It was reassuring to know that we intended to take a full share in the technical problems involved, just as we took an outstanding part in the fundamental research on which these developments were based. But whatever the future may hold in this respect, our urgent problem is that of making the best possible use of our available coal supplies. In the past, coal has been one of the very few indigenous raw materials that we have been able to produce in excess of our needs. The export of coal, as such, has been a very important factor in our home trade, but a consideration of even greater importance is that since the Industrial Revolution the abundance, quality and price of our coal supplies have enabled us to develop our iron and steel, engineering, shipping, textile and other industries, and to utilise the diligence and the skill of our technicians, craftsmen and other industrial workers, which thus became exportable in the form of manufactured goods and enabled us to import essential foodstuffs and raw materials.

During the last ten years, however, a dramatic change has taken place in the coal supply situation. At the beginning of this period we had ample potential production, and we were, in fact, seeking to expand our coal exports. Since that time the number of mineworkers and the coal output have seriously declined, and today our export trade has diminished almost to vanishing point. We are endeavouring, with the assistance afforded by the use of a proportion of opencast coal, and a limited importation of heavy fuel oil, to maintain a very precarious balance between the available fuel supplies and our minimum domestic requirements.

It is not my intention to deal with the economics of coal production, nor do I think it pertinent to comment on impending changes within the structure of the coalmining industry. I feel these matters are not within the scope for which this Conference has been convened. May I, however, be permitted to make a factual statement that at the moment coal is not only in short supply but the price to the average industrial user has increased by over 120 per cent. as compared with 1938. Now, either of these considerations would be extremely important, but taken together they provide a decisive reason for endeavouring, by every practical means, to ensure the greatest possible efficiency in the use of coal, for the greater the scarcity, the greater the need for using our limited supplies with the utmost economy, and the higher the cost of the product, the greater the necessity to restrict the effect of the increase in terms of coal cost per unit of product. It may indeed, I think, be said that our experience over an extended period and in different countries has shown that in conditions of scarcity high prices exercise a compelling influence in promoting economic use.

Developments of this kind in the field of industrial fuel practice may to some extent involve the installation of new or more elaborate and costly equipment, which in effect means the substitution of the labour of the iron and steel works engineers and others for that of the coalminer. This substitution may sound as if it is in the national interest at a time when we are short of mineworkers. It is not without significance that many important improvements in fuel practice have been evolved or developed in countries depending on imported fuel supplies. I venture to suggest that in its application to productive industry the national fuel economy campaign necessarily involves three essential features : first, the orderly distribution of available supplies of fuel with due regard to quality and price ; second, the provision by the consumer of equipment enabling the fuel to be used to the best advantage ; and third, the day-to-day operation of this equipment with the skill necessary to ensure the best practicable economy.

Now, in the allocation of available fuel supplies, it is, of course, quite erroneous to regard coal as a substance which can be supplied to any stores and used for any purpose in a completely interchangeable way. The informative and valuable survey work carried out by the Fuel Research Board during the past 25 years has shown in a very detailed and quantitative way the wide diversity of our coal seams within limited areas, and sometimes even within a particular mine. We have in this small island practically every type of coal, from surface bituminous to anthracitic coal, including some of the best quality coals in the world. But this very diversity, I suggest, may be an embarrassment unless proper discrimination is exercised in its allocation and use. Foreign buyers have often been in a privileged position here and able to enforce their requirements for the purchase of coal of certain specification and quality. In the home market, with only a few exceptions, coal for general industrial use has been sold in a much more empirical and less satisfactory way. I am well aware that the Minister of Fuel and Power is himself entirely sympathetic to the idea of rationalising the sale of coal in a way which would discriminate between different classes and qualities. I hope that one of the tasks to which the Coal Board will give early attention will be that of providing a system of description and classification enabling coal to be bought by industrial consumers, both large and small, more rationally and thus to be used with better knowledge. It is surely quite indefensible that coal, one of the most important materials used in industry, should be dealt with in a crude and empirical way.

An appropriate system of the kind I mentioned would be helpful to the coal supply authority in enabling different fuels to be evaluated on a quality basis ; it would be helpful to the industrial fuel user by assisting him more correctly to check and control the performance of the consuming article, and it would be of value to the community by helping to ensure that their available coal supplies are used for the purposes for which they are best suited. I am therefore delighted to note that one of the business sections of this Conference will be devoted to the consideration of a scheme prepared by an important committee of coal producers and users and designed to meet this particular purpose. The fact that Mr. J. C. Gridley, a member of the National Coal Board, and responsible for marketing, will take the chair at this committee is evidence of the importance attached to a practical and early solution of this problem.

The second condition I mentioned was that industry should provide equipment enabling fuel to be used to the best economic advantage. Here, I suggest, we have a field for continued and improved collaboration between Government Departments and industry which might lead to very important results. In a broad national sense we need to know much more about the fundamental requirements of industry for light, heat and power, and the alternative ways in which these requirements may be satisfied. Take an example by way of illustration. It is known that the quantity of low-grade heat needed for the warming of factory buildings is considerable, and that with the improved amenity standards this is increasing. Such low-grade heat can be and often is provided by by-product steam lines in works with considerable types of steam power plant, but in other cases, and particularly where power is developed and purchased with electricity, low-pressure steam boilers or water heaters are often installed for this particular purpose. I am glad to know that this subject is to receive detailed technical consideration during the proceedings of this Conference, as consideration of this kind may well provide a step in the direction of the distribution of heat for industrial purposes and uses under suitable conditions. You may be interested to know that at the Leicester factory of the Dunlop Rubber Company power and steam are purchased from the Leicester Power Station. That arrangement has proved entirely satisfactory, being reliable in operation and very economic in the use of fuel. Were such a system to be applied to other industries, and incidentally to large public buildings, it should result in considerable saving in fuel. Another instance which may be relevant is that at works where, owing to the particular circumstances, it is possible to generate economically a part, but only a part, of the total power required, under the prevailing conditions it is often very difficult for such works to obtain an ample supply of electricity for the public service except at a very great cost. I therefore venture to suggest that there may be circumstances in which it would be advantageous from the standpoint of fuel economy for arrangements of this kind to be encouraged and facilitated.

With regard to the installation of fuel economy equipment, and more particularly of devices which are relatively new and untried, I believe here there is scope for further useful work by impartial authorities, such as the Fuel Research Board, the British Coal Utilisation Research Association, and the Technical Division of the Ministry. It is certainly the case that in the past many devices for which extravagant claims have been made have been sold by attention to salesmanship rather than on intrinsic merit, and their installation has sometimes tended to discredit the real work of other appliances of very substantial value. With the exception of a very few large organisations, both

the Fuel Research Board and the British Coal Utilisation Research Association are much more advantageously situated and equipped for carrying out investigational work into the claims made for appliances of this kind than are individual industrialists. I suggest that if some suitable system of examination and certification could be established it would be of very real practical value in restraining the sale of the spurious and undesirable, and by directing invention and development into the most useful channels. In the use of fuel-saving devices it rarely, if ever, happens that any particular equipment is in every respect outstandingly the best of its kind. Power equipment requirements vary from place to place, and relative merit has usually to be decided on a balance of advantage. Here the personal contacts established by the technical staff of the Ministry might, I suggest, be turned to very useful account by providing impartial advice on matters of principle without, shall I say, intruding into the field of commercial competition or encroaching on the unrestricted responsibilities of the individual user for installing the equipment best suited to his needs.

Finally, there remains the perennial problem of making the best day-to-day use of the equipment provided. This is to some extent a management question involving the avoidance of the more obvious forms and causes of wastage by the development of a genuine fuel conscience, by the exercise of care and common sense, and by an intelligent appreciation by both works' officials and operatives of the fundamental technical principles involved. Experience of the educational work carried out under the supervision of the Ministry's Fuel Efficiency Committee has shown that there is a useful response to the right kind of tuition given in the right way. When it is remembered that the individual fireman may handle on his shovel a quantity of fuel the annual cost of which, at today's prices, is often more than £4,000, and that the difference between a performance of a given plant, when carefully operated, as contrasted with indifferent use may account for 5 per cent. or more in terms of the quantity of the fuel used, it is understood there is real justification for maintaining and intensifying the efforts so successfully made during the war. Savings of this magnitude are always important and may well be substantial in commercial operations. They are gained with difficulty and they may be easily lost by apathy or neglect. In the larger works, where the cost of coal is high, the appointment of a technical official responsible for the supervision of fuel practice is clearly desirable, and every practicable step should be taken to ensure that a sufficient number of suitably qualified men will be available.

The interchange of data between different works in the same industry has been found to be helpful in stimulating interest and a certain healthy rivalry. Where fuel consumption can be related to output in terms of such quantities as the number of sacks of flour, tons of paper or barrels of beer, this comparison provides a useful indicative starting point for more detailed examination, and although such a comparison is not always strictly accurate because of differences in the technique of processes as carried on in different works, I suggest the broad outlines are usually sufficiently well defined to justify a comparison, and, even more important, the method of such comparison is itself an incentive to the important achievement we all have in view. Economy in the use of fuel is not just a temporary vision or passing phase arising from difficulties that are likely soon to disappear; it is a vital necessity which must have a prominent and continuing place in our plans for future development, and I therefore warmly commend its importance to all concerned. Mr. Shinwell

today has set us a target and issued a challenge. Let me say I am confident that British industry will bear its full share in the tasks that lie ahead.

**Lord Citrine :** I have come here at the request of the British Trades Union Congress. That is evidence of their sustained and cordial support for the Fuel Efficiency Campaign. It has been the habit of the Trades Union Movement for many years past, particularly at times when our country was faced with grave emergencies, as occurred during the last war, regularly to come together with the employers and the Government to collaborate and to explore how they best can contribute to the well-being of our country. It is in that capacity and with that purpose that the Trades Union Movement has asked me to come here today.

We knew perfectly well, as did the Coalition Government, as did our friends of the Federation of British Industries on whose behalf Sir Clive has spoken this morning, that after the war there would be a period of continued difficulties in the transition from war to peace. That period was variously estimated as being from two to five years, and it was foreseen that within that period there would be a series of shortages of greater or lesser degree the effect of which would be to hamper our economy, both nationally and internationally. It is not surprising that we are facing some of the consequences of that shortage, and while I pay my highest tribute to the self-discipline of the British people, which has so patiently withstood restraints and restrictions at a time when every natural aspiration was in the reverse direction, I say we are comparatively fortunate in the aftermath of war to be experiencing nothing worse than we are experiencing now. Social observers would have told you during the war, that we should be lucky if we got through without extended disturbances, political and otherwise, on the continent of Europe, and I myself, as a student of affairs in this country and elsewhere, have been agreeably surprised that they have not been more deep and that their consequences have not been worse.

That is not to say they have not been bad. Except one or two privileged countries, who may not be feeling the pinch to the extent to which it has been common in Europe, every country in some degree or other is experiencing the aftermath of war, and here when we come to face for the second winter in succession the problem of how our people are to get through the approaching few months with a minimum of discomfort, regarding everything in perspective, I am sure we will face it with the same calm discrimination with which we try to resolve our difficulties, and in a spirit of constructive helpfulness all round. We have been told of the increased demand which is being imposed from the supply authorities ; that is something about which the average man or woman knows very little. It was to be expected, in the nature of things, that our people would want brighter cities and brighter homes, better lighting after the long period of the blackout. It was to be expected that individual restraints which had been so tense during the war period, would be relaxed during this period. So it is inevitable that we have in one way or another an increased demand, not as a consequence of waste or anything of that kind, but as a natural desire of the human being to have a little bit more comfort and a little more happiness, particularly in their home surroundings, than they have had during these past six and a half years. Increased demand, therefore, is the consequence of peace. We lived in very narrow and restricted circumstances during the war, and I wish we were in a position to give full vent to the desires of our people to live under a proper peace-time economy. I know that is not possible, and every man and woman here has the responsibility upon him or



her to explain the reasons, if they can, as to why once again the people will be asked during these months, not to make sacrifices, but to restrain their natural impulse to take things a little bit more easily, and to live a little bit more comfortably than they have been doing.

The purpose of this Conference is mainly to create greater efficiency in the use of fuel, and we all know quite well that in the use of coal as a fuel we have only just touched the fringes of the efficiencies which may ultimately be expected. I do not know what the scientific estimate is of the overall efficiency which is today obtained with coal, but I am perfectly sure it would be astounding if people knew it ; if it exceeds 30 per cent. I should be very much surprised. One must take one's hat off to scientists and technicians who have produced the results that have been reported here this morning, but if we apply ourselves most diligently to the devising of better appliances for the use of fuel, it will still mean that the basic efficiency which is left is the efficiency which the individual can achieve. Efficiency in substance means getting the best out of the products that one is using, avoiding waste of the products in other words ; and that is something to which everybody, in greater or lesser measure, can contribute. I am not expecting any miracles to be forthcoming in the next few months as a consequence of the deliberations here, but I am quite sure that on the long-term policy, and in their effect on the wellbeing of this country, the deliberations will be of the highest importance ; their outcome cannot fail to be important, enabling our people to use the precious reserve that we have in this country with greater care and better results than anything we have achieved in the past.

Nonetheless, it is to economies in the main that we must turn. The Trades Union Congress, like many other organisations, is in the position of having members who are at once producers and consumers, and it has six million members who with their wives and their families form a very formidable section of our community. If they can be convinced, both as producers and as consumers, of the vital need for economy, I am perfectly sure that none of us would need to have any anxiety as to the immediate future in respect of fuel. That is why I hope that when the cold weather comes along, when the tendency will be to put on the electric fires a little earlier or light the stove or switch on the lights, everyone will try, by example as well as by precept—and that requires some self discipline—to remember the deliberations held in this hall, and to remember that high above the efficiencies which can be promoted by better devices lies the simple means of not using current and not using fuel if you can possibly avoid it.

So I would deem it the mission of the Trades Union Congress to convey to its membership the necessity for proper and adequate economies. This is not the first time that the Trades Union Congress and the Employers' Organisations have been associated in an effort to save fuel. The fuel watcher system has proved its value, and the resuscitation of that system in the forthcoming winter, more than any other single factor to my mind, will have the consequence of saving the fuel that is so greatly needed.

There will be Trade Unionists who will say, "The position is different now. During the war any economies we made were in the national interest. In those days the Government, in substance, was the owner of the factories and the shipyards where this fuel was used, but now we are back to peacetime economics and every economy we make is an economy that goes into the

employer's pocket. Why should we be expected as workers to make a contribution of that kind?" I am perfectly sure that an effective answer will be given to that reasoning by the Trades Union Congress, and its many affiliated organisations. The Chancellor of the Exchequer still casts a vigilant eye towards incomes. But apart altogether from that, it is perfectly manifest that any saving that is made in fuel is a saving of the most precious asset that we have in this country. Our coal resources are not inexhaustible by any means. Nobody would attempt to forecast what might happen in 100 or 200 years' time, when our resources have altogether diminished or may be approaching exhaustion. Some bright genius may discover a completely new form of energy. We may be on the eve of that now with atomic energy. But coal will remain for many years to come the foundation upon which the industries of this country base their prosperity and their hopes of prosperity.

We no longer export coal, and that at a time when emphasis, and proper emphasis, is being placed on the fact that if we do not export we cannot hope to import those commodities or basic materials which will enable us to get that higher standard of life and that better conception and that better opportunity that peace should bring with it. So I say to the Trade Unionist who feels he is doing the boss a service by exercising economies and keeping his eyes open against waste, that he is doing himself and his family and his country a service by such vigilance. The Trades Union Congress and the Employers' Organisations during the war established what were called Production Committees. The primary purpose of those Committees was to see if they could facilitate the production of munitions. Many of these are still in operation and it is to those joint committees of employers and workpeople that we must look if we are to succeed in getting that co-operation which will make the fuel-watching system inside the factories a real and substantial success.

There are many ways in which economies could be made without hurting anybody. Two examples have come to my notice. At an aircraft factory, one hundred and seventy 300-watt lamps were discovered burning unnecessarily in good daylight during the lunch time together with a battery of fifty fluorescent lighting units, representing 40,000 watts. A fuel survey showed that normally 20,000 to 25,000 watts of electricity could be saved during daylight working hours merely by switching off unnecessary lights. At another factory which was visited during the lunch time a very large number of lamps was found on in isolated shops. In one shop lamps consuming 300 watts were burning, and in another shop there was a similar waste of 60,000 watts. That is not merely something demanding economy, but much stronger action than that. I hope the time will never come when we shall resort to coercion rather than persuasion to get our people to observe proper standards, but nobody can justify that sort of waste at a time when the country is anxious about its fuel position and at a time when it is quite possible that it might be necessary for services to be curtailed with a consequent loss of production, and with the still further postponement of those good days of prosperity for which we are all hoping. Therefore, where we can save from obvious waste we ought to do so, every one of us, and feel it a duty and something we are performing on behalf of the community as a whole.

The T.U.C. is running a series of conferences in different parts of the country to which representatives of the Fuel Efficiency Campaign will be invited, and there we hope to get over to the individual men and women a clear understanding of the depth of the problem and the necessity for the part

that they can play in relieving the difficulties. I hope that in this direction, as in all others, we shall carry our co-operation to the maximum extent. I am quite certain that in this country of ours these difficult years have been got through up to now with such little friction because of the tendency of the British people to combine in the hour of emergency and to sink their differences in some common objective, and I hope it will be realised that this winter we are going to face is another of those contingencies raising its ugly head at this period when we had hoped for so much. I am confident that the deliberations of this Conference will contribute in no small degree to helping this country not merely to face the contingencies of the many months ahead, but the problems of the years to come.

[The Session then concluded]

# FUEL AND THE FUTURE

## CLOSING SESSION

*Chairman:* The Rt. Hon. EMANUEL SHINWELL, M.P.

MINISTER OF FUEL AND POWER

**T**HE CHAIRMAN: There is general agreement that this Conference has proved its worth in spreading a wider knowledge of the facts, in the presentation of new ideas and in the recognition of the vital part that fuel efficiency methods can and will play in maintaining and improving the industrial prestige of the nation. It would be a mistake for this great Conference to separate without being placed in possession of the real facts about the fuel position. That does not require a long and detailed speech from me.

It has been suggested that only within the last few days have the Ministry of Fuel and Power realised the possibility of a grave breakdown in fuel supplies. Such a suggestion is misleading and a complete perversion of the facts. For many months we have repeatedly directed attention to the gravity of the situation, but at the same time have taken every possible step to improve the position. Not a single idea has been rejected if it seemed to offer a practical solution and every possible device has been employed to safeguard the position. The scientific associations, fuel technologists, public utility authorities, independent experts, mining engineers and mineworkers have all been consulted in the hope of reaching a satisfactory solution. There has been no lack of co-operation.

Moreover, the search for additional labour in the mines in order to repair the weekly wastage, which is considerable, has been persistent. But here we suffer from years of disparaging and gloomy propaganda. Now the process must be reversed and we must demonstrate that coalmining can be made safer and more attractive and offers opportunities for engaging in an essential and honourable calling.

The other important factor, which has been fully appreciated by the Ministry of Fuel and Power for over twelve months, has been the steady rise in consumption. In gas and electricity, but particularly in electricity, the rise in consumption compared with 1938 has been phenomenal and, coupled with shortage of plant, the position is disturbing. It is because of this exceptional rise in consumption that we are compelled to ask for the exercise of economy and the elimination of waste. But it is not the first time we have asked for it. There has been a persistent campaign directed to this objective. Leaving exports aside—and no one is more anxious than I am to revive our export trade in coal—what stands between us and the provision of all the requirements of inland consumption, based on the present trend of coal production, is a little more than another 100,000 tons a week. Again I must repeat that the present labour force, provided we can repair wastage, is capable of producing sufficient for our purposes. But if they are to do so, they must be encouraged and not criticised by some whose criticism appears to be directed not to improving the position in the interests of the country, but which savours of prejudice. Deep coalmining is hard work and must be recognised as such.

But at the same time the needs of the nation must be met, and I say to this Conference in a word, the newly-appointed members of the National Coal Board, represented here by my old friend and colleague, Lord Hyndley, who will be in charge of the industry very shortly and who are entrusted with the task of reorganising on modern lines this great industry, must receive the utmost encouragement and goodwill. This fuel problem must be solved, and, in spite of many difficulties—most of which are not of our making, but derive from a disordered and ugly past—we are determined that it shall be.

(At this stage, the Chairman of each Section briefly, in remarks restricted to six minutes for each speech, summed up the principal conclusions that had emerged from the discussions of his Section. These speeches will be found at the conclusion of the proceedings of the Section over which the speaker presided.)

Dr. E. S. Grumell then dealt with the Conference as a whole. He welcomed the report on the Sizing and Preparation of Coal discussed in Joint Session No. 1\* as going a long way towards removing the confusion previously existing and as materially contributing to a higher efficiency in the design and operation of appliances.

The District Heating Session was attended by over 2,000 people. The potential advantages of District Heating were beginning to be more fully appreciated. There was still doubt about the actual costs and many speakers had suggested that a number of these schemes should be undertaken so that the cost could be ascertained by experience. This would involve considerable delay and Dr. Grumell believed that the papers submitted had made out a strong case for the application of District Heating to reconstructed or newly built areas, and would justify an element of risk.

Dr. Grumell thanked the Sectional and Sessional Chairmen, the authors of the papers presented to the Conference, and the staff of the Fuel Efficiency Branch of the Ministry who had organised the Conference in so short a time as six months.

Dr. Grumell gave the Conference three objectives. These he stated as follows:—

*Short Term*

(1) *Fuel Watchers*.—The system of fuel watchers to be immediately and greatly expanded. We agree with the Minister when he said:

“I believe that the best chance of making the necessary savings quickly is to revive the enthusiasm of the Fuel Watcher system. First among the fuel watchers, we place the housewives.”

(2) Is there any other particular object on which we could concentrate immediately to effect substantial savings fairly quickly?—Yes. We believe that an all-out drive on combustion efficiency in shell type boilers and similar plant would reduce consumption to the extent of 2–3 million tons within a few months.

*Long Term*

(3) *Fuel and the Future*.—It is quite evident from the subjects discussed at this Conference that in many directions, both industrial and domestic, developments of major importance are impending. It is also obvious that many schemes which in the past have been rejected when coal was cheap are now due for reconsideration. It is the opinion of my Committee that,

---

\* Reproduced in Volume II of these Proceedings.

given a concentrated and co-ordinated effort on the part of everybody, requirements for equal productivity could within the next five years be reduced by 20 million tons.

**The Chairman :** I have very much pleasure in calling upon my colleague the Rt. Hon. Sir Stafford Cripps, the President of the Board of Trade, to make a final contribution to the Conference. His is the responsibility—and it is a high responsibility—to speed the conversion of British industry from war production to peace production so that we may have the consumer goods of which we have been deprived for the last six years, and so that we may deliver the exports without which we perish. Sir Stafford, I have no doubt, is as anxious as I am that this conversion programme should not be held up for lack of fuel and power. I think he must have appreciated, from the remarks of the preceding speakers, that this Conference is not only determined that that shall not happen but has formulated plans to achieve that end.

Sir Stafford is to speak on fuel efficiency in relation to production, and I expect—I hope this is not asking too much of him—he will make it clear how large the production programmes are, and therefore how great are the additional demands for fuel that will be collated.

**The Rt. Hon. Sir Stafford Cripps, K.C., M.P. :** The Minister of Fuel and Power has called upon all of us to make a general increase in fuel efficiency of the order of 10 per cent. in order to meet the very real danger of a fuel shortage that confronts us during the course of this winter. He also expressed the view—with which I agree—that the proper planning of the use of fuel is not merely a measure to meet an emergency but is an important factor for economical production to which we must all of us pay attention in the future. It is unnecessary for me to tell you how strongly I support Mr. Shinwell in these matters, and in the appeal he has made particularly to industrial users. So far we can, I think, congratulate ourselves upon the smoothness of the change-over in this country from wartime to peacetime production. When you have to transfer about seven million workers in twelve months from one lot of jobs to another, and at the same time switch-over the use of all your raw materials, or most of them, you expect to be in difficulty, and you cannot hope to arrive at an accurate balance between the materials, capacity, and labour. That is why I say we have done very well in our switch over, and though we have not of course achieved all that we should have liked to achieve we have, both as regards home consumption and exports, made a good start, a good start towards reaching a point where we can restore our pre-war standards of living in the home market first by increased production of goods for that market and secondly by sending out sufficient export goods in order to enable us to maintain the essential flow of imports.

I say we have made a good beginning, but it is only a beginning, and it is in the light of that fact that we have to look at our fuel consumption today. We are still deficient in supplies of all kinds in the home market. Despite the banked-up demands, we are still producing for the home market only about three-quarters of our pre-war output of clothing and footwear. Our rate of furniture production in the second quarter of this year was only about 60 per cent. of what it was in 1935. In exports we have reached the pre-war volume, which means that in order to restore the pre-war volume of imports we must increase our present exports by 75 per cent. in volume, and that is a tremendous task. If you add to all these jobs our housing and building undertaking, you

will appreciate the fact that we are trying to do almost more than is possible, and certainly more than is possible unless we can achieve the highest point of productive efficiency.

All this assumes that our objective is merely to get back to the standards of 1938. Of course we want to do much better than that. We want to provide better and warmer houses for our people, more pleasant working conditions, better education and health services, and so on ; and every one of these means more heat and power. Fuel and power are the essential foundation for modern industrial production and for the comfort of our people.

There is only one way in which we can possibly meet this ever-growing demand for production of every kind, and that is by increased efficiency in production. We have neither the manpower nor the materials to be able to proceed upon anything like the basis of our pre-war production. Unless we can achieve a really marked advance in production efficiency there is not the least hope of raising the standards of our people above pre-war levels, and it is very doubtful whether, in view of the absolute need to achieve a balance of payments abroad, we can even maintain that pre-war standard at home.

One obvious way in which we are always attempting to increase our efficiency of production, that is to enable fewer people to produce more goods at a cheaper price, is by substituting machines for manpower. Mechanisation is the basis of mass production, and we have not yet, of course, gone anything like as far as, for instance, the United States of America in that direction. It may well be that we never shall go quite as far as they have gone, because of the difference in our home market and to some extent in our export trade, but we shall certainly have to go much further in the mechanisation of our industries, and that means, of course, more fuel and power. Between 1930 and 1939 we in this country increased the horsepower used per industrial worker from 2·8 to 3·5. In the United States of America it was 6·3. That shows that we still have a long way to go.

To sum up the future requirements—and they are in the immediate future, not the far distant future—we need to produce more goods for the home market and for the export markets in order to maintain our standard of living and ultimately to increase it, and that is only possible by increasing greatly our efficiency of production because we have substantially no more surplus labour available, and almost every step to improve conditions or economise in manpower means the use of more fuel and power.

Perhaps I may add what is almost like an absurdity today, and that is that we badly want to start up again our export market in coal. As it is, we have to make up on the other goods what we have lost in the coal export trade compared with pre-war years. However, that for the moment, no doubt, is out of the question.

You have had from the Minister a forecast of the national production situation, and taking production at the level at which it is today it is clear that not only is there no spare fuel but it is touch and go as to whether we shall get through this winter without some hold-up either of domestic or industrial supplies. If at this stage of our re-conversion and of building up our exports we suffer from an interruption in industry due to fuel and power shortages, it will be the gravest thing for our future national industrial prospects. Apart from the grave discomfort to the workers, who would have to suffer the dislocation of production and unemployment, it would have the most adverse effect upon our export markets at a most critical time, and further it would mean

an even smaller supply of consumer goods in our home market than that which is now coming forward.

There is only one way in which industry can help that situation, and that is to economise in all forms of fuel and power, so that the same production, or a greater one, can be secured by the use of a smaller quantity of fuel.

Fuel and power like labour, before the war, were in plentiful supply, and though many firms were careful in their use there was not that meticulous consideration which is necessary to combat an acute shortage such as we have today ; and perhaps in fuel and power, as you have heard from the Reports of the various Chairmen of the Committees, there is more scope for economy than in almost any other way in the factory. The economy in cost may not always be spectacular if we are saving 10 per cent. of our fuel or power, but we are not looking at it for the moment as a question of costs, but of the preservation of a very scarce and valuable national asset. As a matter of fact, fuel economy is a very good investment, even looked at from the purely financial point of view. Often the total capital cost of fuel economy can be written off in two or three years by the economies achieved. Some of you may remember that on one or two occasions during the war, for special reasons, sudden cuts had to be made in the use of fuel and power, either in special areas or throughout the whole country. I remember those occasions very well, for at that time I was responsible for a rising programme of aircraft production, and a cut of 10 per cent., which was made on one occasion, in gas and electricity used by my factories looked to me as if it must be quite disastrous to my programme. However, there was nothing to be done about it because the fuel was not there. We did our best to help, industrialists did their best to help one another, the workers did their best too. In many factories joint committees of management and workers were set up to study fuel economy and put measures into operation. And what was the result of it all ? There was not even a kink in the upward curve of production of aircraft. We fulfilled our programme completely—and, as I afterwards told many of our manufacturers, it just showed how wasteful they had been before, and I thought the Department deserved some commission on having shown them how to save 10 per cent. on fuel and power costs.

If that can be done in wartime, why should not we repeat that effort—and of course it is an effort—now ? There is today a potential threat of stoppage overhanging every factory due to the narrow margin of stocks. The cost and trouble of such a stoppage are far greater than the trouble of economising in fuel and power, which far from being a cost is, of course, a saving. There is, of course, no chance of increasing production unless we can do it on the basis of using no more fuel or power.

I think the success of this Conference shows that there is a real interest in this problem of fuel economy and fuel efficiency. Of course, the introduction of fuel efficiency and the saving of fuel does not mean that we must cut down the degree of mechanisation or the amount of power used. That would defeat our aim of saving manpower and of getting more efficient production. It is often, indeed, quite possible to increase the power consumption per worker and yet decrease the fuel consumption per ton of product. In fact, in many cases it has been reduced, especially where the fuel was largely used in the form of heat. Let me give an example of the replacement in the biscuit industry of the old draw-plate ovens by modernised travelling ovens. Here the power consumption due to mechanisation is higher, but the rate of production is



much quicker, and so the fuel requirements per ton of biscuits are actually reduced by one-third. The same applies of course in an example which has been quoted, for bricks and pottery in tunnel ovens, but it is not only where heat is a large factor in production that economies can be brought about. Useful results may be achieved by careful planning of fuel efficiency wherever fuel is used. In 1942, when the fuel economy drive was on, one firm in the pottery industry, with a highly efficient production side, was found not to have the same efficiency on the steam utilisation side. With the co-operation of the Ministry of Fuel advisers, alterations were carried out by which in the first year 1,000 tons of coal were saved, and at the same time the output was increased by nearly 10 per cent. There was another case of a general laundry where a saving of 21 per cent. of the fuel was effected without any decrease in output at all. Very often indeed these fuel economy measures are actually the means of achieving greater efficiency in production. Take an interesting case of a nail factory. There the fuel consumption was reduced from 25 to  $7\frac{1}{2}$  cwt. a day, with a doubling of production due to the elimination of delays because of the former inefficient methods of heating the material.

I only cite these cases as illustrative of the enormous field that lies open before us, a field in which there is now a highly specialised technique drawn from a great volume of experience.

The truth is that all forms of efficiency march together. The mere fact that fuel efficiency is studied and encouraged is a great inducement to production efficiency, and vice versa, so the Minister of Fuel and Power and the President of the Board of Trade go hand in hand in this joint campaign for efficiency.

In order to achieve that efficiency there are certain things that we must do. First, we must watch with never-ending persistency. We must chase the squanderbug of waste out in every manner. It is a sort of spring-cleaning process in the best Victorian tradition.

Second, we must always be on the alert to discover new ways and methods of economising ; that is to say, we must see to it that there is constant research.

Third—which is not easy—we must see that the results of research and technical developments are rapidly put into operation in industry.

Day-to-day control—or rather hour-to-hour control—requires good team work throughout the unit. Here the production or works committee can give the greatest assistance, for it is the man working on the floor who both sees the opportunity for saving fuel and power and also is the person who can do most of the wasting. That is why the whole factory team must be brought into this question of fuel economy. We experienced during the war on the occasions that I have mentioned the very remarkable results that could be brought about in the way of economy where the energy and enterprise of the whole personnel were enlisted on the job.

I know, of course, that many of you must be conscious that you have plant in your works which is not the last word in saving fuel and power, and that many of you would gladly change it if you had the opportunity. That state of affairs is, alas, the sequel to six years of war, and particularly of course applies to those civilian industries which were stepped down or concentrated during the war ; but that puts an onus on everyone to operate whatever plant they have at the highest degree of efficiency of which it is capable, and often small alterations or changes, changes of method, may produce quite remarkable results, as in some of those cases I have cited.

What we are looking for is not some spectacular economy in a few large installations, but a general cutting down of waste and improvement of efficiency at every point, each perhaps yielding only a small result but in the total making a most significant contribution.

Mr. Shinwell has mentioned to you the remarkable results that were achieved by fuel watching in the war years. Lord Citrine, on behalf of the Trades Union Congress, has told you of the encouragement and support that they are giving to this guard against waste. Employers, too, are helping the Ministry of Fuel and Power in this way. So what I am asking each individual firm to do is to revive and intensify its fuel-watching service at the earliest possible moment. Time is of the essence of the effort, for it is particularly as regards this coming winter that we are anxious and that you, too, are most of you anxious as well.

We do not want to lose production, and you do not want your works stopped by a shortage of fuel.

So much for the immediate problem, but this is a long term problem as well, not only because of the shortage of fuel and power but also because in the over-all efficiency of production and in the reduction of factory costs the saving of fuel and power plays a growing part. With the increased cost of fuel—which has, alas, probably come to stay—it is essential that we should work out every device that gives a saving. We know that our scientists and technicians led the world in the developments of wartime. What we now want is to switch that inventiveness and ingenuity to the service of our peacetime production, and not least to the campaign for permanent fuel economy.

I hope that a new attitude towards research and researchers will inspire our post-war production drive. I am sure that there is now a much more general recognition of the fact that efficient production must be based on sound research, and I trust that those who carry out this work of research will be given full recognition and a proper status in industry. Too often in the past that terrible phrase “back-room boys” has been a reality as regards the facilities given for research, and the rewards offered to those who devoted their lives to this essential work were far too meagre to attract and keep the best brains.

Then comes the final point of translating research and development into actual terms of industrial production. It is said of one very famous research institute in this country that the average time taken to get the industry to adopt the results of research is 16 years. That may be a slight, but only a slight, exaggeration, but it typifies the great difficulty in transferring results from the research and development establishments to the floor of the factory. This period must be reduced drastically if we are to maintain a lead in world industrial production, and the way to reduce it is to have a much more close and intimate liaison between factory staffs and those of the research establishments. It is this free exchange of experiences which is so essential, and that has been one of the great values of this Conference, at which you have been able to hear from research workers what they are doing and have done, and also at the same time they have been able to get an intimate contact with industrial needs and difficulties.

Those of you who are industrialists will have heard details of the work of the Fuel Research Station, of the Building Research Station, of the British Refractories Research Association, and about the great research that has been done upon materials like glass, non-ferrous metals, and so on, as well as about the latest fuel-burning devices of all kinds.

What I now ask you to do is to go home and make use of all this knowledge. Do not let it get pigeon-holed either in your minds or in your desks. Do not look upon this Conference as merely one further interesting experience, but rather as the beginning of an active campaign within your own plant to carry into practice the good ideas that you have culled at the Conference. In the same way, too, the research workers will go back to their tasks refreshed by contact with the problems of industry, with a realistic appreciation of what needs to be worked out, and I hope encouraged by your response to their efforts to go forward to further discoveries and inventions.

The Fuel Efficiency Committee and the Fuel Efficiency Advisory Service of the Ministry of Fuel and Power are to be congratulated upon the work which they are doing by translating technical knowledge into industrial practice, and this Conference is one very good example of how they are seeking to accomplish that end.

These forms of co-operation between the Government and industry must be welcomed by everybody, and it is clear from the success of this Conference that they have become an accepted part of our industrial structure, at least in the field of fuel efficiency. I would like finally to reinforce the appeal made by the Minister of Fuel and Power from my own point of view as President of the Board of Trade and as one intimately concerned with the volume of industrial production. I trust that each one of you will make the fullest use of all you have learned at this Conference, and that you will make it your objective to plan your fuel and future upon the basis of the maximum attainable efficiency.

This is a great service that you can perform for our nation and our people in the most difficult months that lie ahead of us. You can help us as effectively now in winning victory over the problems of peacetime production as all of you did to work out that marvellous wartime production which enabled our serving men and women to win the war.

The Chairman thanked all those who had worked to make the Conference a success, and expressed his appreciation both to individuals and to representative bodies whose assistance had made the gathering possible. He concluded :

“This has been a great Conference. Let us hope that as a result of our deliberations we shall be able to surmount, not necessarily for the Government, not for the Minister of Fuel and Power, nor for the Ministry, but for the Nation, the difficulties that now present themselves. Should we do so, as I trust we may, it will redound to the benefit of all.

“The Conference is ended.”

TECHNICAL SESSIONS OF THE CONFERENCE

SECTION A

THE GENERATION OF STEAM

*General Chairman:* SIR JOHNSTONE WRIGHT

MEMBER OF THE FUEL EFFICIENCY COMMITTEE, AND GENERAL MANAGER  
OF THE CENTRAL ELECTRICITY BOARD

SESSION I. The Availability of Water-Tube Boilers

*Chairman of Session:* SIR JOHNSTONE WRIGHT

**T**HE CHAIRMAN: Great Britain has always led the way in the design and manufacture of boiler plants for export and home use, and the development of large units brought in train many special problems. The problems to be faced in Great Britain are difficult because the geology of our coalfields is such that fuels of every known variety are mined within quite short distances of each other. I would like to record that British manufacturers have devoted large sums of money and the services of designers and technicians to study our special problems. Much has been done, and I believe it is true to say that the British manufacturer has probably in his possession today more advanced technical data on this subject than manufacturers abroad.

The national importance of obtaining high boiler availability will perhaps be more appreciated if a brief review is given of the rapid development in total steaming capacity of plant used for electricity generation over the period from 1919 to 1946, together with some indication of the estimated increases over the next 12 to 14 years.

When the Electricity (Supply) Act, 1919, was passed, a 50,000 lb./hr. boiler was considered a large unit. During the interval between 1919 and 1926, in which year the Electricity (Supply) Act (based on the recommendation of the Weir Committee) was passed, municipalities and power companies were anticipating a rapid expansion of the electrical power requirements of the country and in association with manufacturers developed designs for boilers and generating sets of greatly increased capacity. By 1926 there were a few boilers in operation of about 160,000 lb./hr. capacity.

The construction of the Grid system during the years 1927-1933 enabled a large proportion of the spare plant capacity installed in the country to be effectively pooled, and for a time this had the effect of retarding the rate of installation of new plant. Between 1933 and 1939, however, a number of large plant installations were commissioned and operated under interconnected conditions on the then new Grid system. The operation of a large number of interconnected generating stations revealed, however, that a serious divergence existed between the availability of the turbo-alternator and boiler plants. Under the new conditions of operation, the boiler plant was called upon to

work at much higher sustained loads than under independent operation, and investigation showed that the lack of availability was largely caused by fouling of the furnace and heating surfaces of the plant. In 1938 it became necessary to de-rate quite a number of boiler plants by as much as 15 per cent., which in the aggregate meant a loss of about 250,000 kW on the interconnected Grid system.

By 1939 it was deemed necessary for discussions to take place between representatives of the industry and the manufacturers, with a view to bridging the gap which existed between the availabilities of turbo-alternator and boiler plants, and this finally resulted in the setting up of the Boiler Availability Committee, under the chairmanship of Mr. Adams. The committee comprises power station engineers and chemists, design and technical staff of the boiler manufacturers, the British Coal Utilisation Research Association, the Fuel Research Station and the Central Electricity Board.

Although the war naturally impeded large scale investigations in the field, much valuable work was accomplished in the laboratories. At a little later date, through the continued help extended by the manufacturers and others, these activities in both the field and the laboratory were materially increased and most valuable data were collected relating to the fundamental causes of formation of deposits on the heating surfaces and the cleaning of deposits from the heating surfaces.

As a result of this evolution of efficient cleaning methods, a very material increase in availability has been made, the period of commercial operation in many cases having been improved from around 700 hours to around 5,000 to 6,000 hours without the boiler having to be taken off for hand cleaning of the heating surfaces.

In both the war and post-war periods, there has been a definite deterioration in the quality of fuels delivered to large power station boiler plants. A steadily increasing ash content has accentuated the difficulties of the operating staff in maintaining boiler availability, which is of national importance at the present time of serious shortage of plant and the consequent need to get a continued rated capacity from the plant installed.

The rapid development of the national electricity load is established by the estimates for the current year representing a maximum demand of over 10 million kW associated with the consumption of over 34,000 million units. Some 23 million tons of coal will be consumed in the boiler plants at stations under control of the Central Electricity Board, aggregating about 135,000,000 lb./hr. evaporative capacity, and ranging in size from an average of about 175,000 lb./hr. to a maximum of 550,000 lb./hr.

Mr. Adams, Chairman of the Boiler Availability Committee, and a generation engineer of long experience, will demonstrate that thorough cleaning of the heating surfaces at appropriate intervals is vitally necessary to the attainment of high availability, and will indicate how operation control can assist in achieving both long hours in commercial service, with a saving in our national fuel resources.

Another speaker will deal with the problems of cleaning boilers under steaming conditions, stand-by, or during overhaul periods. Others will show how investigation has established that the distillation of incombustible volatiles takes place from the high temperature coke zone and that these, depending on their chemical structure, sublime on the heating surfaces, each selective as to temperature, and provide the necessary sticky film for continuously binding

the entrained dust traversing the boiler passes. The design trends of large modern boiler plants operating under high pressures and temperatures will then be dealt with, showing how modifications to furnace design and the disposition of the heating surfaces and their associated sootblowing equipment can assist in attaining high availability and saving of fuel.

The importance of the whole of this work cannot be too highly stressed if we are to make the best possible use of our fuel resources. Much can be done with respect to increasing the availability of existing plant by the methods recommended by the committee.

Finally, as preliminary investigation would indicate that during the next 12 or 14 years boilers having an evaporative capacity of approximately 15,000,000 lb./hr. will have to be installed annually in the large electricity generating stations in this country, it will be clear that the continued efforts of the committee in all its phases is a matter of real national service.

Before calling on Mr. Adams, I would like to pay tribute to the splendid team spirit which has existed between the boiler manufacturers, the electricity supply industry, the Fuel Research Board, the British Coal Utilisation Research Association and the Central Electricity Board throughout the investigations, the results of which have proved to be so beneficial, both from a fuel efficiency and improved boiler availability point of view.

Improvement in availability means greater production for the capital employed and better use being made of manpower that has been spent in the manufacture of the boiler plant. This, surely, should be the aim of all connected with industry if we are to compete in the world's markets. Prior to the work of the Boiler Availability Committee, the amount of capital lying idle due to the boiler plant being out of commission for hand cleaning of heating surfaces, tubes, superheaters, economisers, etc., had reached serious proportions.

## 1. Remarks on Boiler Availability

By M. H. ADAMS, M.I.MECH.E.

The Boiler Availability Committee has been asked to give an account of its work and progress in connection with boiler deposits and corrosion. It is impossible, in the time at our disposal, to give any idea of the tremendous amount of work which has been done by and for the committee or the extent of our knowledge of deposit formation. We can only give a very brief summary of the work and for further details must refer those interested to the publications made from time to time by the committee.

When we commenced our work, very little was known of deposits or the mechanism of their formation. Today, we cannot say that we have solved the problem which was presented to us but we are well on the way to doing so and there is no doubt that we in this country know far more about this subject than any other country in the world.

An account of the formation and functions of the Boiler Availability Committee has been given in Bulletin MC/131, which was distributed by the committee to the owners of all selected power stations in September, 1945. It is, therefore, unnecessary to go into past history on this occasion, beyond stating that the formation of the committee was entirely due to the initiative of Sir Johnstone Wright. The committee has been financed largely by the

Water Tube Boiler Makers' Association, and the supply industry owes a debt of gratitude to this Association. The committee has received valuable support from individual boiler makers and their staffs.

The work of the committee is twofold. Firstly, it has a short-term objective which is to find means for improving the present low availability of boiler plant, due to external deposits, and secondly, it has a long-term objective which is to try and find the fundamental cause or causes of this unfortunate affliction.

The committee has given an account of its progress in the short-term work in Bulletin MC/131, already referred to, and its progress in connection with fundamental research will be given in an Interim Report in the form of a further Bulletin.

My remarks here will be confined to our short-term objective. In spite of the issue of Bulletin MC/131, we find that boiler plant is still not being cleaned in such a way as to obtain maximum availability. I offer no apology, therefore, for returning to this subject as the committee is still convinced that in the better cleaning of boiler plant lies the greatest hope of improving availability for the time being.

(At this point slides were shown illustrating bad cases of deposit trouble. These and other illustrations shown by the author have been reproduced in a publication issued by the Boiler Availability Committee containing the complete text of all the papers read at this session).

After seeing this state of affairs you will want to know what advice the committee can give to improve the availability of plant under these distressing circumstances. We have such advice but unfortunately we find it very difficult to get our advice universally accepted.

The committee's "short-term" recommendations will be explained by the aid of Figs. 1 to 3.

Fig. 1 shows the rate of fouling of a certain boiler plant as determined by observation. The vertical scale shows the rate of fouling as indicated by the draught loss across the plant in excess of this loss when the plant is in a perfectly clean condition. There is no better way of ascertaining the degree of fouling than by taking the draught loss across the plant with a reliable and sensitive draught gauge equipment.

The zero point of this vertical scale is the point at which the boiler is as clean as it was on the day it was new. When a boiler is installed it should be provided with a certificate on which is clearly indicated the draught loss across the plant when it is new and when it is operating at normal output and at a suitable CO<sub>2</sub> reading. This certificate can then be used as a target whenever boiler cleaning is carried out. The figures on the scale mean very little as they are only there to divide up the space between minimum and maximum draught loss and the scale will vary with each individual plant.

The horizontal scale on the diagram represents the time run by the plant from "clean" to "dirty", and the full 100 per cent. represents the maximum possible availability of the plant between "off-load" cleanings with soot-blowing only in use. The length of the curve and the availability could be extended by adopting "on-load" cleaning as described in the Bulletin but such cleaning was not used during the making of this curve and the lesson to be learned is the same whether "on-load" cleaning is used or not.

Attention is directed to the curve at what may be termed the "clean" end. It will be noticed that the growth of deposit is slow at the commencement

% DRAUGHT LOSS ACROSS BOILER PLANT

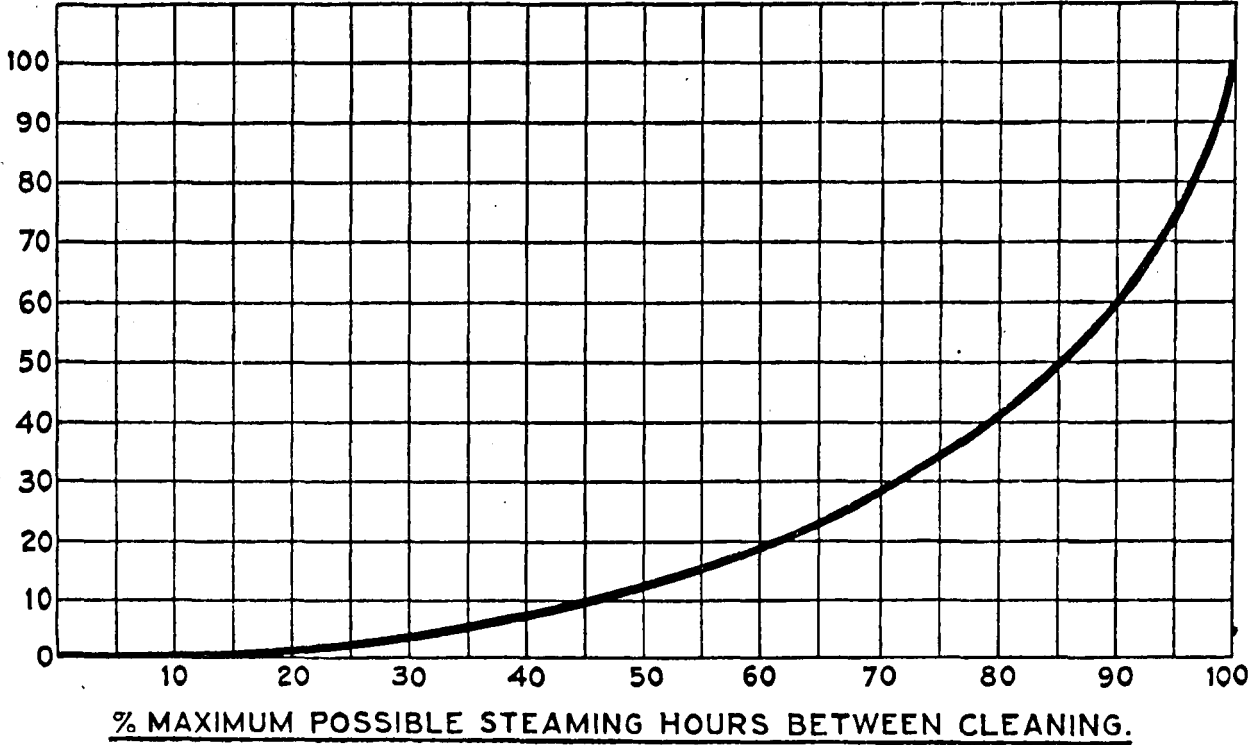


Fig. 1



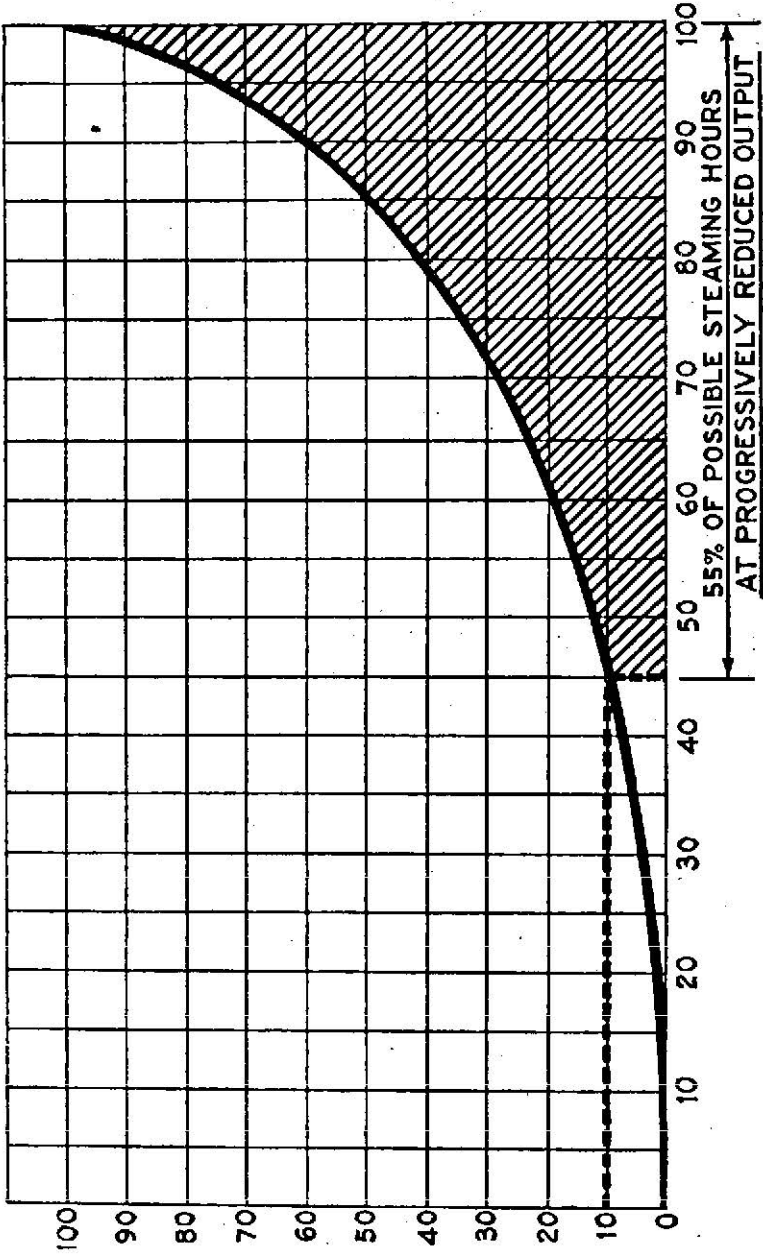


FIG. 2

and that the curve travels a considerable distance before it has much effect on the draught loss. The formation of deposits is progressive. Deposits encourage further deposits. When deposits occur, a shift of temperature takes place transferring the tendency to deposit to heating surfaces further down the gas pass.

(78908)

Fig. 1, as has been indicated, represents the maximum availability of the plant. We find that the curve is not being used to its fullest extent at the "clean" end. The cleaning is being stopped before the draught loss is back at the zero point and it is impossible to reach this point with the old methods of cleaning, i.e. hand cleaning. Unless special methods of cleaning are used an excessive draught loss is bound to remain when the boiler is put back to work.

In the second curve (Fig. 2) is shown the point at which hand cleaning ceases to be effective at 45 per cent. of the possible availability. This is a conservative estimate and in many cases 50 per cent. or even more would be nearer the correct figure.

(At this stage there were shown photographs, not reproduced here, taken during the cleaning operations of the boilers from which Figs. 1-3 had been obtained.)

Slide 1 shows a compartment of the boiler, immediately above the superheater, after hand cleaning has been completed. This is a very clean boiler judged by 1939 standards. Someone may say that the tubes on the ceiling of the compartment could have been made much cleaner with hand cleaning. This is so, but what about the row of tubes above and the row above that, and so on through the bank? It would be a physical impossibility to clean the tubes inside the bank by hand cleaning any better than the outer tubes shown here and, therefore, some other means have to be found for cleaning these tube banks. The answer is a steam bath so that steam and gravity can do this difficult work for us. We will therefore close up the compartment and give it a steam bath for 72 hours.

The result is shown on the next slide where in the same compartment are seen perfectly clean tubes and not only are the tubes which can be seen quite clean but every tube in the bank is in the same condition of cleanliness. This is the standard of cleanliness demanded in 1946 to give maximum availability.

A word of warning must be given in connection with steam cleaning. Do not ask the steam to do too much. In other words, do not be careless with the hand cleaning, hoping that the steam will do the work for you. Hand cleaning must be as efficient as possible before the steam is applied.

Having dealt with the "clean" end of the curve the "dirty" end will next be examined.

It will be appreciated that as the deposit grows the output and efficiency of the plant will be adversely affected. The committee recommends that the plant be shut down for cleaning before it reaches the point at which it puts itself out of commission. This recommendation is made not only on account of a falling off of output and efficiency but also because it is much easier and quicker to clean a boiler that is not completely choked. It must not be forgotten that any time saved in cleaning is a gain in availability.

It will be seen that in Fig. 3 there is cut off from the bottom scale 15 per cent. to cover this recommendation but the amount can be varied to suit individual circumstances. Our recommendations are, therefore, that the plant be operated in accordance with this curve which gives 85 per cent. of the possible steaming hours instead of 55 per cent. shown on Fig. 2. This is a gain of 30 per cent. in availability due entirely to special attention to cleaning the plant.

Several methods of cleaning are given in Bulletin MC/131. These methods have been devised by station engineers and others who have spent much time

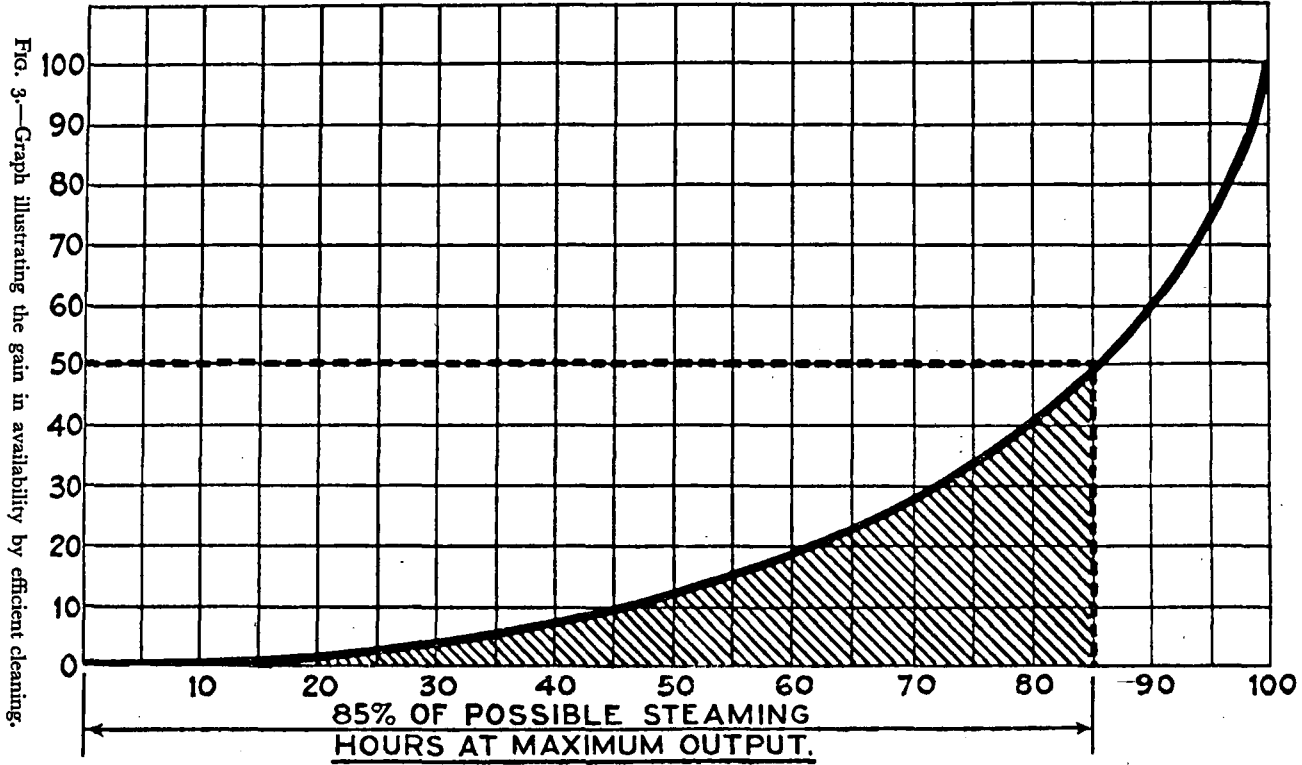


Fig. 3.—Graph illustrating the gain in availability by efficient cleaning.

and trouble in experimenting. Full advantage can be taken of this splendid work with confidence.

If difficulties arise or further information is required in connection with the cleaning of boilers enquiries should be addressed to the makers of the particular plant concerned and not to the Boiler Availability Committee. This is not because the Committee does not want to be bothered or because it may not know the answers, but because it would be altogether wrong for the Committee to step in between the boiler maker and his customer.

And, lastly, a word to power station engineers. Remember that every unit you fail to deliver on your quota will have to be generated by some other poor fellow who already has his own quota to deal with.

A summary of the recommendations given in Bulletin MC/131, referred to above, is as follows :

*Steaming Hours.*—Boiler plant should not be operated for longer periods between cleaning than is absolutely essential. Whenever possible boilers should be taken off for cleaning before the total draught loss has increased by 50 per cent. in excess of the initial loss for new boiler plant.

*Availability and Cleanliness.*—Boilers, economisers and air-heaters must be cleaned down to the metal. Plant that is put into service after thorough cleaning may have an availability from four to five times greater than the same plant put into service only half cleaned.

*Methods of Cleaning.*—Steam soaking, spray soaking and sluicing are available. Each method if properly applied will enable the heating surfaces to be cleaned down to the metal in a reasonable time with the minimum labour.

During sluicing, water walls must be protected, especially where brickwork is superposed. The stoker must be kept running throughout the operation and must be washed down and dried immediately after the sluicing is completed.

After any wet cleaning process the whole of the boiler plant must be dried as rapidly as possible to prevent corrosion.

*Sootblowing.*—Single nozzle sootblowers for the first bank generating tubes and superheater tubes are of real value, but it is vitally important that they should be properly maintained and adjusted, and have the correct steam pressure at the blower head when in operation.

Strict supervision of sootblowing operations is essential.

In many cases sootblowers can be entirely dispensed with after the superheater.

Sootblowers not in use must have their steam and drain piping systems blanked off.

*Water Lancing.*—Where sootblowers are ineffective in cleaning boiler and superheater tubes, water lancing in service is usually successful, provided it is carried out at frequent intervals of, at least, once a fortnight.

Water lancing will not clean a superheater that is already choked.

*Inspection.*—The success of all cleaning processes, both on and off load, depends upon competent supervision and thorough inspection, especially before the plant is passed for service.

## 2. Investigations and Recommendations Regarding Cleaning

By W. G. MARSKELL, B.SC., M.INST.F.

The main factors regulating the formation of deposits are :—

- (1) The nature of the fuel ; in particular the nature of the mineral matter contained in it.
- (2) The method of combustion.
- (3) Boiler design.

Many of the present-day troubles with deposits are due to the general deterioration of coal quality. A fruitful source of such trouble is the burning of difficult fuels on boilers which were not designed for such fuels ; this applies particularly to old boiler plant.

Methods of combustion and boiler design are the special business of the boiler maker, and the avoidance of deposits and their removal have always received close attention. Economic as well as technical factors, however, cause boiler design to be a compromise between conflicting requirements.

### CLEANING

The primary object is to keep the boiler clean while in operation, or if this is impossible, to limit the duration of shut-down to the minimum. The problem may, therefore, be conveniently divided into "on-load" cleaning and "off-load" cleaning. The importance of removing all deposits, and not only those readily accessible, cannot be over-emphasised.

#### "ON-LOAD" CLEANING

*Sootblowing.*—For cleaning boilers on load, the steam sootblower is still effective in most cases, provided that the blowers are properly located, that there is an adequate supply of steam at sufficient pressure, and that the sootblowing is regular and systematic.

Sootblowing, however, should not be overdone, and is often unnecessary in the medium and lower temperature gas passes. Much improved equipment is now available, in particular automatic control has largely removed the human element which so often has led to a neglect of this important operation.

*Water Lancing.*—Some hard, tenacious deposits cannot be removed by sootblowing unless the steam velocity is so high that there is grave risk of eroding the tube metal. Deposits of this type are usually brittle, and when subjected to a jet of water from a lance the thermal stresses cause them to fall away from the tube. In some plants it has been possible, by water lancing the first bank generating tubes or the superheater once or twice a week, to keep the plant in commission from one annual overhaul to the next.

Water lancing should be used only as a supplementary process where sootblowing is inadequate.

*Economisers.*—Below 250° F. feed temperature, it is rare to encounter deposits which cannot be removed by sootblowing, and even this may be unnecessary. Above this feed temperature harder deposits may be formed, and it may be necessary to wash the economiser with sprays at approximately monthly intervals. For this purpose the boiler should be taken off the line, but not necessarily shut completely down. The operation may be carried out during a banked period.

*Air Heaters.*—Air heater deposits are similar in many respects to those formed on low temperature economisers. In stoker-fired plants the use of sootblowers on plate or tubular air-heaters may intensify deposit trouble. In difficult cases, a certain amount of success has been obtained by hand-operated air lances.

Sootblowers are generally used on rotary air-heaters and designs have lately been developed which may be washed in operation.

#### “OFF-LOAD” CLEANING

*Steam Soaking.*—When “on-load” cleaning fails, “off-load” cleaning is necessary. Hand cleaning is unsatisfactory and generally only partial.

As much of the deposit is normally water-soluble, recent methods aim at dissolving the soluble part of the deposit in water. Steam is the best form of water application as it reaches all parts and if the tubes are filled with cold water, penetrates the deposit to condense on or near the tube surface. The deposit is loosened and may then be removed by rodding or high-pressure water jets. Experience shows that in the course of a few days the heating surfaces can be cleaned down to the metal.

In an emergency, when a choked boiler is required for service at once, it may be cleaned within a day or two by high-pressure water jets, using pressures of 300–400 lb./sq. in.

*Economisers.*—Economiser deposits are most easily removed by washing, if the layout of the plant permits. If the deposits are rich in phosphates a special technique is required, otherwise the deposit may be changed into a form which is far more difficult to remove.

*Air Heaters.*—Plate and tube heaters usually respond to washing with copious supplies of water. Rotary air heaters may be cleaned by soda-ash and hot water.

The processes are described in detail in the Boiler Availability Committee's Bulletin MC/131<sup>1</sup>, but users should *always* consult the manufacturers before adopting these methods. To avoid damage (1) any change in sootblower steam pressure should be accompanied by periodical examination of the tubes for possible erosion; (2) water lancing jets must not be allowed to impinge upon brickwork, superheater supports, or upon superheater tubes made of certain alloy steels; (3) where any wet cleaning process is used, the whole of the boiler plant must be dried quickly to prevent corrosion.

#### CAUSES AND PREVENTION OF DEPOSITS

Experiments have been conducted by Babcock and Wilcox, Ltd., mostly on an experimental boiler of 25,000 lb./hr. capacity, having a compartment type chain-grate stoker, Bailey rear and side furnace walls with a refractory front wall, and an interdeck superheater, plain steel-tube economiser and tubular air heater. This unit was not subject to economiser and air heater deposits or corrosion, and the research mainly concerned the formation of deposits on the generating tubes and superheater.

#### EFFECT OF COMBUSTION CONDITIONS

At equal loads, short, clean fires gave no harmful deposits, while long, and particularly ragged, fires gave harmful scale deposits.

#### EFFECT OF ALKALIES

As experience had shown that a high concentration of sodium chloride in the coal is objectionable, sufficient of this salt was added to the coals used to raise their content to 0.6 per cent. The deposits on the tubes immediately increased to become the heaviest experienced and the blockage of the gas passages was so severe that it was barely possible to finish the tests.

## EFFECT OF HYDROCARBON SMOKE

Laboratory experiments, later confirmed by large-scale tests, showed that the presence of hydrocarbon smoke diminished the formation of deposits to a marked extent. The clear gases towards the rear of a chain-grate stoker are favourable to deposit formation ; by burning either oil or pulverised coal above the fuel bed to produce a canopy of flame above the clear gases, deposit formation was reduced.

## CONCLUSIONS

Investigations on the plant and in the laboratory indicate that there are two main types of harmful deposits on boiler and superheater tubes :—

- (1) Birdsnesting or fused slag type. These are dark in colour and have a chemical analysis similar to that of the coal ash.
- (2) Bonded type. These are generally much lighter in colour, and have a high content of alkali sulphates or phosphates.

Fused slag deposits generally occur in zones of high temperature or where the ash has a low fusion temperature, so that the fly-ash is sufficiently hot to be sticky.

Bonded deposits possess an inner white layer of very high alkali content, probably formed from inorganic material volatilised from the fuel bed, which condenses on the tubes forming a key or bond for other material in the gas stream which could not otherwise adhere. The outer material has a much higher fusion temperature than the inner layers.

When the fuel bed temperature is high, alkali salts may be volatilised, and as this occurs when the coke is burning, smoke is absent. When the volatile is being evolved, the fuel bed temperatures are lower, salts are volatilised to a lesser extent and smoke is present

Why the volatile hydrocarbons and dust should suppress deposit formation is still obscure. They may absorb the volatile inorganic salts or they may interfere with sulphur trioxide formation in the gases, and thus may prevent the formation of the sulphates which form the inner white layer. Any feature which tends to eliminate two-stage combustion and to mix the products of combustion will assist in eliminating bonded deposits.

Thus the means at our disposal for preventing harmful deposits appear to be :—

- (1) The use of fuels containing the minimum quantity of harmful constituents, such as alkali chlorides and sulphur.
- (2) The promotion of good combustion conditions in the fuel bed with the minimum of excessively hot areas.
- (3) Creation of maximum turbulence in the furnace so that the deleterious material may be absorbed on particles of fly-ash or carbon in the gas stream.

## LOW TEMPERATURE DEPOSITS

Deposits forming on the cooler parts of boilers such as the economisers and air heaters seem to be largely associated with the presence of sulphur trioxide in the flue gases. Whilst the sulphur trioxide has a very important influence, it is present in very small quantities compared with the sulphur dioxide content. It is, therefore, very difficult to measure the quantity of sulphur trioxide present and to establish its mode of formation.

International Combustion, Ltd., have produced evidence indicating that sulphur trioxide may be produced by the catalytic oxidation of sulphur dioxide on the superheater tubes if these are at a sufficiently high temperature<sup>2</sup>.

Investigations on the function of low temperature deposits and corrosion have also been carried out by the Mitchell Engineering Co., Ltd.<sup>3</sup>

Experiments carried out by E. Green & Son, Ltd.<sup>4,5</sup>, have indicated that if economisers can be so thoroughly washed as to remove all acid deposits they will run for at least twelve months between shut-downs. They have also shown that the ratio of phosphate to sulphate in economiser deposits is of great importance, as deposits high in sulphate can be removed by washing while deposits high in phosphate are difficult to remove.

#### CONCLUSION

Details of the experimental work dealt with above have been given in published papers by the individual investigators and in the publications of the Boiler Availability Committee. In particular, Bulletin No. MC/160<sup>6</sup> should be consulted for further details.

#### References.

- 1 Boiler Availability Committee Bulletin No. MC/131. Methods of cleaning modern stoker-fired boiler plant.
- 2 Harlow. Proc. I. Mech. E. 1944, Vol. 151, No. 3, p. 253.
- 3 Taylor. J. Inst. Fuel. 1942, Vol. 16, p. 25.
- 4 Rylands and Jenkinson. J. Inst. E. E., Vol. 91, Part II pp. 77 to 100 and 562 to 568.
- 5 Rylands and Jenkinson. Electrical Power Engineer, 1946, pp. 461 to 464 and 529 to 533.
- 6 Boiler Availability Committee Bulletin No. MC/160. Seven papers on boiler availability.

### 3. Research Work at the Fuel Research Station on Boiler Deposits

By H. E. CROSSLEY, PH.D., M.SC., B.SC.TECH., A.R.I.C.

This work has concerned the effects due to the various constituents of coal. It has involved the examination of 700 deposits, and 500 coals, collected from 43 power stations. As a result deposits have been classified in the following types :—

#### HIGH-TEMPERATURE DEPOSITS

These involve birdsnesting on generator tubes nearest the combustion chamber and hard deposits on superheater tubes. They appear to be of three types : re-fused ash, alkali-matrix and phosphatic.

Sufficiently high temperatures cause the fly-ash particles to be partly molten, or to soften after deposition, and to form a clinker-like mass. The formation of this, the re-fused ash deposit, is encouraged by a low ash fusion temperature but it is essentially caused by high temperatures. These are primarily associated with the design or method of operation of the boiler.

In the alkali-matrix type, the fly-ash spheres are embedded in a white matrix, which acts as the bonding agent.

The phosphatic type, which is relatively uncommon, possesses a hard outer shell inside which there is a soft core of fly-ash.

Typical analyses of the various kinds of deposit are given in Table 1.

The white substance acting as the bonding agent in the alkali-matrix type of deposits is rich in the sulphates or bisulphates of the alkali metals, while the phosphatic type is much richer in phosphates than the coal ash. Alkalies occur in coal in two forms, as relatively non-volatile constituents of shaly matter, and as chlorides, which are readily volatilised. Phosphorus occurs in coal mainly as fluor-apatite.



## ECONOMISER DEPOSITS

There are two types of economiser deposit. The sulphate type is readily disintegrated by soaking in water, but the phosphatic type is not, since the phosphates of aluminium and iron are insoluble in water.

## AIR-HEATER DEPOSITS

The most troublesome air-heater deposits are sticky and contain a considerable amount of sulphuric acid. The acid accumulates by condensation and it is reasonable to assume that the amount of acid which condenses will be affected mainly by the temperature of the metal surfaces which depends on the design and operation of the boiler, and by the amount of acid in the flue gas. The acid is derived from the sulphur in the coal.

It can be deduced from this classification of boiler deposits that the constituents of coal which are most concerned with trouble are alkalis (indicated by the chlorine content), sulphur (giving rise to sulphuric acid and sulphates), and phosphorus. The Fuel Research Coal Survey has enabled coals to be classified as in Table 2. The chlorine, sulphur and phosphorus contents of coal are to some extent characteristic of the coalfield; this sometimes leads to a remarkable uniformity in the coals at a given station with respect to the three constituents.

TABLE I

Position and type of deposit	Silica	Iron Oxide	Alumina	Alkali oxides	Phosphate	Sulphate
	SiO <sub>2</sub> Per cent.	Fe <sub>2</sub> O <sub>3</sub> Per cent.	Al <sub>2</sub> O <sub>3</sub> Per cent.	(Na, K) <sub>2</sub> O Per cent.	P <sub>2</sub> O <sub>5</sub> Per cent.	SO <sub>3</sub> Per cent.
<b>BOILER TUBES :—</b>						
Birdsnesting :—						
Re-fusion—whole deposit	30·7	21·2	27·8	3·6	0·3	2·9
Alkali-matrix :—						
White inner layer . . .	9·2	21·1	10·0	14·7	0·2	29·8
Brown outer layer . . .	21·6	25·0	18·1	9·5	0·6	20·6
<b>SUPERHEATER :—</b>						
Phosphatic :—						
White inner layer . . .	49·9	7·8	6·2	4·4	10·6	6·5
Brown friable core . . .	43·0	6·2	22·4	0·5	3·5	1·8
Brown hard outer shell . . .	42·8	5·7	18·1	0·5	8·2	1·8
Alkali-matrix :—						
White inner layer . . .	10·0	14·5	2·0	24·9	2·6	42·5
Brown hard outer layer . . .	18·6	15·6	17·5	12·8	2·5	27·3
Re-fusion :—						
White inner layer . . .	17·3	28·3	11·1	8·6	0·2	30·9
Black hard outer layer . . .	35·5	23·4	21·7	3·5	0·3	6·0
<b>ECONOMISER :—</b>						
Sulphate :—						
Hard scale . . . . .	7·2	11·6	0·6	17·7	2·3	44·0
Dust . . . . .	20·4	18·7	16·3	8·7	1·2	23·4
Phosphate :—						
Hard scale . . . . .	23·6	3·0	8·5	4·4	25·0	12·6
Dust . . . . .	35·1	5·6	18·8	4·2	6·9	9·0
<b>AIR HEATER :—</b>						
Coal of high phosphorus, low sulphur content. Dry dust deposit.	47·1	4·7	5·0	4·8	3·1	13·8
Coal of high phosphorus, high sulphur content. Sticky dust deposit.	6·7	25·2	3·8	2·2	0·4	43·8

TABLE 2

Constituent	Classification limits, per cent. of coal		
	High	Medium	Low
Chlorine . . . . .	Over 0.3	0.15—0.3	Less than 0.15
Sulphur . . . . .	Over 1.8	1.3 —1.8	Less than 1.3
Phosphorus . . . . .	Over 0.03	0.01—0.03	Less than 0.01

## PHOSPHATIC DEPOSITS

The first correlation worked out was that of phosphorus in coal with the relatively uncommon phosphatic type of deposit. Phosphorus is not volatilised by the combustion of pulverised fuel ; therefore no phosphatic deposits can be formed. There is a relatively slow volatilisation of phosphorus from travelling grates, with coals of high phosphorus content, and a correspondingly slow development of phosphatic deposits. In deep fuel beds, however, such as may occur with retort stokers, if the phosphate content of the coal is high and the fuel bed temperature is high, phosphatic deposits can form rapidly. No case has yet been found where coals of low and medium phosphorus content have been associated with phosphatic deposits.

## CHLORINE

The correlation of chlorine content of coals with birdsnesting and superheater deposits trouble for 80 power stations is given in Tables 3 and 4. These tables indicate that with pulverised fuel firing there is slight or no trouble whatever to the chlorine content of the coal. With mechanical stokers the high-chlorine coals are shown to be likely to lead to the formation of deposits.

TABLE 3

CORRELATION OF HIGH-TEMPERATURE DEPOSITS TROUBLE WITH  
CHLORINE CONTENT OF COAL BURNED

*Mechanical Stokers*

Chlorine content	Acute trouble		Slight or no trouble
	No. of power stations	Average run (hours)	No. of power stations
High—medium . . . . .	28	980—1180	0
High—medium—low . . . . .	10	1270—1390	1
Medium—low . . . . .	5	2760—3600	13
Low . . . . .	0	—	15

TABLE 4  
CORRELATION OF HIGH-TEMPERATURE DEPOSITS TROUBLE WITH  
CHLORINE CONTENT OF COAL BURNED  
*Pulverised Fuel*

Chlorine content	Acute trouble		Slight or no trouble
	No. of power stations	Average run (hours)	No. of power stations
High—medium . . . . .	0	—	8
High—medium—low . . . . .	0	—	2
Medium—low . . . . .	0	—	2
Low . . . . .	0	—	2

## SULPHUR

The correlation is shown in Tables 5 and 6.

High-sulphur coals are likely to lead to air-heater deposits trouble when fired on mechanical stokers ; with low and medium sulphur coals, generally only minor or no trouble is recorded. There is rarely air-heater deposit trouble with pulverised fuel firing.

TABLE 5  
CORRELATION OF AIR-HEATER DEPOSITS AND CORROSION TROUBLE  
WITH SULPHUR CONTENT OF COAL BURNED  
*Mechanical Stokers*

Sulphur content	Acute trouble		Minor trouble	No trouble
	No. of power stations	Average run (hours)		
High—medium . . . . .	9	1380—1610	0	0
High—medium—low . . . . .	4	2080—2450	6	0
Medium—low . . . . .	0	—	6	14
Low . . . . .	0	—	0	8

TABLE 6  
CORRELATION OF AIR-HEATER DEPOSITS AND CORROSION TROUBLE  
WITH SULPHUR CONTENT OF COAL BURNED  
*Pulverised Fuel*

Sulphur content	Acute trouble		Minor trouble	No trouble
	No. of power stations	Average run (hours)		
High—medium . . . . .	0	—	2	0
High—medium—low . . . . .	0	—	0	0
Medium—low . . . . .	0	—	1	6
Low . . . . .	0	—	0	4

## CONCLUSION

There is good evidence for the correlation of the chlorine and sulphur contents of coal and certain kinds of deposits trouble. Boilers fired by pulverised fuel are affected much less than stoker-fired boilers, being in fact almost immune. With stoker firing it is probable that in the second and third categories of each correlation, that is, with medium and low contents of chlorine and sulphur, the severity of trouble, if any, is concerned mainly with the design and method of operation of the boiler, the factors primarily responsible for re-fused ash deposits, and, to some extent, phosphatic deposits.

The work described above formed part of the programme of the Fuel Research Station, D.S.I.R. and this account is published by permission of the Director of Fuel Research.

#### 4. Research Work on Deposits by the British Coal Utilisation Research Association

By DR. G. WHITTINGHAM

##### NATURE AND FORMATION OF HIGH TEMPERATURE DEPOSITS

Experimental work on the analysis of deposits and the softening temperatures of mixtures of alkali and other sulphates led to the view that in bonded

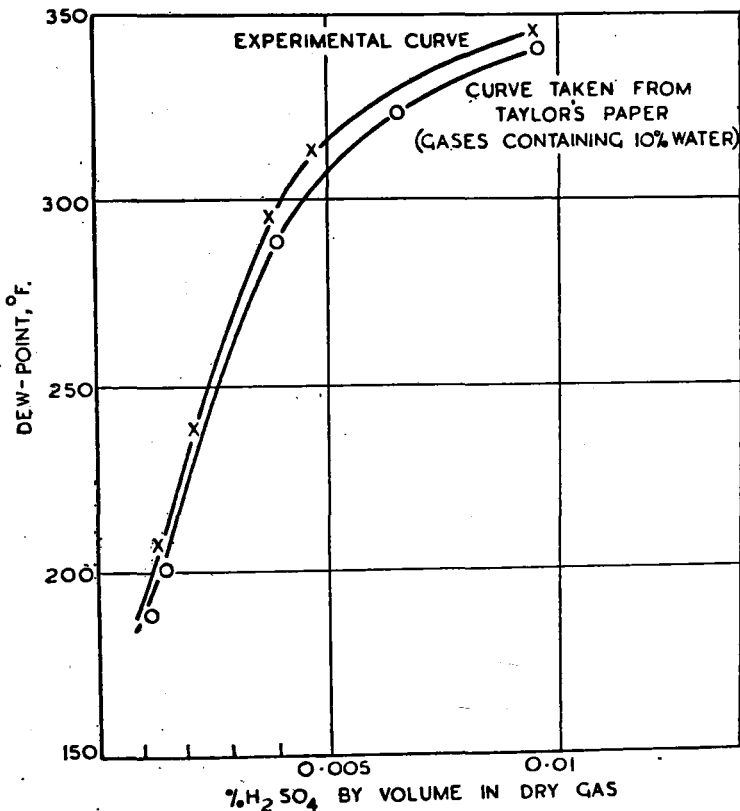


FIG. 4.—Relation between dewpoint and H<sub>2</sub>SO<sub>4</sub> content of dry gas. Coal gas/air flame giving 15 per cent. water vapour in products.

deposits the alkali sulphates act as a "cement" to which ash particles readily adhere, giving rise to a hard, consolidated deposit. At the same time work carried out on an experimental pot furnace in which suitably cooled probes were exposed to the products of combustion showed that combustion conditions were a vital factor and that deposit-forming material was released from the fuel bed during the "burning out" period when the bed consisted of burning coke and the volatiles had been distilled off. Under conditions of equilibrium burning no deposits were obtained.

#### ROLE OF SULPHUR OXIDES IN HIGH AND LOW TEMPERATURE DEPOSITS

Mainly as a result of the researches of Johnstone in the U.S.A. and workers in this country, corrosion in air heaters and low temperature regions was associated with the formation of sulphuric acid in the combustion products. The fact that sulphates were also involved in superheater deposits provided a link between the researches into high and low temperature deposits and we have devoted much attention to the existence and behaviour of sulphur oxides derived from the sulphur in coal.

The greater part of the sulphur released appears as sulphur dioxide which appears to play no more than a secondary part in deposit formation. On oxidation, however, it forms sulphur trioxide which reacts readily with water vapour to give sulphuric acid and with alkali metals and water to give sulphates. Investigations were, therefore, put in hand with a view to ascertaining:—

- (a) The extent of the oxidation of sulphur dioxide in flue gases.
- (b) The mechanism of formation of sulphur trioxide.

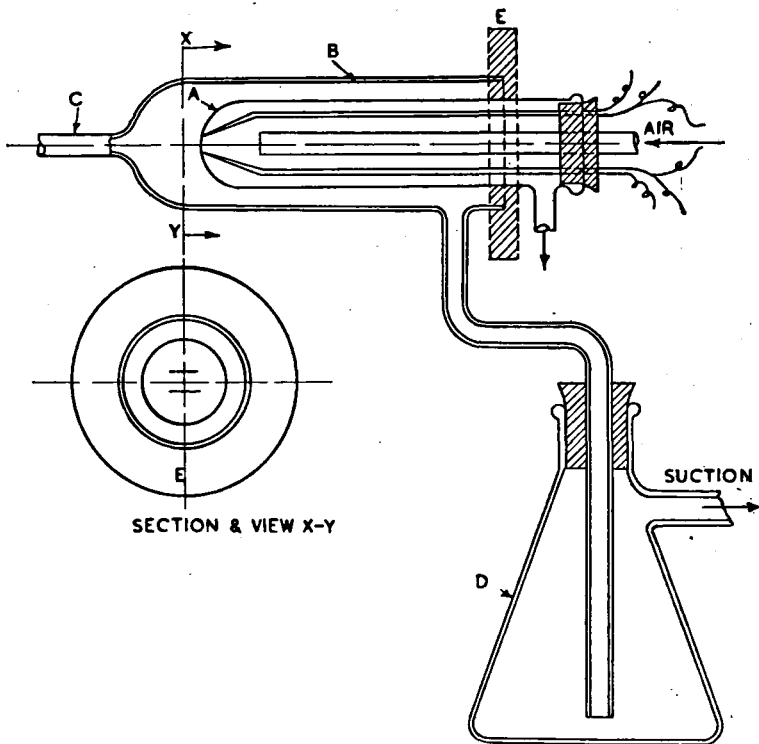


FIG. 5.—Estimation of Condensation Temperature.

(c) The subsequent behaviour of sulphur trioxide in regard to deposits and corrosion.

Small traces of  $\text{SO}_3$  have a marked influence on the dewpoint of flue gases, as shown in Fig. 4. The lower curve relates to data given in a paper by A. A. Taylor (J. Inst. of Fuel, 1942, 16, 25). Using the published data for clean gases, dewpoint observations can be related directly to  $\text{SO}_3$  concentration. Instruments have been devised suitable both for the laboratory (Fig. 5) and for use on large scale plant and are designed to give accurate readings of condensation temperatures. In addition, a direct chemical method of improved accuracy has been developed for the estimation of sulphur dioxide and sulphur trioxide, based on absorption from the gases in water containing an inhibitor of the oxidation of sulphur dioxide in solution.

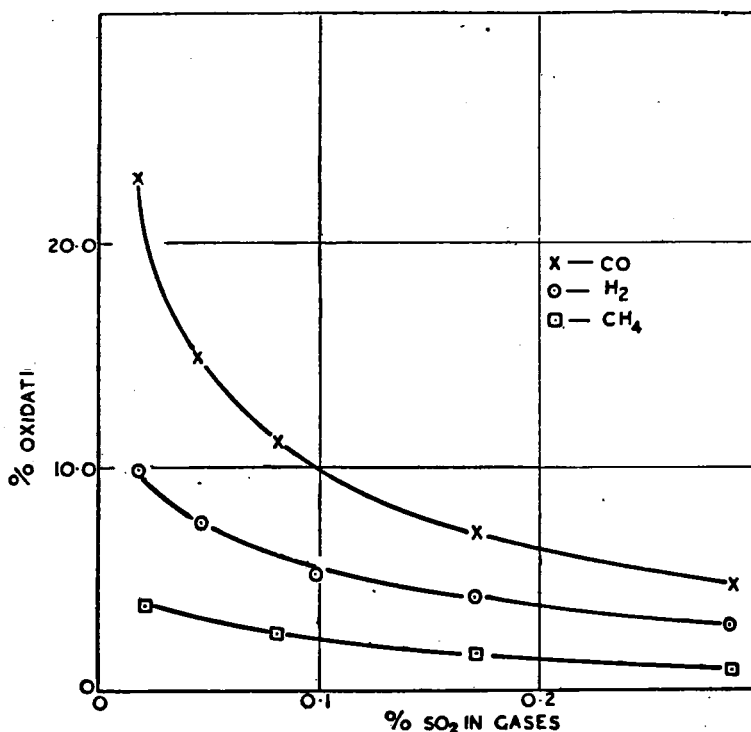


FIG. 6.—Oxidation of  $\text{SO}_2$  in various flames.

Sulphur dioxide is oxidised to sulphur trioxide in gas flames and reference to Fig. 6 shows that oxidation of sulphur dioxide in a luminous smoky methane flame is much less than in a carbon monoxide flame. These experiments were carried out on clean gases; when alkali salts were introduced it was found that sulphur trioxide reacted rapidly with any alkali metal vapour present with the deposition of bisulphate and sulphate layers on cooled surfaces. The effect of alkali salts on dewpoints is shown in Fig. 7. This provides a possible mechanism for deposit inner layer formation. It suggests at the same time that if the sulphur trioxide could be removed by reactive material which did

not produce a bonding layer, both high and low temperature troubles would be mitigated, at least so far as sulphate-based deposits are concerned. This line has been successfully pursued, as is described later.

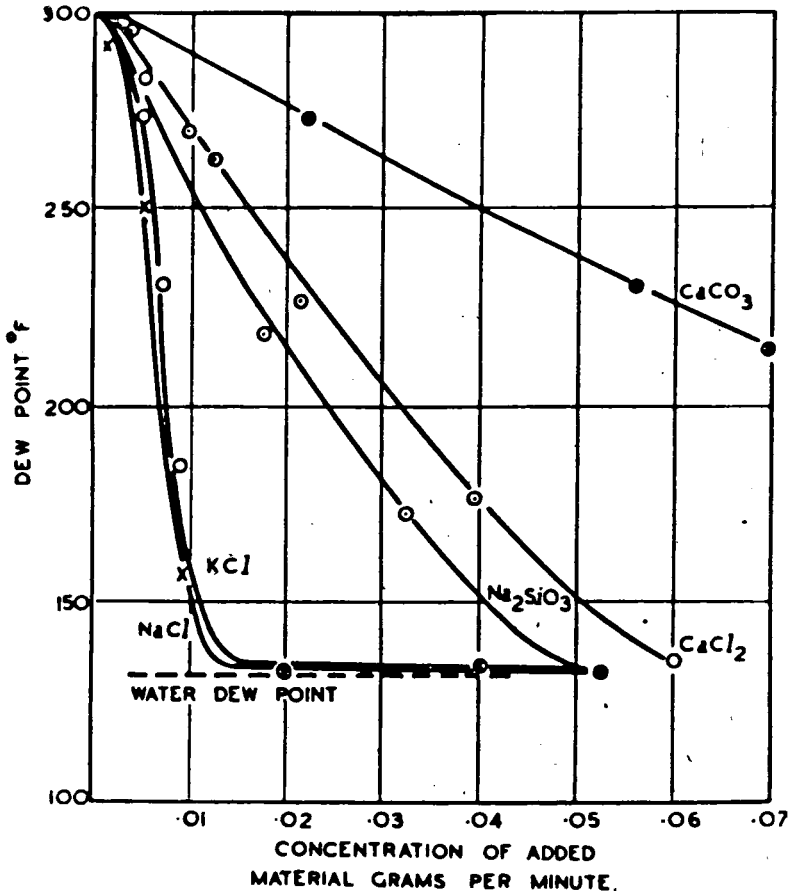


FIG. 7.—Effect of various salts on the dewpoints of flame gases containing 0.05 sulphur dioxide.

Many dewpoint readings have been taken on large-scale plant and dewpoints of the order of 300° F. are often encountered, but the interpretation of the readings obtained is extremely complicated. It can be said, however, that the rate of condensation of acid at a temperature just below the dewpoint may be at least as important as the dewpoint temperature itself.

The dewpoint meter has also been used to study the tendency of flue gases in boiler plant to deposit bisulphates and similar low-melting salts. The observations made to date suggest that the type of condensate or deposit obtained, that is, whether liquid acid, sticky bisulphate or dry normal sulphate, is determined by the relative concentrations of volatile alkali metal and sulphur oxides released from the coal.

#### THE MITIGATION OF DEPOSITS AND CORROSION TROUBLE

The laboratory work described above suggests that it may be possible to remove sulphur trioxide (thereby depressing the dewpoint and decreasing the

tendency to form low-melting sulphates) by providing active material forming an inert product. In support of this it was found that a "Down Jet" type furnace, burning coke and producing a large amount of fine silica smoke and dust, ran with a low dewpoint and gave loose deposits. It was subsequently found possible to release silicon oxide smoke from silica/carbon and silicate/carbon mixtures at temperatures of 2,000° to 2,600° F., which appreciably depressed the dewpoint of a flue gas into which it was passed. Fig. 8 shows the

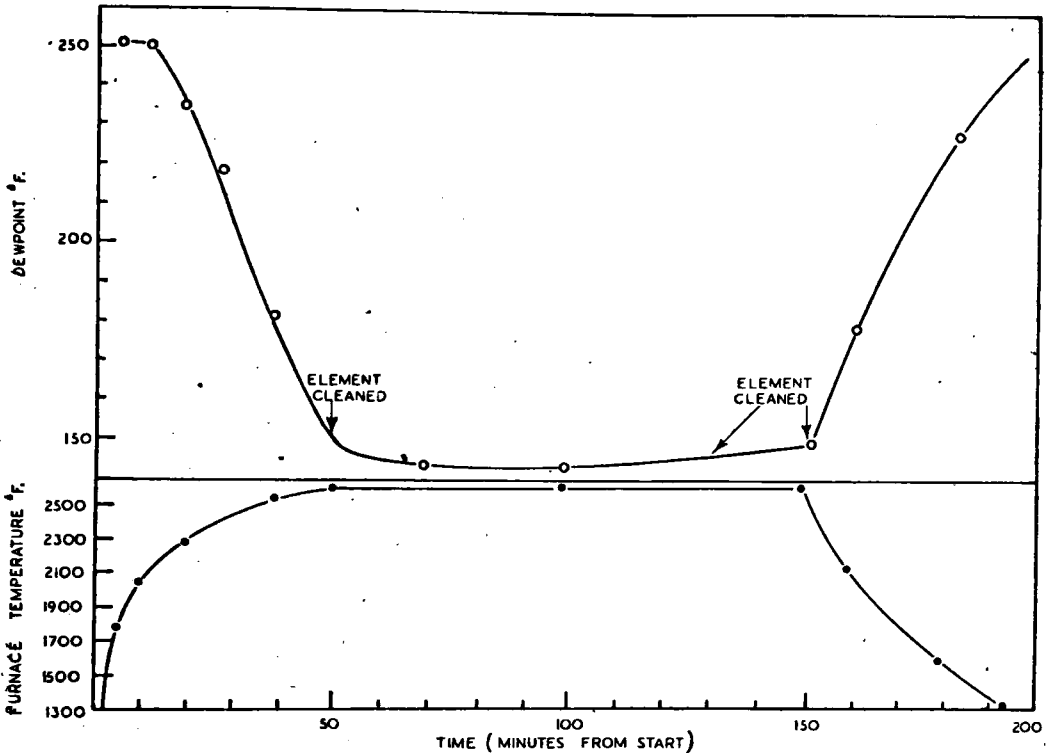


FIG. 8.—Variation of Dewpoint with time. Silicon monoxide emission from mixture of aluminium silicate and carbon.

effect of fine silica smoke on dewpoints. Following up the theory that active dusts were responsible for this effect, certain metallic oxide smokes were then injected into flue gases of high dewpoint, when the dewpoint was immediately and sharply reduced. The amount of smoke-producing material required was very small, in some cases less than the  $\text{SO}_3$  present in the gases. The laboratory work also suggests that apart from any interference in the reactions leading to the production of sulphur trioxide, fine dusts can act as nuclei for the condensation of sulphuric acid at or near the dewpoint. This fact may be one of the explanations why serious corrosion troubles are not encountered in certain boiler plant when other considerations would cause such trouble to be expected.

Quite apart from the important effect of smokes and dusts on sulphur trioxide concentration in the flue gas, which would directly reduce the amount of bonding material present, these finely divided materials, when co-deposited,



were found to depress the stickiness of bisulphate, pyro-sulphate and sulphate layers on which deposit formation is based.

This work will be continued on large-scale plant. Many differences and apparent anomalies between one plant and another may be due to differences in the type and amount of dust and smoke present in and carried away from the combustion chamber. The freedom of pulverised fuel fired plant from air-heater corrosion may, for example, be explained by the nature of dust carried forward. The inhibition of deposit formation when the coal volatiles are present may be due to the action of carbon smoke.

Until further work is completed it is not yet possible to suggest means for mitigation of trouble on existing plant burning available fuel supplies. The desired result may be achieved by arrangement of secondary air nozzles or by control of combustion conditions so as to release suitable fine dusts ; on the other hand, it may be simpler to add some active smoke-producing material to the fuel bed or to the flue gas. These alternatives are at present being examined.

## 5. Research Work by the Boiler Availability Committee

By R. LLEWELLYN REES, M.A. (CANTAB.), F.R.I.C., M.I.CHEM.E.

It is my duty to give a concise summary of the present situation as it appears to the Boiler Availability Committee.

Our Chairman, Sir Johnstone Wright, has pointed out that the inter-connection of power stations on the Grid system enables economies to be made by working boiler plants at much higher sustained loads than was formerly required from them. The demand for boilers in service has been made still greater by the shortage of spare plant capacity which was caused by the war. The availability which is required from boilers today is therefore much greater than it used to be. At the same time, advances in the design of stoker-fired boilers have naturally led to a more concentrated release and exchange of energy in the plant. This has tended to make some plants less tolerant of deposits. It has also altered the form and the rate of growth of deposits, so that they are much less easily amenable to the methods of cleaning which were developed to deal with the earlier types. The problem before us is constituted from these several factors, complicated by the degradation of coal quality and by the shortage of skilled and experienced boiler operators.

It is most important to notice that this problem is by no means wholly one for the research scientist. It contains mechanical, administrative and human elements that cannot be neglected. I shall refer to them again later, but I want first to summarise the scientific investigations.

It has been evident from the remarks of earlier speakers that this research has ranged, and still ranges, over an unusually wide field of physics, chemistry and engineering. There is a wealth of technical detail, interesting in itself, and vital to a proper understanding of the research, which it would be a pleasure to describe ; but no speaker today can find time to give more than a glimpse of it. In attempting to put before you a balanced picture of the investigation, I must restrict myself to the essential salient features, as they appear to the Boiler Availability Committee at the present time.

You have heard already that the harmful constituents of coal are sulphur, phosphorus, and the alkali metals, sodium and potassium. Sodium, potassium

and sulphur are evolved from all fire beds, much of the sulphur probably being evolved first. Phosphorus can be evolved from coals which contain it if the fire bed is thick and the temperature high. These materials act in certain combinations as cements to bond fly ash particles into deposits. There is one noteworthy exception to this : if the ash particles are hot enough, they can stick to each other, and therefore act as their own bonding material, to form a deposit of the birdsnesting or re-fused ash type ; this is common in lower generator banks, and it also occurs sometimes in superheaters when the gas temperature is sufficiently high. All other deposits are bonded by sulphates or phosphates.

Phosphate deposits can be very troublesome in some plants, especially in economisers. The conditions which produce them—coals rich in phosphorus associated with deep fuel beds and high fuel-bed temperatures—are fortunately uncommon ; this fact limits the extent of the trouble which is experienced with phosphate deposits. Deposits which are bonded by sulphates are usually easier to remove than phosphate deposits, but they are nevertheless a more serious problem on the national scale because their incidence is spread more widely.

Laboratory experiments suggest that sodium and potassium combine very readily with sulphur trioxide in the flame gases to form deposits. If they combine with sulphur dioxide at all, they appear to do so very much less readily than with sulphur trioxide. Sulphur trioxide also causes corrosion of air-heaters by depositing sulphuric acid on them. It is obviously important to trace the history of sulphur trioxide through the plant.

According to laboratory experiments there appear to be three likely sources of sulphur trioxide : it can be released directly from calcium sulphate in the fuel bed ; it can be formed by the oxidation of sulphur dioxide in flames, even in the relatively powerful “reducing” atmosphere of a carbon monoxide flame ; and it can be formed by the catalytic oxidation of sulphur dioxide at temperatures which occur in modern superheaters. Sulphur trioxide which is formed in the superheater cannot, of course, cause deposits on lower-bank generator tubes, but it may be important in later stages of the plant. The sulphur trioxide which is responsible for lower-bank deposits seems to be formed largely in the flame ; it may be important in all stages of the plant.

The concentration of sulphur trioxide in the gases is quite small—less than one hundredth of one per cent. In addition to combining readily with sodium and potassium to form deposits, it combines very readily with water vapour at lower temperatures to form sulphuric acid.

Sulphuric acid can cause very severe corrosion by condensing on heater surfaces. It can also act as a binder for deposits in the air heater and on fan-blades. There are, however, reasons for believing that the acid can condense on fly grit particles in certain circumstances, or on even smaller nuclei to form a mist which is almost unaffected by its material surroundings. Acid which has condensed on particles in the gas stream in a suitable manner may pass harmlessly through the plant without producing either serious corrosion or serious deposits. If this is so, the conditions which govern the manner of condensation are very important. They are now being studied by the Boiler Availability Committee.

In kindred fashion, sulphur trioxide in earlier stages of the plant may be taken up by fine solid particles in the gases. You have heard, in Dr. Whittingham’s description of laboratory work, that the presence of very small particles of certain oxides can lower the dewpoint of the gases, i.e. can reduce

the quantity of easily condensable material in them. These oxides can also lessen the formation of deposits and restrict the range of temperature in which the sulphate compounds can act as the bonding material for deposits.

Silica is one of these important oxides. It is sometimes generated during combustion as a very fine dust. This has been done experimentally on a pilot plant scale. The effect of these materials is now being studied on the full scale.

Except for deposits of the fused ash type, pulverised fuel plants are comparatively free from the particular troubles that we are discussing today. Phosphate deposits do not occur because phosphorus is not released from coal in a p.f. flame ; but p.f. plants are also nearly always free from serious sulphate deposits. There may be several reasons why this should be so, not the least of them being the immense amount of dust in the gases, upon which the deposit-forming materials can condense.

Pulverised fuel boosters have been tried experimentally in stoker-fired boilers as a possible means of diminishing the rate of growth of bonded deposits ; these experiments have given very promising results.

Thus, although solid particles in the flue gases become the main constituent of fused ash deposits, and a bulky constituent of alkali-bonded deposits, they may, in certain circumstances, be beneficial instead of harmful. The classification of dusts into harmful and beneficial types is being investigated.

The presence of volatile matter burning throughout the flame may be another important factor in the comparative immunity of p.f. plants. It was found early in the researches that the deposit-forming materials appear to be derived from the back of the grate, and not from the front where the volatiles are burned. Liquid fuel burners, which produce a similar kind of flame, were therefore fitted experimentally as boosters in a stoker-fired boiler, and their use was found to diminish the rate of growth of deposits. We do not yet know definitely why it is that the presence of a luminous flame of burning volatile matter tends to inhibit the growth of bonded deposits.

We are now in a position to take a constructive view :—

The constituents of coal that are known to affect the problem are potassium and sodium chlorides, sulphur, excess of which is usually present as pyrites or marcasite, and phosphorus which occurs in coal as fluor-apatite. The influence which these constituents have upon boiler deposits and corrosion could be controlled, at least to some extent, by re-arranging fuel supplies, as Dr. Crossley has suggested, so that plants which are least sensitive to any of these constituents receive the coals which contain them in highest proportion, leaving the less troublesome coals for the more sensitive units. It is obviously very difficult to make this arrangement at the present time, but the suggestion merits serious consideration, especially at stations where incoming coals can be allocated to two or more different types of plant.

It is also possible to gain some control over the harmful constituents of coal by suitable preparation of the fuel. The sulphur content, for example, can often be diminished by cleaning the coal. High sulphur coals are really only suitable (in power stations) for the less efficient boilers which are not fitted with air heaters, and these boilers, incidentally, should be located in areas where a relatively large concentration of sulphur dioxide in the chimney gases can be tolerated.

The control of sodium and potassium chlorides requires special arrangements at the washeries. It is very unlikely that these salts can be removed to

such an extent that deposit troubles will vanish. But it is an undoubted fact that really salty coals are very much more troublesome than others, and this fact deserves serious attention, especially at washeries where the water supply is restricted.

Methods of preparation sometimes have little effect upon the phosphatic mineral in coal, and it happens that many of the coals that are rich in it have other characteristics which affect the design of combustion equipment. It should be possible to use these coals satisfactorily in pulverised fuel plants if their supply is so assured that the plants can be specially equipped to burn them. There is evidence that phosphatic coals do not usually cause serious deposits throughout the boiler system if the fuel bed is thin, but they should not be burned in thick beds at high temperature.

Having briefly surveyed the characteristics of fuel, we can turn to operational practice in the boiler house, and it is here that the human element enters the problem. It is not without significance that investigators working for the Boiler Availability Committee have found that boilers ran for much longer periods than usual when kept under observation. It is difficult to escape the conclusion that these boilers were cleaned more thoroughly and operated with greater care because it was known that they were subjects of special interest. We may expect that this part of the deposit problem, which is caused by weakness of operation, will diminish in importance as new operators, many of whom were drafted into boilerhouses during the war, acquire the necessary training.

It has been found that deposits grow more rapidly when the fires are irregular, with long tails of burning coke. Blow-holes in the bed seem to be especially bad. Every effort should therefore be made to keep clean and even fires with a sharp cut-off at the rear. This is often impossible when the coal supplied is unfamiliar, badly mixed, very dirty or unsuitable in other ways for the plant in which it is burned, as it so often is today. Attempts have been made to counter this painfully common situation by modifications to grates. In one instance, the pressure under the front of a chain-grate has been increased by fitting a diaphragm to shut off the air-supply to the rear ; it has given much benefit in burning difficult coals, but the effect upon the rate of growth of deposits has not been proved.

Increasing the turbulence in the combustion chamber by high velocity secondary air or other means is a matter for experiment. Success cannot be guaranteed in every plant at this stage of the research.

I must emphasise that in these or any other experiments on boilers it is essential to have a carefully prepared plan, and to follow it strictly. Individual tests can sometimes give useful guidance, but sound conclusions can only be drawn from a sufficient number of tests which are chosen from a statistical point of view.

Fused ash deposits which occur on lower bank generator tubes and in the earlier stages of a superheater can be controlled to some extent by changing to a coal of higher ash-softening temperature, but it may be necessary to lower the temperature of gases leaving the combustion chamber in order to gain full control. This may be a matter of boiler design ; but it can sometimes be done by using secondary air to shorten the flame. Fused ash deposits can be removed by water lancing.

Severe corrosion of air heaters by sulphuric acid can often be mitigated by using methods such as recirculation of air to raise the metal temperature, and

by burning coal with less sulphur in it. It will be realised from what has been said today that there are promising ways of inhibiting the formation of sulphuric acid, and perhaps of removing it harmlessly if it is formed, at least in theory. The Boiler Availability Committee is investigating these possibilities.

Owing to the failure of older methods of cleaning to deal adequately with the deposits that grow in modern plants, it has been necessary to develop the new methods of cleaning which Mr. Marskell has described. The Boiler Availability Committee believes that these methods, or still better ones when they are devised, are indispensable, that provision for them must be made in future plant, and that they should be used as extensively as possible in existing plant, which should, if necessary, be adapted for the purpose.

These new methods of cleaning make it possible, in all but the most difficult cases, to get boilers clean and to keep them clean in the way that Mr. Adams has shown to be essential for the highest availability and efficiency. This, however, may be an administrative matter as well as a technical one. Cleaning a boiler down to the metal, as it is termed, is a relatively lengthy process, but it is a necessary first step. Executive engineers who are responsible for availability may need assurance that the extra time which is allowed for thorough cleaning will be more than repaid by the longer term of service at a higher average load which can be expected. This assurance is best gained by planned trials, and the Boiler Availability Committee, basing its opinion on practical evidence, has no doubt whatever about the results. Time must be made for proper cleaning in order to save more time.

It is often said that modern boilers are more susceptible to deposits than older units. This may be true of individual boilers, but it is not necessarily true of boilers as a class. A survey of nearly 1,150 boilers in 136 power stations has shown, among other things, that on the average it is the older boilers that are shut down more often for cleaning. This observation must be interpreted in the light of the greater demand for availability from modern units. On the average, availability may be no worse than it used to be, showing that boiler design has not lagged behind the development of the problem; but it is certainly not good enough for modern conditions. The work of the Boiler Availability Committee has the two-fold purpose of mitigating these troubles in existing plants, and of discovering so much about their fundamental causes that boilers of the future can be designed to avoid them, without the rule-of-thumb limitations which might restrict development in other ways.

## 6. Boiler Design

By J. MAYER, B.SC. (VICT.), A.M.I.MECH.E.

I should like to refer to the "Boiler Availability Test" since it has given a new stimulus to boiler design and firing technique.

The emphasis in British design had hitherto been on thermal efficiency, so much so that this "Availability Test" was officially described as a "Deferred Efficiency Test", the criterion of success being a minimum fall in efficiency over the operating period of six months without off-load cleaning.

Fortunately, some years' experience of the practical operation of this test has shown that the original efficiency can be maintained without undue difficulty, provided the availability feature is achieved. This is a conclusion of primary importance, not only to the designer but to the user, in view of

the past six years' unfortunate trend of rising coal costs, accompanied by deteriorating coal quality.

The boiler designer realises that in dealing with plant fired by a retort stoker or travelling-grate stoker, he may expect bonded deposits or low temperature end deposits, or both, while with pulverised fuel his problems are confined to those arising from the physical deformation of the ash substance. In the absence of any decisive lead from the research investigations as to the fundamental factors responsible for the formation of the various chemical deposits arising with stoker firing, the designer must rely on a physical manipulation and distribution of his heating surfaces, and a discriminating choice in the auxiliary items of heat recovery apparatus.

Thus furnace volumes are increased, accompanied by an increase in radiant heat absorbing surface ; and every endeavour is made to introduce over-fire air in sufficient quantity, pressure and direction to promote thorough mixing of the gaseous contents of the furnace. Thereafter, heating surface is so spaced, both laterally and in depth of bank, as to provide well-defined stages of gas temperature reduction in relation to metal surface temperature and the fullest accessibility for the cleaning methods to be employed.

It is essential that the arrangement of surface cleaning apparatus should be studied as an integral part of the unit design and the provision of automatic remote operation of this equipment enables blower location to be selected with a freedom not possible in older designs.

The next few years will see the introduction in commercial operation in this country of water tube-boilers of substantial evaporative capacity fired by spreader stokers. With this machine the combustion principle is such that the ash bed is maintained at a temperature level where there is little likelihood of the volatile elements being released, and if they are driven off they must pass through the main flame body. Bonded deposits formed by volatilisation may therefore be expected to be suppressed with consequent improved availability.

(The author showed three slides\* at this stage illustrating the application of these principles. No. 1 was of a header-type boiler fired by a chain-grate stoker built for an evaporation of 180,000 lb./hr. at a pressure of 650 lb./sq. in. and 850° F. temperature. This had the modern open type of furnace setting. The superheater was divided into primary and secondary sections with inter-stage attemperators and the setting provided for large aperture blowers under each bank of superheater tubes.

No. 2 showed a vertical 3-drum boiler, also fired by a chain-grate stoker, having steam conditions similar to the preceding unit but with an evaporation of 230,000 lb./hr. and using as fuel one part of coke dust to three parts of low grade bituminous slack. Here the setting was as open as possible, the furnace being of the bare tube type. The furnace cooling was extended past the line of the few convection tubes to the first superheater section. The spacing of the convection tubes and secondary superheater bank was of the order of 3 d/p ; thereafter, having adequately reduced the temperature, a high mass flow (velocity) was permissible in order to achieve maximum heat transfer.

No. 3 showed a setting for a spreader stoker unit, with moving bar grate. Since the largest coal particles are thrown further than the smaller ones, the

\* The illustrations referred to in this paper and others shown at the meeting by the author are available in a publication issued by the Boiler Availability Committee containing the complete text of all the papers read at this Session.

grate travelled in the reverse of the conventional direction, that is from back to front. The setting was water cooled and of maximum height. This boiler had an evaporation of 175,000 lb./hr. and represented the largest spreader-fired unit under construction in this country.)

So far as the pulverised-fired unit is concerned, it has already been emphasised by previous speakers that the design problems are limited to those arising from physical ash deformation, and it can be said with confidence that the back end deposit or elevated dewpoint problem does not exist in the sense of restricting availability.

The role of burning volatile hydrocarbon in deposit suppression has already been mentioned, but the main reason for the pulverised fuel fired boilers' immunity is probably the passage through the heating surfaces of large quantities of highly absorptive dust, and against the flying start that the pulverised-fired boiler gets in the availability rate the provision of apparatus to collect and dispose of the dust is a very small price to pay.

The boiler designer, however, has a real problem to face, due to the continuous increase in steam temperature up to a level of 925–975° F. required to be maintained over a substantial range of evaporation ; he is thus regularly required to strike a very delicate balance between a safe gas temperature leaving the furnace in accordance with the predicted ash softening/fusion temperature, and one sufficiently high to permit of superheater heat transfer under economic conditions.

This problem is accentuated through an increasing demand for larger boilers which has coincided with the upward trend of steam temperatures and which results in an increased furnace-leaving temperature in the large unit as compared with the small for an equivalent volumetric heat release.

This feature, however, can be corrected by varying the shape of the furnace to produce an increased surface/volume ratio as compared with the cubic shape, resulting in a correspondingly lower furnace-leaving temperature. Thus, the natural demand for greater output from a single unit need not have a fundamentally detrimental effect from the availability standpoint as it can be met within limits by the skyscraper furnace or alternatively by a twin furnace design.

The necessary reduction in gas temperature leaving the furnace has been reached in two ways : firstly, by a progressive increase in the bare tube water cooling of the furnace to a maximum, and secondly, to a lesser degree, by a reduction in the volumetric heat release in the unit. The former method is capable of achieving a temperature reduction up to about 400° F., and the latter has contributed about 100° F.

Contrary to the ideas which prevailed for many years, the fullest use of water cooling is not detrimental to combustion so long as there is no interference with ignition and propagation of the flame. Experiments carried out at the U.S. Bureau of Mines have provided good evidence that high temperatures beyond the ignition point retard combustion, and this fact can also be demonstrated by mathematical analysis.

This important fact is stressed since delayed combustion is one of the most potent factors in preventing availability being obtained.

Burner type and location must be necessarily reconsidered, bearing in mind availability over the widest possible range of ash and volatile content ; and here the short flame turbulent type of burner reveals a weakness in being sensitive to the lower volatile coals and producing local high-temperature zones with a consequent danger of local slag build-up.

The most satisfactory burner for overall performance is the long flame type, since its stable ignition properties can be combined with forced flow mixing either by placing the burners in an arch with progressive secondary air admission over the entire flame path, or locating them at the furnace corners so as to set up an intense swirl in the furnace at right angles to the general direction of flow of gases to the furnace exit. With this latter type of burner location, tilting of the burners can be utilised to modify the flame position, and to some extent control the temperature both at the top and bottom of the furnace.

From the availability point of view, two-shift operation imposes no handicap on the designer; in fact, it is an admirable cleaning procedure, since deposit formation on the bare tube surfaces cracks on cooling and either falls away or can be very readily dislodged.

(The author here showed slides of two p.f. fired units. One was a boiler of 360,000 lb./hr. evaporation operating at 630 lb./sq. in. and 850° F. The burners were placed in a high arch setting with secondary air admission through the front, side and rear block-covered walls. The other was of a type of boiler relatively rare in this country—a reheater designed for 1,310 lb./sq. in. at 850° F., reheated to 850° F., the equivalent steam evaporation being just over 300,000 lb./hr. As the superheater and reheater duty are both obtained by convection transfer, the balance of furnace-leaving temperature is critical and although full water cooling is employed the furnace rating has to be higher than the average for modern designs. Corner firing was employed and, to assist in the steam temperature control, tilting burners were fitted. The free spacing of the several heat transfer zones in this design was well defined.)

Up to the present time all the furnaces that have operated in this country have been of the dry ash discharge type. In the U.S.A., and to a lesser extent on the Continent, there have been a fairly large number of installations of the intermittent or continuous slagging type in which a deliberate attempt is made to puddle the slag in the furnace bottom. The absence of installations of this nature in this country has usually been attributed to the wide diversity of coal supplies here as compared with the situation in the U.S.A., but extensive experience of the slagging furnace has not shown that a wide variation in ash fusion temperature is a real disability to furnace operation.

In the present speaker's view, however, the slagging type of furnace is fundamentally unsuited to the intermittent shift operation of boiler units, which requirement is almost certain to continue to be a dominant one for power station design in this country.

One such unit, however, is now being built in this country, and at the conclusion of this talk I shall show a slide of it, and also one of a dry ash discharge furnace boiler designed for almost identical steam conditions.

The applications of these two types of furnace design, however, are not unlimited and each must be considered in relation to the particular fuel problem involved, the slagging furnace having an upper limit and the dry bottom furnace a lower limit of ash fusion temperature in relation to size of unit.

An alternative method of controlling the discharge in a dry condition is to arrange the firing of the furnace not from the bottom with gas flow upwards, but from the top with gas flow downwards. In this way, if the temperature reduction can be sufficient, all the ash particles will reach the furnace exit below their danger point, a proportion being removed through the hopper opening and the remainder passing out with the gases over the convection surfaces in the usual way.



Slide 6 (not reproduced here) showed a boiler of this type being built for an evaporation of 430,000 lb./hr. at a pressure of 1,350 lb./sq. in. and a temperature of 960° F.

In this design the distinction between radiant and convection heating surface is even more pronounced than usual, while a further special feature is the shielding of the ash hopper chamber contents from furnace radiation.

Provision is made to sweep the long hopper side by sootblowers.

When deposits occur the cleaning requirements between stoker and pulverised fuel fired units differ widely.

The use of water washing or soaking as applied to stoker-fired units and described by previous authors is not required in pulverised fuel boilers, but the use of water lances in place of steam blowers has been very effectively applied both by hand and by automatically operated units. In several stations throughout the country, the change over from steam to water has not only been of benefit from cleanliness but has been of great relief to the problem of overstrained make-up water supply.

In the temperature zones where dusty accumulations are the only problem, such as the lower temperature passes of superheaters, rapping or agitation of the heating surfaces is often all that is required.

In many modern designs of plant it becomes increasingly difficult to cover the heating surface by fixed position blowers and in such circumstances the advantages of the traversing or alternatively the telescopic type of element, whether using steam, water or air, are apparent in that the cleaning jets may be arranged to traverse down the lane of the heating surfaces. Certainly the traversing element requires additional clearance external to the boiler unit but the potential value of that type of cleaner is so great that a slight increase in boiler spacing is not too much to pay for it.

I would like to mention again the importance of interrelated design considerations in the disposition of heating surface and the location of the cleaning apparatus as a vital contribution to increased availability.

(The author concluded by showing two slides illustrating the two most modern boiler units that have been designed in this country and which are both now under construction, the first illustrating the slag tap unit to which earlier reference was made and which is designed for an evaporation of 525,000 lb. per hour, pressure of 1,275 lb./sq. in. and temperature of 975° F. The other slide showed a dry ash removal boiler designed for an evaporation of 540,000 lb. per hour operating under dual steam conditions of 1,350 lb./sq. in. and 965° F., alternatively 950 lb./sq. in. and 920° F. It was noticeable in the last slide that the general layout had been largely regulated by maximum economy of floor space.)

#### *Discussion*

**Mr. T. W. Oliver** (written contribution) deprecated unconstructive criticism on the reliability of instruments and asked that the users of instruments should co-operate with the manufacturers. Instruments played a very great part in the day-to-day operation of the plant. He added : We have not enough instrumentation in industry, and in connection with the aims of this conference, I should like to make an appeal to the Ministry to obtain priority on delivery of instruments directly affecting fuel economy. Automatic controlling apparatus involving electrical equipment is requiring a most excessive order-delivery period ; cannot something be done here ?

## SECTION A. THE GENERATION OF STEAM—*continued*

### SESSION II. Design and Operation of Smaller Boilers

*Chairman of Session:* MR. P. A. SANDERS, O.B.E., D.L., J.P.,  
MEMBER OF COUNCIL OF COMBUSTION APPLIANCE MAKERS ASSOCIATION

#### 1. Considerations affecting the Efficiency of the Heating Surface of Shell Boilers

By E. G. RITCHIE, D.SC., A.M.I.C.E., A.M.I.MECH.E.

(Dr. Ritchie first described the organisation of the boiler research work in the steam engineering department of British Coal Utilisation Research Association and pointed out that the work of the Shell Type Boiler and Firing Equipment Committee (known as R/16 Committee) had been conducted on external boiler plants pending the construction of the B.C.U.R.A. Experimental Station at Leatherhead.)

##### (A) THE EFFECT OF RATING ON GAS TEMPERATURE AND USEFUL HEAT-TRANSFER DISTRIBUTION

###### LANCASHIRE BOILERS

A large number of investigations were carried out at Woolwich Arsenal on Lancashire boilers, 9 ft. in diameter by 30 ft. long, having a nominal rating of 11,000 lb./hr. F. & A. 212° F., fitted with different stokers and tested with different fuels. In these tests, amongst other observations made, flue-gas temperature was measured in the downtake, at the front of the side flues, and at the boiler exit over a range of ratings from 5,000 to just over 12,000 lb./hr. F. & A. 212° F.

The results obtained are shown in Fig. 9, from which it will be observed that although there is a good deal of "spread" in the results, as one might expect, the relationship between gas temperature at any point in the boiler and rating is substantially linear, the gas temperature rising with increase in rating. In particular, the boiler exit gas temperature rises by about 67° F. for each increase in evaporation of 1,000 lb./hr. From the temperature observations and from a knowledge of the quantity of flue gas, based upon an ultimate analysis of the fuel used, the heat transfer in each section of the heating surface, expressed as a percentage of the total useful heat transfer, was determined in each test, with the results shown in Fig. 10. From this it appears that of the total useful heat transfer in a Lancashire boiler, about 83 per cent. occurs in the furnace tubes, 9½ per cent. in the bottom flue, and 7½ per cent. in the side flues, percentages which are not greatly affected by change in rating. The results show how admirably efficient are the furnace tubes in a Lancashire boiler and how admirably the type is suited to a varying load, a fact which might be inferred, since radiation plays such an important part in heat transfer. The construction of the furnace tubes is, of course,

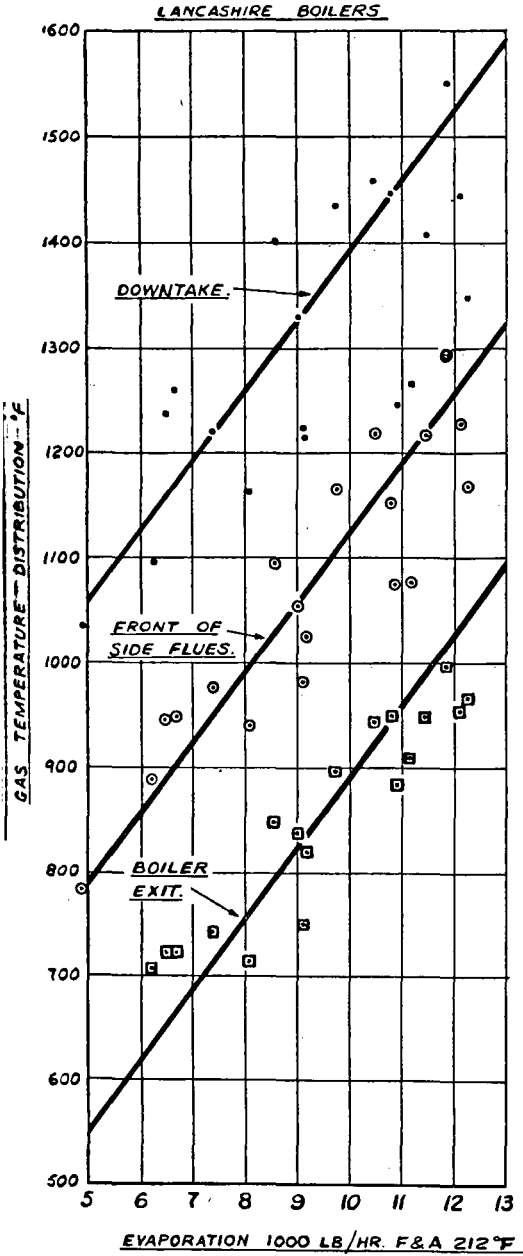


Fig. 9

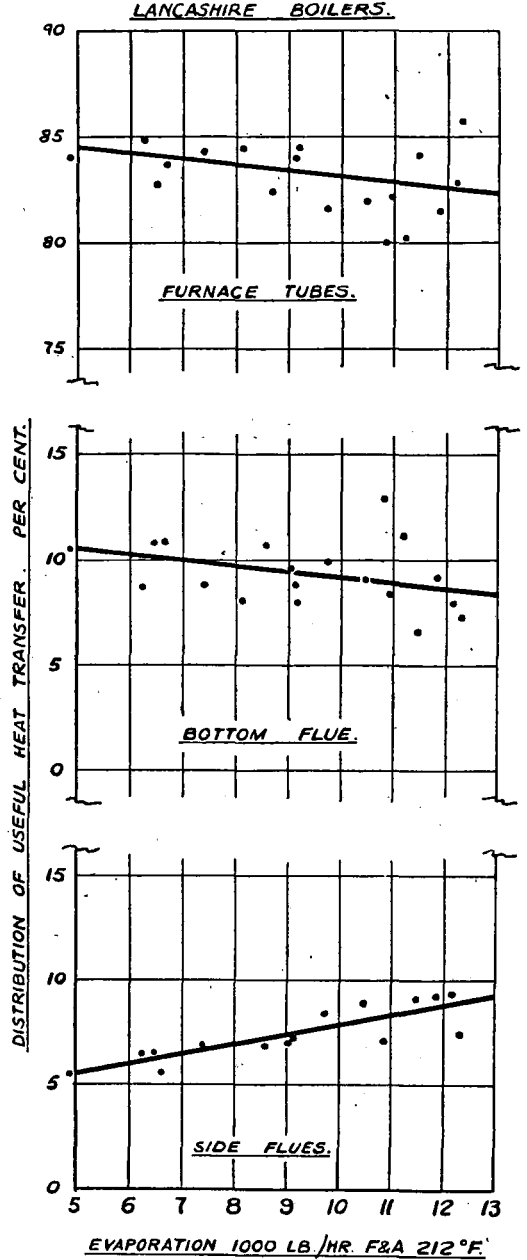


FIG. 10

almost ideal, providing water-cooled heating surface completely surrounding the radiating fuel bed and the radiating mass of gas in that part of the system where the gas temperature is high and the velocity is relatively low.

Important difficulties in the operation of a Lancashire boiler are the prevention of the by-passing of gas between the downtake and the side flues and the infiltration of air through leaky brickwork. The results plotted in Fig. 10 inevitably raise the question as to whether or not the bottom and side flues are worth while, having regard to their relative unimportance from a heat-transfer point of view. The gas temperature in these zones is reaching a point where heat recovery can best be achieved by introducing properly designed convective heating surface. Is the rational future development of the Lancashire boiler not towards the elimination of side flues and/or bottom flue and the incorporation in or beyond the downtake of tubular convective heating surface? There may be a case here for the steaming economiser. If it were practicable to eliminate the brickset side flues of a Lancashire boiler, this would be an enormous improvement, while retaining the highly efficient feature of the type, namely, its long internal furnace tubes.

The results discussed above relate to the Lancashire boiler alone, i.e. the Lancashire boiler *without an economiser*. The addition of an economiser would, of course, improve the performance of the plant in relation to rating, as it represents the addition of convection heating surface so lacking in the boiler itself. By inference from the results plotted in Fig. 9, and assuming the installation of a normal economiser, the temperature of the gas leaving the economiser would increase by only about 40° F. for each increase in evaporation of 1,000 lb./hr., compared with 67° F. for the boiler alone.

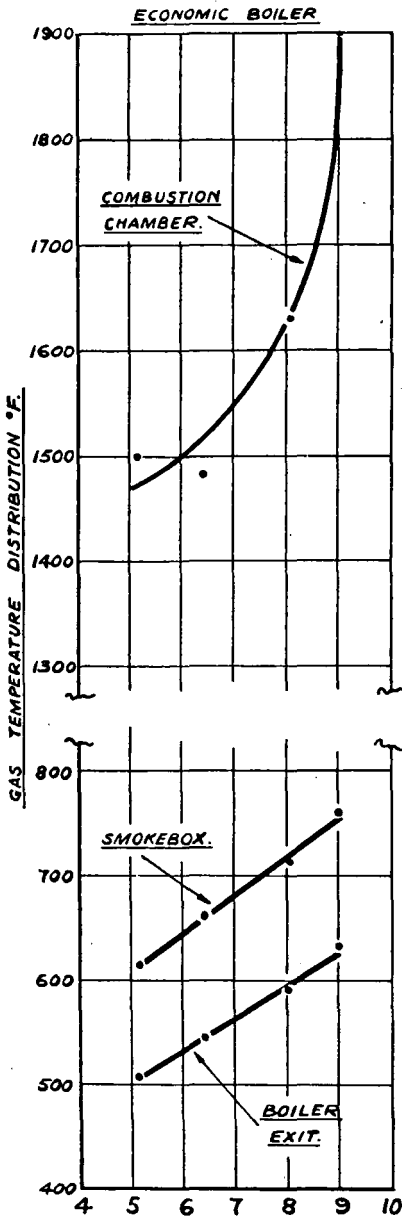
#### ECONOMIC BOILERS

Fig. 11 shows the results of gas-temperature measurement at different ratings in the case of a 9-ft. 6-in. diameter by 14-ft. long double-pass Economic boiler with brickset side flues and no economiser, the nominal rating of which was 7,500 lb./hr. F. & A. 212° F., while Fig. 12 shows the distribution of useful heat transfer. From Fig. 11 it will be observed that above the nominal rating the combustion chamber temperature rises very rapidly, due to the fact that the short furnace tubes absorb a decreasing percentage of the total useful heat as the rating is increased. Exit gas temperature increases by only about 30° F. for each increase in evaporation of 1,000 lb./hr. as compared with 67° F. for the Lancashire boiler alone and 40° F. as inferred for the Lancashire boiler with economiser.

Fig. 12 is extremely interesting as showing how the smoke tubes in an Economic boiler compensate for the loss of heat transfer in the short furnace tubes. The results clearly indicate the very great importance of convection heating surface in a shell boiler, and the variation of the distribution of heat transfer with rating.

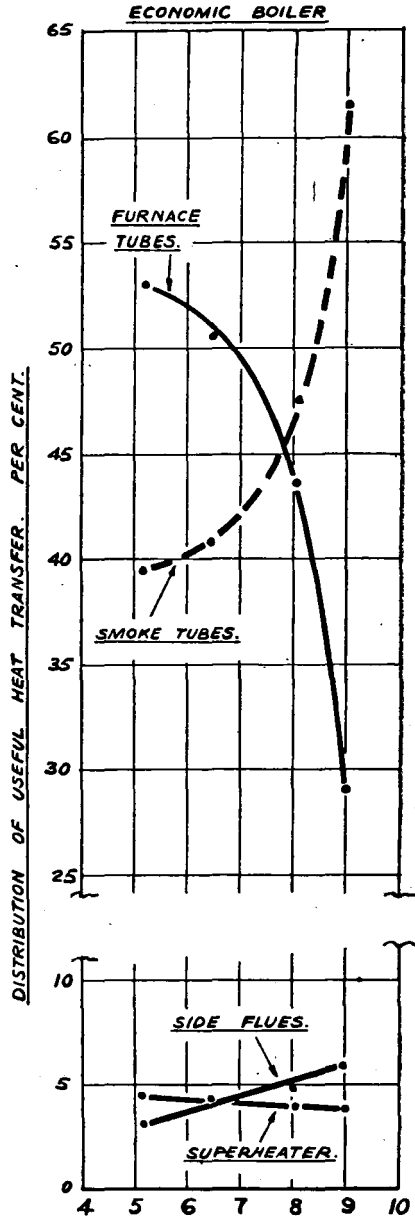
#### EFFICIENCY

From the variation of exit gas temperature with rating here discussed it might be inferred that the efficiency of a shell boiler decreases with increase in rating, which is, of course, the case. The many tests carried out by the Committee have been examined from this standpoint and the conclusion reached that, over a very wide range of ratings, the basic efficiency of a Lancashire boiler, that is the efficiency of the boiler itself, considered as a heat exchanger divorced from all thermal loss attributable to the fuel and the



EVAPORATION 1000 LB./HR. F&A 212 °F.

FIG. 11



EVAPORATION 1000 LB./HR. F&A 212 °F.

FIG. 12

firing appliance, to imperfect insulation, or to defective brickwork, decreases by approximately 2 per cent. for each increase in evaporation of 1,000 lb./hr.

It is not to be assumed that this relationship necessarily holds for an actual boiler installation, as in the complete plant—boiler and stoker—the variation in efficiency with rating is, to a considerable extent, governed by the thermal losses in the firing-appliance and, particularly, the amount of excess air. With mechanical firing, however, and assuming a grade of coal suitable to the maintenance of high combustion efficiency with the minimum of excess air, the relationship does hold over a range of ratings from normal maximum down to 60–70 per cent. of normal maximum. With ratings lower than this, the efficiency usually drops off, due to the leakage of air through the burned-out fuel bed at the back of the grate. In a word, the most efficient firing-rate is about 60–70 per cent. of the maximum. At this rating the investigations of the R/16 Committee show that the Lancashire boiler with an economiser and the double-pass Economic boiler without an economiser are capable of an efficiency approaching 80 per cent. Considerably higher efficiencies can undoubtedly be obtained in three-pass boilers of the Economic type.

The effect of rating on efficiency ought always to be borne in mind in the design of a new boilerhouse or the running of an existing one, particularly having regard to the present very high cost of coal. In many cases the fuel-saving likely to be effected by reducing the operational load to, say, 70 per cent. of normal maximum by running an additional boiler or boilers should more than justify the extra capital or operating cost involved. This is especially so where the plant is running night and day with a high load factor. In most industrial plants heavy peak demands have to be met and, of course, boiler and stoker capacity must be installed to meet this.

In the above discussion of the relationship between rating and efficiency reference is made to the boiler alone, and the figure given of 2 per cent. decrease in efficiency for each 1,000 lb./hr. increase in evaporation more particularly applies to the Lancashire boiler. Where a Lancashire boiler is fitted with an economiser, or in the case of the Economic boiler, the convection heating surface somewhat modifies the relationship, but not to any great extent.

(B) THE EFFECT OF EXCESS AIR AND INFILTRATED AIR ON THE PERFORMANCE OF A SHELL BOILER

In a Lancashire boiler about 25 per cent. of the total effect of excess air is due to gas temperature rise. Excess air is therefore detrimental to the performance of a boiler, not only on account of the added heat which the extra air carries to the stack, but also because it lowers the efficiency of the heating surface.

In a Lancashire boiler without an economiser, the exit gas temperature was found to rise by about 17° F. for each 10 per cent. increase in the amount of excess air. Had an economiser been installed, then, by inference from the results obtained on the boiler alone, the exit gas temperature rise would have been about 15° F. The corresponding figure for a double-pass Economic boiler was found to be 3° F. In an Economic boiler, therefore, the influence of excess air on efficiency is very much less than it is in a Lancashire boiler, either alone or with an economiser. The relevant figures are as follows :—

Lancashire boiler without an economiser.	2.0 per cent.	} Loss of efficiency for each 10 per cent. increase in the amount of excess air
Lancashire boiler with an economiser.	1.5 per cent.	
Economic boiler . . .	0.7 per cent.	

The advantage of the Economic boiler in relation to the effect of excess air is important in a practical sense as in many firing-appliances the amount of excess air is difficult to control, especially at low ratings. In any event, even where close control is possible, it is seldom fully exercised by the boiler operating staff, as the  $\text{CO}_2$  can be allowed to drop a long way before excess air interferes with the steaming capacity of the boiler, and steam output is nearly always the main consideration in the running of industrial boiler plant.

The lesser effect of excess air in the case of the Economic boiler as compared with the Lancashire boiler is, of course, due to the fact that the smoke tubes provide convection heating surface in the hot zone of the boiler. Loss of radiant heat transfer due to the effect of excess air is, therefore, to a considerable extent offset by increase in convective heat transfer due to increased gas velocity.

The investigations above referred to were carried out over a range of excess air from 25 to 140 per cent., corresponding to a range of  $\text{CO}_2$  at the boiler exit from 15 to 8 per cent. Over this range of conditions the furnace tubes of the Lancashire boiler recovered from 82 to 84 per cent., while the bottom flue and side flues each recovered 7-9 per cent. of the total useful heat transfer. The distribution of useful heat transfer is not, therefore, greatly affected by excess air. In the Economic boiler the range of excess air was from 45 to about 200 per cent., corresponding to a range of  $\text{CO}_2$  from 13-6 per cent., and here, as in the case of the rating tests, the smoke tubes showed their astonishing power of compensating for the loss of heat transfer in the furnace tubes due to high gas velocity.

From what has been said it will be realised that excess air is of the greatest importance in relation to boiler efficiency. If due attention were paid to air leakage in the design of the stoker and if proper care were exercised in operation to limit the amount of excess air, the fuel consumption of many industrial plants could be reduced by 20-30 per cent.

It may not be inappropriate here to refer to the relative effect of excess and infiltrated air in a Lancashire boiler installation. Air infiltration in such a plant is usually into the side flues through defective brickwork and, in this connection, it is to be borne in mind that by the time the gases reach the point at which infiltration occurs, some 85 per cent. of the total useful heat transfer has already been done and, therefore, in general terms, infiltrated air can only have a relatively small influence, mainly confined to its effect on the efficiency of the economiser. Moreover, as the economiser is built up of convection heating surface, the loss in gas temperature due to dilution with infiltrated air is partly compensated for by increase in gas velocity.

From the Lancashire boiler tests on the influence of excess air it has been determined by inference that if in the combined plant—boiler and economiser—the  $\text{CO}_2$  at the economiser inlet were reduced from 14-9 per cent., due to air leakage through the setting between the boiler and the economiser, this would reduce the overall efficiency by only 2 per cent. as compared with 11-3 per cent. if the deterioration in  $\text{CO}_2$  were due to excess air admitted through the furnace tubes. In terms of increase in fuel consumption per lb. of steam produced, the corresponding figures are 3 and 17 per cent. respectively.

The moral of this is that, for the future, we must put considerably more emphasis on the effect of excess air. It is not suggested that infiltrated air is not important. It is so, and it represents a thermal loss which is continuous. The point is that excess air admitted through the furnace tubes is far more

important, affecting as it does the efficiency of the whole of the heating surface and not merely the latter part of it, as does infiltrated air. An additional point of importance is that air leakage, whether through the furnace tubes or through defective brickwork, increases the draught loss. The effect, especially of excess air, in this connection may well be such as to limit the steaming capacity of the plant. This aspect of the subject is dealt with in Mr. Pearsall's paper.

(c) GENERAL CONCLUSIONS

The investigations here discussed show that, over a considerable range of ratings, the efficiency of a shell boiler, as reflected in the heat-absorbing capacity of the heating surface, decreases with increase in rating. Shell boilers should be operated at about 70 per cent. of their normal maximum rating.

The results discussed demonstrate the very high efficiency of the long furnace tubes in a Lancashire boiler but suggest the abandonment of the bottom and side flues and their replacement by tubular convection heating-surface.

The investigations carried out on a double-pass Economic boiler demonstrate the value of properly designed and properly disposed convection heating surface. In shell boilers the effect of excess air on efficiency is extremely important, and much more so in a Lancashire boiler than in an Economic boiler, due primarily to the more effective convection heating surface of the latter. The influence of excess air as a factor in fuel economy is a subject which requires emphasis and is one deserving of much more careful study than is usually given to it. In comparison infiltrated air is relatively unimportant.

This paper is published by permission of the British Coal Utilisation Research Association and the Shell Boiler Makers' Association.

## 2. Water-Tube Boilers for Industrial Purposes in Great Britain

By A. S. PEACOCK, A.M.I.MECH.E., M.INST.F.

[Abridged]

The range of water-tube boilers available today for industrial purposes is very great indeed, both as regards output and the pressure and temperature at which the units operate. This paper will deal primarily with the lower and intermediate ranges which generate between 5,000 lb./hr. and 50,000 lb./hr.

### PRESSURE

For an industrial undertaking with total steam requirements up to 50,000 lb./hr. at pressures below 250 lb./sq. in. there is adequate scope for comparing the economic as well as the thermal values between a scheme embracing cylindrical boilers and the alternative possibility of installing water-tube boilers, and in many fields the overall considerations may be favourable to the Lancashire boiler.

Where the pressure is below 250 lb./sq. in. and the evaporation of each boiler is less than 15,000 lb./hr. and the fuel supplies are reasonably good, there is much to be said for the cylindrical boiler.

### STEAM TEMPERATURE

Where the desired steam temperature exceeds 700° F. the water-tube boiler with integral superheater is undoubtedly the most satisfactory equipment available at the present time.



**FUEL**

A cylindrical boiler furnace is, to some extent, pre-determined as regards size and shape which, in turn, limits the coal consumption and correlates the evaporation to the grade of coal and its calorific value.

The size of the combustion chamber available with a water-tube boiler enables the firing equipment to be designed not only for a wide range of solid coal, but for utilising many of the waste or surplus fuels which are available in certain industries, such as wood chips, coke-oven and blast-furnace gas, and coke breeze.

Water-tube boilers are equally suitable for oil fuel and, for overseas territories, can be adapted for bagasse, rice husks, wood logs, and many other similar fuels.

Many alternative arch settings can be introduced, together with front and rear secondary air, to enable the best combustion conditions to be maintained over a wide range of load.

Water-cooled surface is introduced into the majority of combustion chambers and, as the size of the unit increases, the ratio of furnace water-cooling to the boiler surface proper can be substantially increased.

**EFFICIENCY**

The design of the water-tube boiler, without an economiser, enables the products of combustion to be reduced to a lower temperature than that which is obtainable with a cylindrical boiler, and such auxiliary equipment as economisers and air heaters, while equally suitable for installation with either class, results in a higher overall thermal efficiency with water-tube boilers than with cylindrical boilers, basing performance on identical fuel and steaming conditions.

**COAL AND ASH HANDLING PLANT**

The water-tube boiler lends itself admirably to the installation of mechanical coal and ash handling equipment, which reduces the operating costs to a minimum.

**STEAM FOR POWER AND PROCESS**

A number of industrial undertakings have developed their own power and process installations, the steam being generated at a pressure and temperature which is determined by joint consideration of the steam conditions required for process and the electrical load required. Apart from the economic merit on financial grounds, the more efficient utilisation of coal in the national interest should not escape the notice of all executives. In this field of industrial steam production the water-tube boiler is used almost exclusively as a result of the higher pressures and temperatures required.

**LOW-GRADE FUEL**

The purchase of capital equipment for the utilisation of very low-grade fuels may be fully justified in specialised industries, such as collieries or others, which have a ready access to very low-grade fuel which has a very low market value and is therefore available in large quantities at low cost.

In these circumstances it may be highly desirable to spend a substantial amount of capital on the purchase of elaborate firing equipment and yet restrict the boiler plant to a comparatively simple unit that is lowly rated and not necessarily operating at the highest possible efficiency from a thermal point of view. Thus, a boiler, or a boiler plus economiser (as determined by the

feed-water temperature), will generate the steam required by utilising semi-waste fuel and obtain a fairly high degree of boiler availability at a comparatively low capital cost for the boiler plant itself, but with extra capital cost being utilised for the firing equipment.

The introduction of air heaters in such a case, while increasing the efficiency of the unit and bringing about a saving in fuel costs, is not likely to be justified from a purely financial point of view. The present fuel shortage may, however, justify expenditure which from a too narrow viewpoint might be considered uneconomical, in order that a reduction in fuel consumption may be secured.

#### WATER TREATMENT

This is a specialised subject and is to be taken into account when assessing alternative schemes for steam and power generation.

The capital cost of treatment should not be neglected, and the recommendations of water-treatment specialists should be taken into account when determining the pressures and rating at which the boiler should operate and the type of boiler best suited for the duty required.

Water-treatment equipment, which also embraces de-aerators to keep the oxygen content down to a minimum, has been developed to a satisfactory stage, and a very large number of smaller industrial undertakings are now operating satisfactorily with highly efficient water-tube boilers with a considerable percentage of make-up, and are not experiencing difficulties with regard to the operation of the plant.

The overall economies introduced permit the employment of the more technically qualified boilerhouse operative who is capable of maintaining in good order the equipment usually provided with water-tube boilers operating at medium and high pressures.

Similar comments apply with regard to instruments, since a reasonable number of essential instruments enables the operators to obtain results which more than justify the initial capital cost of the equipment.

#### SPACE REQUIRED

The choice of type is frequently determined by the site space available, and although the water-tube boiler is usually provided with mechanical coal-handling plant, it can be safely assumed that greater floor area is required per pound of steam generated with cylindrical boilers than with water-tube boilers when the total output is more than, say, 25/30,000 lb./hr., and the advantage becomes progressively more favourable to the water-tube boiler as the total steam output increases.

### 3. Mechanical Stokers for Shell Boilers

By H. E. PEARSALL, A.M.I.MECH.E., F.INST.F.

[Abridged]

Approximately 50 million tons of coal are consumed each year in shell boilers. It is estimated that of this tonnage, 28 million tons are mechanically fired and 22 million tons hand fired, and further that the fitting of mechanical stokers has already saved at least  $3\frac{1}{2}$  million tons per annum. The fitting of the remaining hand-fired boilers could save another  $2\frac{1}{2}$  million tons.

The mechanical stoker can do what the best fireman cannot do : put fuel on to the grate without opening the fire door, and constantly maintain a level, even fuel bed. Mechanical stokers are also available with self-cleaning grates, thus obviating the necessity for opening the fire door to de-ash.

The R/16 Committee (an Advisory Committee called "The Shell-type Boiler and Firing Equipment Committee" founded by the B.C.U.R.A. in association with the Fuel Efficiency Committee, to gather together the different interests and to initiate a programme of research and development) has carried out intensive research on boiler firing, and some of the particulars and details of its findings are given here.

#### SUMMARY OF R/16 REPORT ON EXCESS AIR

The investigations were carried out for the purpose of determining the effect of excess air on the performance of a shell boiler.

Three cases were studied—

- (a) Lancashire boiler without economiser ;
- (b) Lancashire boiler with economiser ;
- (c) Economic boiler (brick-set type) ;

and the following conclusion was reached :—

"The influence of excess air is considerably greater than is usually assumed, due to the fact that, with increases in the amount of excess air, the temperature of the gas leaving the boiler rises."

In the three cases investigated the increases in temperature of the exit gas were as follows :—

- (a) For Lancashire boiler without economiser 17° F. for each 10 per cent. increase in the amount of excess air.
- (b) For Lancashire boiler with economiser 15° F. for 10 per cent. extra excess air.
- (c) For Economic boiler, 3° F. for 10 per cent. increase in excess air.

These results can be studied from the graphs (Fig. 13).

In terms of efficiency—for each 10 per cent. increase in excess of air—the reduction in efficiency is :—

Lancashire boiler without economiser . . . . .	2.0 per cent.
Lancashire boiler with economiser . . . . .	1.5 "
Economic boiler . . . . .	0.7 "

The efficiencies in each case with various percentages of CO<sub>2</sub> are shown in Fig. 14.

A 1 per cent. drop in CO<sub>2</sub> when the boiler efficiency is low produces very much greater fuel loss than the same drop when the efficiency is high.

#### MECHANICAL FIRING *v.* HAND FIRING

If we compare the mechanically-fired Lancashire boiler without an economiser with one of the very many badly hand-fired boilers, we shall see a difference in fuel consumption up to 40 per cent. Such a case will be when the mechanically-fired boiler is operating at 68 per cent. efficiency, maintaining an average CO<sub>2</sub> of 14 per cent. and using 1,500 tons of coal per annum. The same boiler plant, hand fired, with an average CO<sub>2</sub> of 8 per cent. (which is not infrequent) would only be operating at 48 per cent. efficiency and would be consuming 2,125 tons of coal per annum, an increase of 625 tons or 42 per cent.

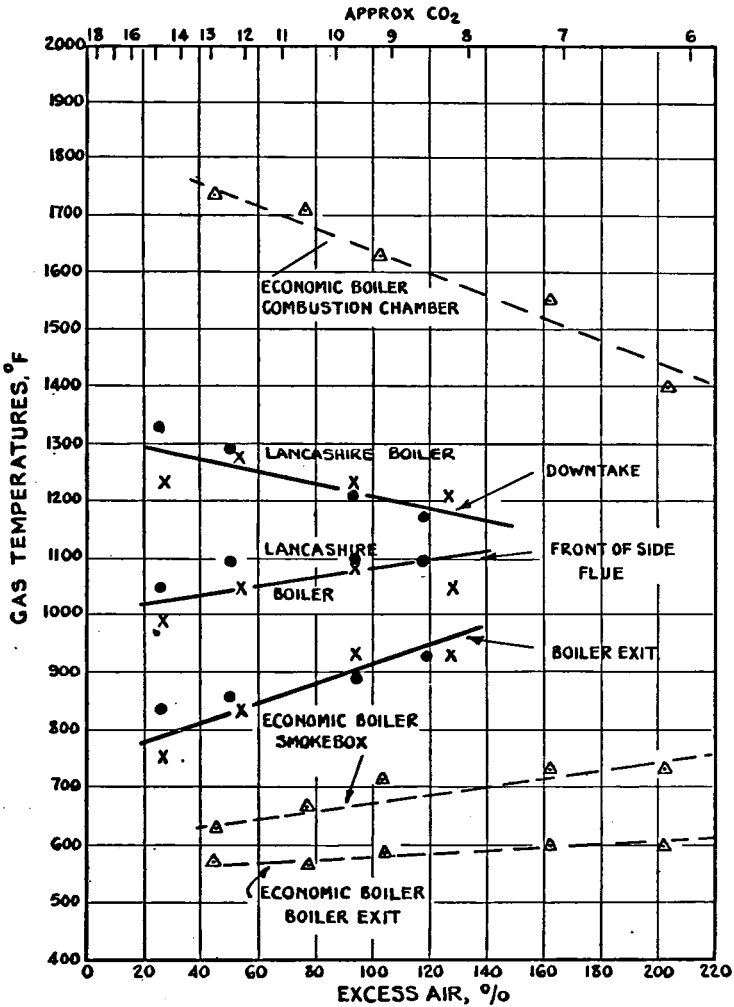


FIG. 13.—Excess air and gas exit temperature.

It may be claimed that 14 per cent. CO<sub>2</sub> is somewhat high for the average operative to maintain, but there are thousands of mechanically-fired plants operating at 12 per cent. CO<sub>2</sub> and many thousands of hand-fired plants operating at 8 per cent. CO<sub>2</sub> or below.

Such figures mean that if the mechanically-fired boiler used 1,600 tons of coal per annum, the hand-fired boiler would consume 2,130 tons with a difference of 530 tons, or nearly 33 per cent. more.

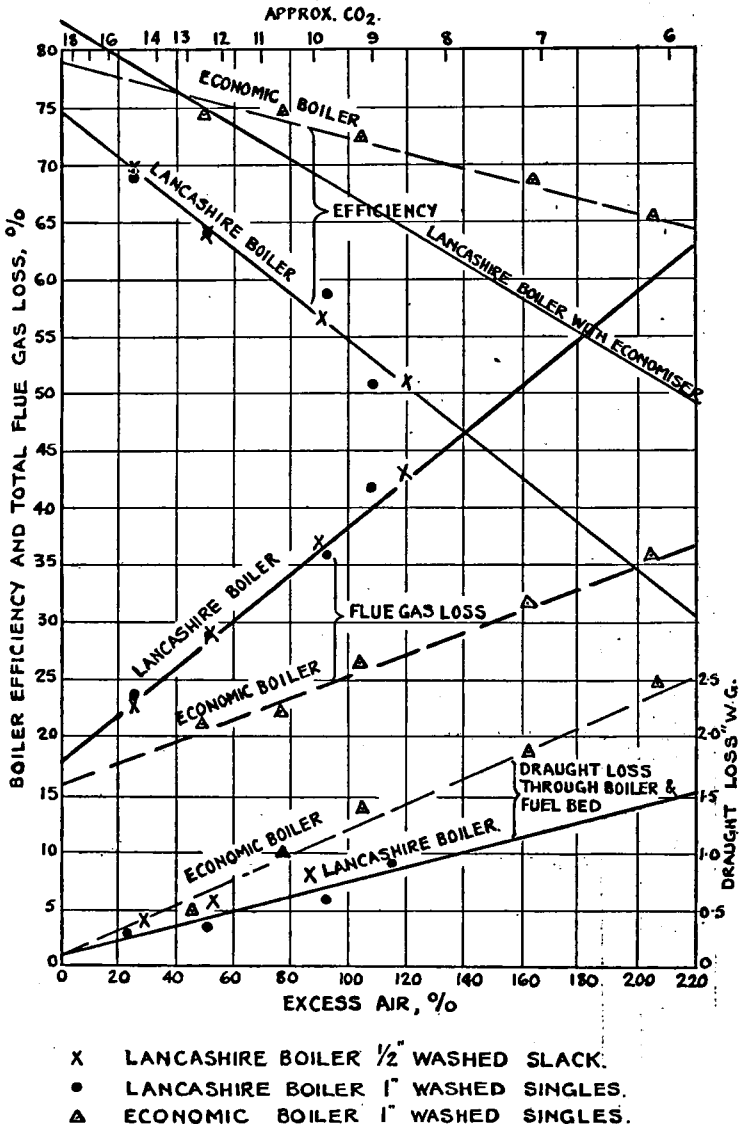


FIG. 14.—Excess air and Boiler efficiency.

HAND FIRING AT ITS BEST

The R/16 Committee carried out most careful investigations on both hand-fired and mechanically-fired boilers. Tables I and II show what must be considered a really first-class hand-firing performance.

The boiler was a natural draught Lancashire boiler 30 ft. 0 in. long × 8 ft. 0 in. diameter and was operated at the output which gave the best performance.

The test lasted  $7\frac{3}{4}$  hours, during which :—

- (a) Each furnace was fired approximately at 15-minute intervals.
- (b) Fire doors were open 20 seconds for each firing.
- (c) Four times during the test each of the fires was sliced and levelled.
- (d) Each hour the boiler was fired eight times.
- (e) During the  $7\frac{3}{4}$  hours—including the time for cleaning the grates—a fire door was wide open for 40 minutes, or nearly 9 per cent. of the trial period.
- (f) The period for cleaning and fire recovery of each furnace was 90 minutes.
- (g) The average  $\text{CO}_2$  for both furnaces for the whole trial was  $11\frac{1}{2}$  per cent.
- (h) It was possible to obtain a  $\text{CO}_2$  reading of over 15 per cent.

TABLE I  
CO<sub>2</sub> READINGS WITH  
HAND-FIRED LANCASHIRE BOILER

Gas analysis at boiler exit					
Left-hand furnace			Right-hand furnace		
Time, mins.	Per cent. CO <sub>2</sub>	Remarks	Time, mins.	Per cent. CO <sub>2</sub>	Remarks
0	14.0		0	12.3	
15	11.0		15	—	
30	—	Fire sliced and levelled	30	10.5	Fire sliced and levelled
45	15.9		45	—	
60	—		60	15.6	
75	12.9		75	—	
90	—		90	14.0	
105	12.9		105	—	
120	—	Fire sliced and levelled	120	15.0	
135	14.4		135	—	
150	—		150	11.2	
165	10.6		165	—	
180	—		180	8.9	Fire sliced and levelled
195	13.4		195	14.6	
210	—		210	11.7	
225	7.9		225	—	
240	10.4		240	12.0	
255	11.6		255	—	Fire sliced and levelled
270	—	Fire sliced and levelled	270	15.4	
285	14.3			285	—
300	—		300	11.0	
315	12.0		315	—	Fire sliced and levelled
330	11.6	Fire sliced and levelled	330	9.8	
345	14.7			345	14.2
360	—		360	14.5	
375	11.0		375	11.0	
390	10.6		390	11.0	
405	5.1	Fire being cleaned, etc.	405	6.0	} Fire being cleaned, etc.
420	4.6		420	6.8	
435	8.5	} Fire reviving after cleaning.	435	—	} Fire reviving after cleaning.
450	—		450	10.9	
465	12.8		465	8.9	
	11.4	Average CO <sub>2</sub>		11.7	Average CO <sub>2</sub>

TABLE II  
OBSERVATIONS DURING CLEANING OF LEFT-HAND  
FURNACE OF HAND-FIRED LANCASHIRE BOILER

Time	Per cent. CO <sub>2</sub> at back of L.H. side flue	Time	Operations	Doors open
11:45	9.9	—	Damper fully open.	
11:50	12.0			
12:00	11.1			
12:05	11.7	12:05	3 shovelfuls fired . . .	10 secs.
		12:08	Fire sliced . . . . .	63 secs.
12:10	8.5			
12:15	6.6			
12:20	11.2			
		12:23	Fire raked . . . . .	10 secs.
12:30	9.2			
		12:32	Cleaning commenced Door open. Damper shut to 24 in.	} 11 mins.
12:33	5.8			
12:36	5.7			
12:39	4.8			
12:42	4.0			
		12:43	Fire spread and door shut	
12:45	6.8	12:43½	6 shovelfuls fired . . .	20 secs.
		12:46	Damper opened 4 ft.	
		12:47	3 shovelfuls fired . . .	10 secs.
12:48	8.1			
12:51	8.0			
		12:52	Damper fully opened	
		12:52½	3 shovelfuls fired . . .	10 secs.
12:55	8.2			
13:00	7.3			
13:05	9.3			
		13:08	6 shovelfuls fired . . .	20 secs.
13:10	9.6			
13:15	6.6	13:15	Fire raked . . . . .	10 secs.
13:20	9.4			

## MECHANICAL FIRING

For comparison tests were carried out with mechanical firing, and the observations are given in Table III.

TABLE III  
CO<sub>2</sub> READINGS WITH  
MECHANICALLY-FIRED LANCASHIRE BOILER

Time, minutes	Boiler Exit Side flue		Time, minutes	Boiler Exit Side flue	
	Left	Right		Left	Right
	CO <sub>2</sub> Per cent.	CO <sub>2</sub> Per cent.		CO <sub>2</sub> Per cent.	CO <sub>2</sub> Per cent.
0	14.5	14.6	210	16.2	15.6
15	14.6	15.0	225	15.8	15.6
30	14.6	14.6	240	15.6	15.4
45	14.6	14.8	255	16.4	16.4
60	15.2	15.2	270	15.8	16.0
75	16.0	15.8	285	15.6	15.8
90	15.8	15.6	300	13.0	12.8
105	15.0	14.0	315	13.0	13.2
120	14.2	14.6	330	15.0	14.8
135	14.8	14.8	345	15.6	15.0
150	14.8	14.8	360	15.4	15.6
165	15.6	15.8			
180	14.9	15.1			
195	15.6	16.3			
			Average CO <sub>2</sub>	15.1	15.09

The boiler was of the Lancashire type—30 ft. 0 in. × 9 ft. 0 in., giving an output of 11,800 lb. of steam per hour from and at 212° F. The test lasted 6 hours and particulars for each flue were obtained.

The average CO<sub>2</sub> for both furnaces, mechanically fired, was 15·1 per cent. as compared with 11·5 per cent. for the hand-fired furnaces.

Taking the efficiency at 15 per cent. CO<sub>2</sub> as given in Fig. 14 as 70 per cent., the efficiency of the hand-fired boiler would be 62 per cent. and the coal consumption would be increased by 13 per cent.

It may be suggested that an average CO<sub>2</sub> of 15 per cent. is rather high even for mechanical firing, but it must be pointed out that such figures are obtainable, and in the demand for fuel economy we must endeavour to obtain the best results. Similarly the figures with hand firing are as good as one can get so that the comparison is quite fair. It is not possible to say just how much coal is used in shell boilers, but the figure of 50 million tons already mentioned is a reasonable approximation.

Table IV shows the percentages consumed on the various types of shell boilers based upon the Ministry of Fuel and Power's census.

TABLE IV  
SHELL BOILERS HAND-FIRED AND MECHANICALLY-FIRED

	Hand fired per cent.	Mechanically fired per cent.	Total per cent.
Cornish boilers . . . . .	0·7	0·5	1·2
Lancashire boilers . . . . .	39·2	46·5	85·7
Economic boilers . . . . .	1·7	8·5	10·2
Other stationary types— marine, loco., etc. . . . .	2·3	0·6	2·9
All shell boilers . . . . .	43·9	56·1	100

It seems reasonable to assume, therefore, that of the 50 million tons, 22 million tons is used on hand-fired boilers and 28 million tons on mechanically-fired boilers.

If we apply the Ministry figures as being representative of all plants, the coal consumed in the various types of boilers would be approximately as shown in Table V.

TABLE V  
COAL BURNED ON SHELL BOILERS PER ANNUM  
*Based on total coal consumption of 50,000,000 tons per annum and percentages as given in Table IV*

	Hand fired (tons)	Mechanically fired (tons)
Cornish boilers . . . . .	350,000	250,000
Lancashire boilers . . . . .	19,600,000	23,250,000
Economic boilers . . . . .	850,000	4,250,000
Marine, loco., etc. . . . .	1,150,000	300,000
Total . . . . .	21,950,000	28,050,000



From the data already given, we can safely anticipate that the increase in average  $\text{CO}_2$  for mechanical firing over hand firing will not be less than 3 per cent., the basis of  $\text{CO}_2$  being taken as low as 12 per cent. for mechanical firing and as high as 9 per cent. for hand firing. By fitting mechanical stokers fuel savings would be effected of—

Lancashire and Cornish boilers without economiser . . . . .	17.3 per cent.
Lancashire and Cornish boilers with economiser . . . . .	10 „
Economic boiler . . . . .	4.75 „

From the table of estimated consumptions we can estimate the total saving (assuming that two-thirds of the Cornish and Lancashire boilers are fitted with economisers).

TABLE VI  
ESTIMATED COAL SAVING FROM MECHANICAL FIRING OF PRESENT  
HAND-FIRED BOILERS

Hand fired	Present consumption (tons)	Consumption if mechanically fired (tons)	Saving (tons)
Lancs. and Cornish boilers without economisers . . . . .	6,650,000	5,500,000	1,150,000
Lancs. and Cornish boilers with economisers . . . . .	13,300,000	11,970,000	1,330,000
Economic and stationary marine boilers . . . . .	2,000,000	1,905,000	95,000
<b>Total . . . . .</b>	<b>21,950,000</b>	<b>19,375,000</b>	<b>2,575,000</b>

#### MECHANICAL STOKERS AND DRAUGHT

Perhaps the most common complaint in the operation of a Lancashire boiler is lack of draught.

Fig. 14, prepared from data obtained by the R/16 Committee, clearly indicates how the draught falls with the quantity of excess air.

With 12 per cent.  $\text{CO}_2$  the draught loss through the boiler and fuel bed is 0.45 in. w.g., but with 9 per cent.  $\text{CO}_2$  the draught loss is 0.8 in. w.g. The evaporation of the boiler and also its capacity for burning low-grade fuel depends upon the draught available. This is one of the reasons which enables the mechanically-fired boiler to produce more steam than the hand-fired boiler, and also to burn a wider range of fuels.

#### BOILER RATINGS

It has been determined that somewhat higher boiler efficiencies could be obtained by reducing the present recognised boiler ratings (c.f. Dr. Ritchie's paper). It can, however, be stated that with mechanically-fired boilers the total heat release per hour from the grate at which maximum efficiency is obtained is much above that of the hand-fired boiler. This means that the mechanically-fired boiler will produce considerably more steam per hour than the hand-fired boiler before passing its maximum efficiency figure.

In support of this, and by permission of the R/16 Committee, Fig. 15 is quoted. Here it will be noted that in the hand-fired boiler the efficiency falls rapidly as the boiler evaporation increases, but in the mechanically-fired boiler the gradient is considerably less.

The hand-fired boiler was one of a battery of four, operating under natural draught with a chimney 100 ft. high, and the mechanically-fired boiler was operating under induced draught.

## EFFICIENCY %

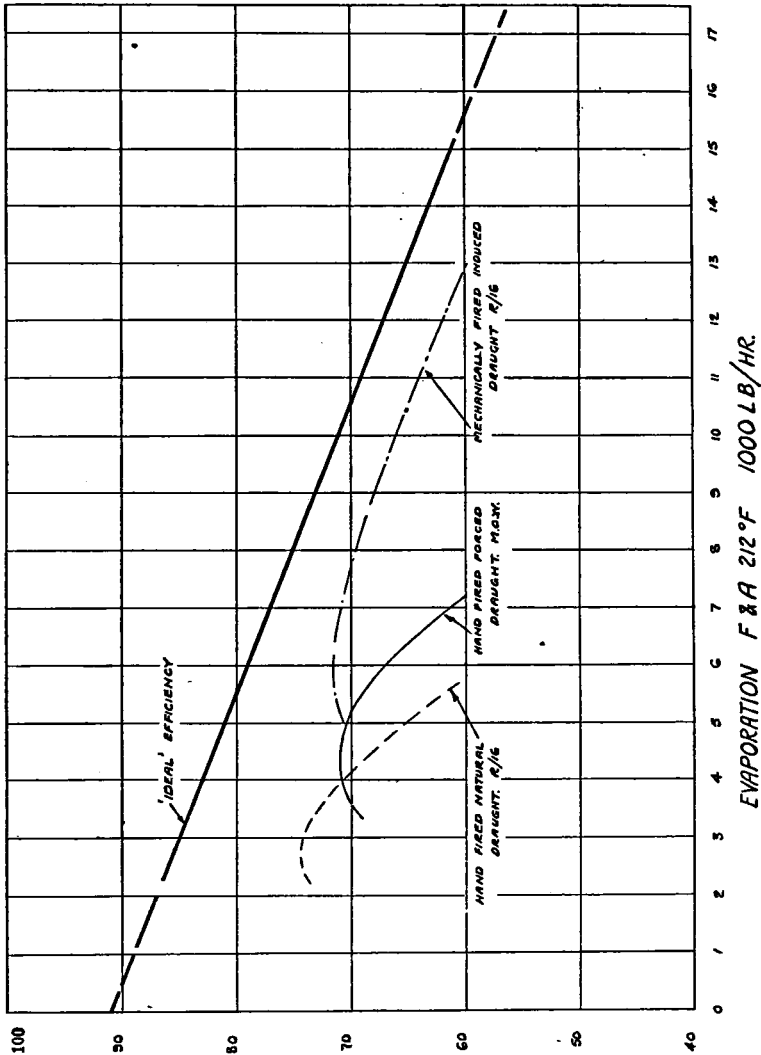


FIG. 15.—Efficiency curves for hand-fired and mechanically-fired Boilers.

The chart is based on a fuel of 12,000 B.Th.U. calorific value and a grate area of 45 sq. ft. The curve for mechanical firing is plotted from the mean figures obtained with moving-grate coking stoker and sprinkler stoker burning 1-in. singles and  $\frac{1}{2}$ -in. slack.

The ideal efficiency curve is based upon rating tests, corrected to a constant 25 per cent. excess air (14.8 per cent.  $\text{CO}_2$ ) in the flue gas at the boiler exit.

Correction is also made for surface heat loss to the atmosphere and also heat loss in ash and clinker.

## FUELS

Mechanical stokers are not selective, particularly as shown by a survey in different parts of the country carried out by the R/16 Committee during the war. They can successfully burn a very wide range of fuels—their upper limit being about  $2\frac{1}{2}$ -in. cube and the lower limit about 45 per cent. through  $\frac{1}{8}$ -in. screen. They can handle any of the fuel from 2-in. slack to and including  $\frac{1}{2}$ -in. slack, as given in Table V in "The Efficient Use of Fuel". There are a few fuels which cannot as yet be mechanically fired, e.g. anthracite duff, slurry and aspirated bituminous dust.

The mechanical stoker is a flexible machine and under present fuel restrictions it is of considerable benefit that it is so responsive, for it has to deal very frequently with sudden fuel changes and it is often the case of 1-in. slacks yesterday, opencast today, and "who knows what" tomorrow. If only the quality of coal supplied to each plant could be kept constant, considerable fuel saving would result and most engineers would be prepared to say that poor coal all the time is better than having to handle unknown variations day by day.

It would also be more economical, whenever possible, to remove excessive ash before the coal is fired into the boiler. It is certainly expensive and wasteful to remove it from the boiler furnace.

## LABOUR

With a single boiler the saving in labour from fitting mechanical stokers is but little, but an installation of 2, 3, or 4 boilers fitted with mechanical stokers and coal-conveying plant can be operated by one engineer.

Moreover, with hand firing the boiler output depends upon the capabilities of the fireman, whereas the mechanical stoker can always be designed to meet the maximum capabilities of the boiler.

There are many firemen handling 6 tons of coal per day and in addition removing from 1 to  $1\frac{1}{2}$  tons of ash. Is it to be expected that their firing efficiency will be maintained all through the day?

This is the mechanical age—the mechanical stoker should do the "heavy work" and the operative should use his ability to keep the machine in efficient working order. Mechanical-stoker manufacturers also offer efficient works service to assist any boilerhouse engineer if called upon.

A single boiler working 50 hours per week may have a coal bill of £4,000 a year. There are few pieces of apparatus in a factory costing such a figure. Is it not time that boilerhouse personnel were chosen because of their combustion and mechanical ability rather than their strength? Too much importance cannot be paid to the training of boilerhouse staff and remunerations must be such as to attract the best type of man.

## AUTOMATIC CONTROL

The ideal condition for a boiler plant would be when the load was constant so that a constant rate of firing could be maintained. This condition seldom occurs and fluctuating loads have to be met—particularly in collieries, steelworks, dyeworks, and many other industries. With a hand-fired boiler the operative works to the pressure gauge—and as the pressure begins to fall he increases his rate of firing. His aim is to keep up the pressure and his "standing" as a stoker will be measured by his ability to maintain the pressure and not by the amount of fuel he has used or wasted in doing so. The mechanically-fired plant can be automatically controlled so that fuel and air are adjusted to suit an increase or decrease in load. The maintenance of a steady steam pressure can mean considerable fuel saving.

## SMOKE ABATEMENT

The mechanical stoker maintains a constant fuel-bed condition. The coal is fed in very small regular quantities and provided it is not called upon to feed more coal than the grate will consume, smokeless conditions can be maintained. The comparatively large quantities which have to be fired, at longer intervals, on the hand-fired boiler make it most difficult to operate under smokeless conditions.

SUMMARISED, THE CASE FOR MECHANICAL FIRING IS :

(1) A saving of coal of 10/20 per cent. due to operating being possible with a minimum quantity of excess air.

(2) A greater evaporative capacity with the boiler operating at its maximum efficiency.

(3) A saving in labour cost.

(4) The boiler operative's work is less arduous and more interesting.

(5) It permits the use of automatic control and helps to maintain a constant steam pressure.

(6) It ensures smokeless and efficient combustion.

(7) A very wide range of fuels can be used successfully.

In conclusion it may be stated that, in general, stoker design in this country is very much in front of design in Germany. Here we have been able to burn very much lower grades of coal and our shell boiler plants are more efficient in fuel consumption and operation. In Germany it has been usual to have a graded fuel for mechanical firing, and so far as can be ascertained all sprinkler and spreader stokers are operating with stationary grates.

In the past much unearned credit has been given to continental designers, perhaps because of the grossly exaggerated claims often made in the foreign technical press for designs which never even get beyond the patent office.

British mechanical stokers could be fitted to German shell boilers and produce good dividends from fuel saving.

## FUTURE TRENDS

Mechanical stoker design is never stationary—improvements and new ideas are continually being developed. During the last few years we have seen great improvements in the development of the fan forced-draught stoker.

Research with materials and fuels is receiving full and careful attention. There is also close co-operation between the shell boiler makers and mechanical stoker manufacturers. Work is being carried out to determine the most efficient rates of burning the various fuels now available. The correct proportioning of primary and secondary air and the value of pre-heated air are not being neglected.

The mechanical stoker of the future will most certainly be fully automatic. Recording instruments will control the correct ration of primary and secondary air to the fuel bed and automatically increase the rate of fuel feed in accordance with the steam load. The grates will be self-cleaning and ash-handling plant will remove ashes and clinker.

The mechanical stoker for shell boilers will easily hold its own against any threat from oil or pulverised fuel. A clear policy from the Ministry of Fuel and Power upon the types of fuels to be expected in the future would be of the greatest assistance in stoker design and would, without question, assist in the battle to conserve coal.

This paper is published by permission of the British Coal Utilisation Research Association and the Shell Boiler Makers' Association.

## 4. The Chain-Grate Stoker as applied to Shell Boilers

By C. H. G. HAYWARD, A.M.I.MECH.E., M.I.MAR.E., M.INST.F.

In the days when ample coal supplies were available and prices bore some relationship to quality, the lower grades were largely utilised in boilers of the water-tube type, which have the advantage of large combustion chambers and the possibility for making provision for dealing with a large quantity of ash.

As the quality of these coals deteriorated, the firing equipment was developed to the degree that the present chain-grate stoker fitted to the water-tube boiler can handle a very wide range of coals, including fine coals and those with a high percentage of ash.

With the coal situation which arose during the war and is still with us, and seems likely to remain for some little while, it has become necessary to deal with lower grades of coal in Lancashire boilers than has hitherto been considered practicable. This has directed attention to the further consideration of the chain-grate stoker for this type of boiler. Little progress appears to have been made hitherto in this direction, but with the greater urge of the present situation and by taking full advantage of about 60 years' experience with chain-grate stokers for water-tube boilers, a successful stoker has been developed (Fig. 16). A quick solution of the problem was facilitated by experience in the larger field enabling many potential "snags" to be avoided.

An outstanding difference between the use of a chain-grate stoker with a water-tube boiler and its application to a shell boiler arises from the much smaller space available in the latter case for its accommodation and for the handling of the ash. The magnitude of the problem will be appreciated from the fact that the depth of the machine alone as applied to water-tube boilers is from 3 ft. 0 in. to 4 ft. 0 in., whereas the total space available in the case of the shell boiler is normally a flue tube of about 3 ft. 0 in. diameter or a little more, for the stoker, the combustion space, and the removal of ash.

To deal with the low-grade fuels it is considered necessary to employ forced draught always and the stoker has been designed on this basis. The air is delivered to an air box located between the top and bottom runs of the chain and provision made for the air supply to the front and rear portions of the grate to be separately controlled. The air box is of all-welded monobloc construction and supports the grate. In this way it has been found possible to construct a very substantial machine for its purpose within a depth of only 10½ in.

In the design of the cast-iron grate links, which are necessarily of much smaller dimensions than on the larger stokers, it has been possible to retain the advantages of fine air-spacing, which is so important in dealing with fine low-grade fuels.

Rear sprockets, as frequently employed with the larger chain grates, could not be readily accommodated in such a limited space, and the lubrication of these sprockets could not be considered a satisfactory feature in such conditions. Accordingly no rear sprockets are employed, but at the rear the chain returns over a curved guide plate.

Space restrictions also limited the choice of drive. The design adopted is a worm and worm-wheel on the front shaft, as is normal for this type of stoker, operated by a pawl and ratchet, each stoker having its own individual driving motor, reduction gear, and speed control. The whole being combined in

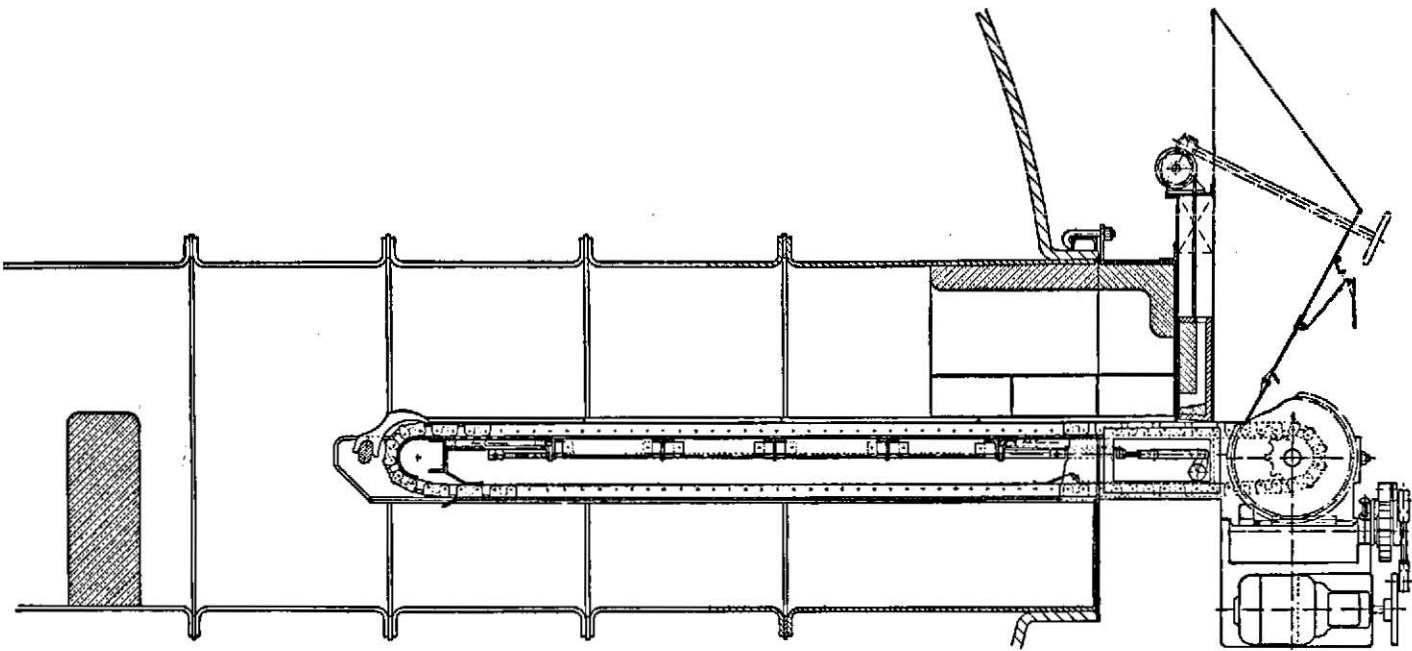


FIG. 16.—Arrangement of Chain-grate Stoker for Lancashire Boiler.

monobloc construction and the stoker being supported on runners attached to the flue, it is quite a simple operation to withdraw one stoker from its flue for inspection or overhaul. The stoker can be withdrawn without difficulty in about half an hour on the special trolley provided for the purpose. With a pair of stokers in a Lancashire boiler, in the event of a breakdown on one grate the boiler could, in an emergency, be steamed with one stoker only, as the removal of one stoker does not disturb the other.

Hopper design is a very important feature on an efficient chain-grate stoker, it being particularly necessary with low-grade fuels to have an evenly distributed low-resistance fuel bed across the full width of the grate. Special attention has been given to this matter.

As with all chain grates, fire thickness is regulated by means of a refractory lined fire door. This door, however, has a unique feature in that it provides accommodation for secondary air which is delivered through suitable openings in the fire door to the furnace above the fire at the front of the grate. This secondary air supply is taken from the forced-draught fan which delivers the air under the fire.

To enable a wide range of fuels to be burned, ash plates or clinker dams are provided. They are not, however, as is often the case, necessary for the purpose of providing an air seal. This being so, should the fuel be of suitable quality, the ash plates may be dispensed with. They are quite easily replaced in a matter of minutes when necessary to suit a particular fuel.

The first machine has been in operation for about three years and a variety of fuels has been burned in the meantime. By means of a special device, coke breeze and fuels of low volatile content can be burned. The rate at which coke breeze can be burned is governed primarily by the amount of grit carry-over which can be tolerated. The very high swelling fuels, such as Kent and Somerset, present difficulties on all chain grates, and owing to the limitations of what can be done within the confines of the flue of a shell boiler, these fuels are extremely difficult to burn off with a reasonable  $\text{CO}_2$  content in the flue gases.

Within the limits of these two extremes of non-caking and caking fuels, very satisfactory results are obtained. The only restriction on size appears to be in the maximum dimensions, which of course applies to all chain grates. In the cause of best efficiency it is desirable to limit these to about  $\frac{3}{4}$  in., although in a case of necessity this figure can generally be exceeded somewhat. In an emergency it would be possible to hand-fire pieces up to 8-in. cube. Throughout the wide range of fuels which can be dealt with combustion is absolutely smokeless, and although the boiler heating surface is only a matter of inches away from the fuel bed, ignition is maintained right up to the fire door, which is a matter of considerable interest when one remembers the height of the average stoker-fired furnace on a water-tube boiler. Table I shows the result of three tests on these stokers.

Stokers have recently been installed at a colliery in an attempt to burn the very fine fuels which result from modern washery practice, and whilst it is too early yet to give any reliable information on this installation, the preliminary results have been most encouraging. A start has also been made in trying out the lower volatile South Wales fuels, and here again the first trials show promise for the future.

Up to date, in order to get the machine into production on a reasonable scale, under the difficult conditions prevailing, it has been necessary to con-

centrate on Lancashire boilers only. It is hoped in the near future to adapt it for use with Economic and similar types of boiler, and also to the tubular type of high-pressure hot water boiler.

TABLE I

REPORT ON TEST OF FLAT-ENDED LANCASHIRE BOILER FITTED WITH CHAIN-GRATE STOKERS

DATES OF TESTS : 3/10/45, 20/3/46 and 29/3/46.

PARTICULARS OF PLANT :—

Boiler, Lancashire, 30 ft. 0 in. × 8 ft. 0 in. Heating surface, 1,085 sq. ft.  
 "Oldbury" C.G. Stokers. Two of 20 sq. ft. each. Grate area, 40 sq. ft.  
 Forced Draught and Chimney Draught employed.

Duration of test	5 hours	5 hours	4 hours
FUEL	Griff D.S.	Griff Nutty	Outcrop
	Nuts	Slack	
<i>Proximate Analysis as weighed—</i>			
Moisture . . . . . per cent.	12·4	13·97	19·00
Volatile matter . . . . . per cent.	30·6	28·41	28·03
Fixed carbon . . . . . per cent.	45·2	40·20	42·79
Ash . . . . . per cent.	11·8	17·42	10·18
	100·0	100·0	100·0
Gross calorific value as weighed . B.Th.U./lb.	10,757	9,919	9,805
Net calorific value as weighed . B.Th.U./lb.	10,105	9,449	9,277
Fuel fired per hour . . . . . lb.	1,232	1,440	—
Fuel fired per hour per sq. ft. of grate area . . . . . lb.	30·8	36·0	—
<b>ASHES AND CLINKER.</b>			
Collected per hour . . . . . lb.	110·4	177·6	—
Percentage of fuel fired . . . . . per cent.	8·96	12·4	—
Percentage of combustible in ash . . . . . per cent.	6·31	10·3	—
<b>WATER.</b>			
Temperature entering boiler . . . . . ° F.	255	257	—
Evaporation per hour . . . . . lb.	9,144·4	9,766	11,199
Evaporation per lb. of fuel as weighed . . . . . lb.	7·42	6·78	—
<b>STEAM (SATURATED).</b>			
Gauge pressure . . . . . lb./sq. in.	99·0	98·5	—
Heat per lb. above feed temperature . B.Th.U./lb.	966·6	968·3	—
<b>FLUE GASES.</b>			
Temperature leaving boiler . . . . . ° F.	861	812	848
CO <sub>2</sub> leaving boiler . . . . . per cent.	11·5	10·7	10·9
<b>DRAUGHT.</b>			
Suction over fires . . . . . Ins. W.G.	0	0	0
Suction leaving boiler . . . . . Ins. W.G.	0·54	0·52	0·43
<b>AIR.</b>			
Pressure at grate . . . . . Ins. W.G.	0·77	1·59	2·47
Temperature of air supply to furnace . . . . . ° F.	80	68·6	—
<b>RESULTS.</b>			
<b>OVERALL THERMAL EFFICIENCY ON GROSS C.V. OF FUEL . . . . . per cent.</b>			
	66·68	64·33	—
<b>HEAT ACCOUNT CALCULATED ON THE NET C.V. OF THE FUEL.</b>			
Overall thermal efficiency . . . . . per cent.	71·00	67·63	—
Loss due to sensible heat in chimney gases . . . . . per cent.	23·65	26·28	—
Loss due to unburnt CO . . . . . per cent.	0·00	0·00	—
Loss due to combustible in ash . . . . . per cent.	0·81	1·96	—
Balance—radiation and unaccounted . . . . . per cent.	4·54	4·13	—
	100·00	100·00	—
<b>OVERLOAD TEST</b>			
AVERAGE EVAPORATION OBTAINED FOR TWO HOURS . . . . . lb./hr.	12,372	12,630	—

Note.—All calculations in accordance with B.S.S.845—1939.



## 5. Underfeed Stokers for Firing Steam Boilers

By E. L. TINLEY, M.I.MECH.E., F.INST.F.

### INTRODUCTION

In the face of adverse circumstances, and indeed stimulated by them, stoker manufacturers have been able to improve the design of their machines, so that they are now capable of burning with reliability and efficiency a much wider range of fuels than was once thought possible.

### CLASSIFICATION OF UNDERFEED STOKERS

Underfeed stokers may be classified as follows :—

- Types :     (a) Screw feed.  
              (b) Ram feed.
- Varieties : (a) Standard hopper model.  
              (b) Flue model.  
              (c) Bunker feed model.

The flue model is especially designed to fire horizontal shell boilers, such as Lancashire, Cornish, and Economic, and some makers are combining the features of this model with those of the bunker feed model.

The bunker feed model feeds coal direct from the main coal-storage bunker and has the obvious advantage of reducing fuel-handling costs. Another advantage is that the coal-feed tubes and air ducts can be frequently run beneath the firing floor level, thus leaving the boiler fronts completely unobstructed. The ram type is not yet available as a bunker feed model.

The screw feed types are made in a range of sizes with coal-feeding capacities from 12·5 to 1,200 lb. of coal per hour, and the ram feed from 250 to 750 lb. per hour.

### POWER-TRANSMISSION UNITS

The power-transmission units of underfeed stokers are precision made, totally enclosed, and are very reliable.

Where a pawl and ratchet mechanism is employed, the feed screw is given an intermittent rotary motion ; in other cases it rotates continuously. A means is provided for selecting one of a number of rates of feed, either manually or automatically.

The ram feed type stoker has an electro-hydraulic transmission unit. The rams are coupled to pistons which are hydraulically operated by oil delivered at pressure from an indirectly driven gear-type pump. Oil is admitted to, and released from, the operating cylinders of the primary and secondary rams alternately by means of hydraulic reversing valves. The pistons are returned by means of racks and a common idler pinion ; thus, whilst the primary ram is delivering fuel, the secondary rams are returning and vice versa. A needle valve controls the feeding rate, which is infinitely variable, and an automatic relief valve is provided to control the pressure limit of the system.

### FUEL TRANSMISSION

In the screw type stokers the screw which conveys the coal from the hopper or bunker to the retort is usually an alloy steel casting of composition which

ensures toughness and resistance to abrasion, chrome molybdenum or chrome manganese being generally favoured. The largest size of coal which can be accommodated without crushing is, of course, determined by the free space between the flights, and the relation between pitch and speed is chosen for a minimum power consumption and fuel degradation in transit. A smaller pitch along that part of the screw which receives the coal from the hopper than that of the rest of the screw does much to eliminate packing in the coal feed tube.

Where the coal has to be conveyed for long distances, a U-shaped trough with detachable cover plates has much to recommend it.

Bunker feed stokers seem to fall into two categories : (a) those which convey the fuel from the bunker to the retort through a continuous screw, and (b) those which convey the coal in two stages by means of separate screws : the first carries the coal from the bunker to a transfer box and the second, at a slightly lower level, conveys it to the retort.

#### AIR SUPPLY

The air required for combustion is supplied by a low-pressure centrifugal fan, usually of the multi-vane type. The static head against which the fan must operate depends on the resistances of the duct system, tuyeres, and fire bed ; it is usually from 0·75 in. to 2 in. w.g. The fan is generally mounted on the transmission unit and can be clearly seen in most of the illustrations already referred to. Where a number of stokers are used for firing one boiler, they are in some cases supplied by a single fan. The quantity of air supplied may be controlled by means of a hand-set damper situated on the fan inlet, or in the discharge ducting, or it may be under automatic control.

#### RETORTS

The success of any stoker is measured by the efficiency with which it fulfils its primary function of burning the range of fuels for which it is designed.

The main principles governing retort design are :—

(a) That the air and fuel should be introduced and mixed so that unrestricted ignition of the fuel can take place at all points in the fire bed as rapidly as the inherent characteristics of the fuel will permit.

(b) The area of the live fire bed should be the largest possible, governed by the burning rate and the space available, so that the fullest advantage may be taken of heat transmission by radiation.

(c) Sufficient space must be left round the perimeter for ash and clinker deposits, so that favourable combustion conditions may be preserved as long as possible without cleaning the fire.

(d) That the tuyeres and surrounding grates or dead plates should be designed so as to ensure reasonably long life : this implies the use of heat-resisting material, properly proportioned for strength and adequate air cooling. It should be possible easily to replace individual tuyeres when the necessity arises. Provision must be made for cleaning out ashes and " fines " which may find their way into the air chamber beneath the tuyeres and impede air flow.

The elementary retort shown in section in Fig. 17 is rectangular in plan and may be surrounded by a solid refractory hearth, as illustrated, or by air-cooled dead plates. This is the type of retort which is still in general use for firing small vertical and loco. type boilers.

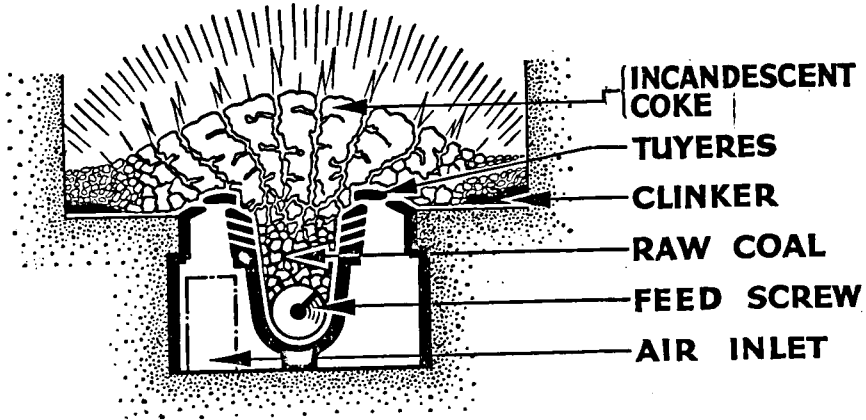


FIG. 17

In boilers of moderate size, principle (b) may be fulfilled by surrounding the retort with a grate (through which air is supplied) and so extending the area of the live fire bed. This arrangement is shown in Fig. 18. The same effect could, of course, be obtained by widening the tuyeres and providing several rows of ports on the outside.

The extent to which the fuel will travel towards the perimeter is limited and is affected by the characteristics of the fuel, particularly its caking properties. It is undesirable to increase the area to any extent by increasing the horizontal

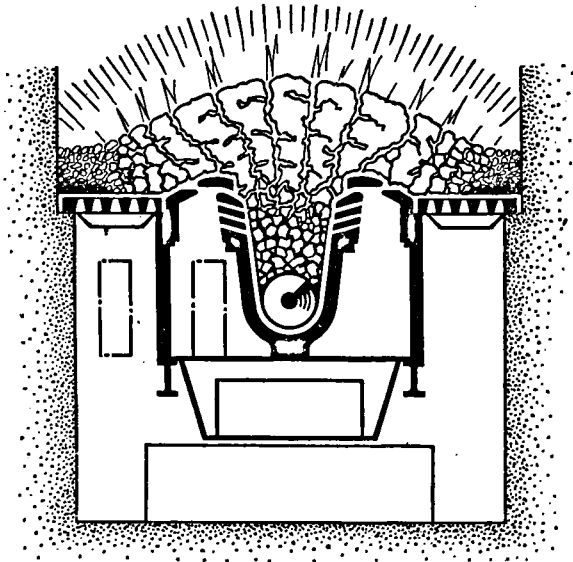


FIG. 18

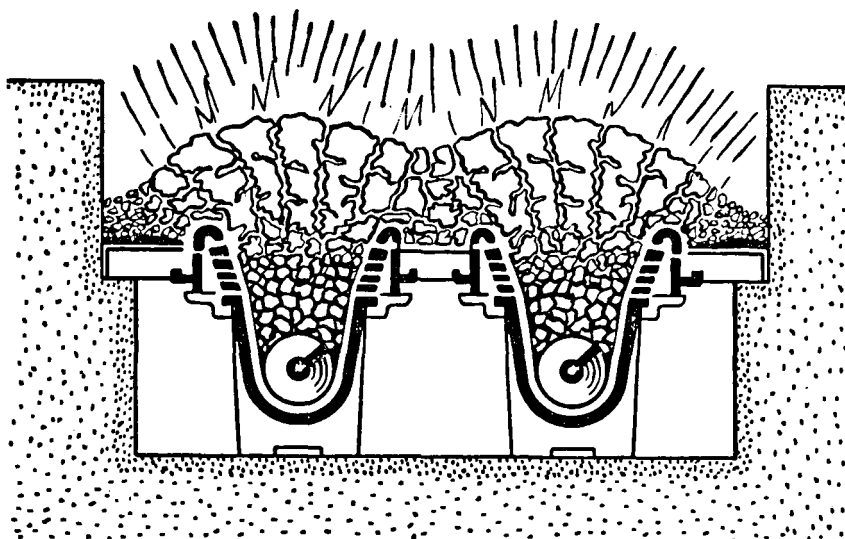
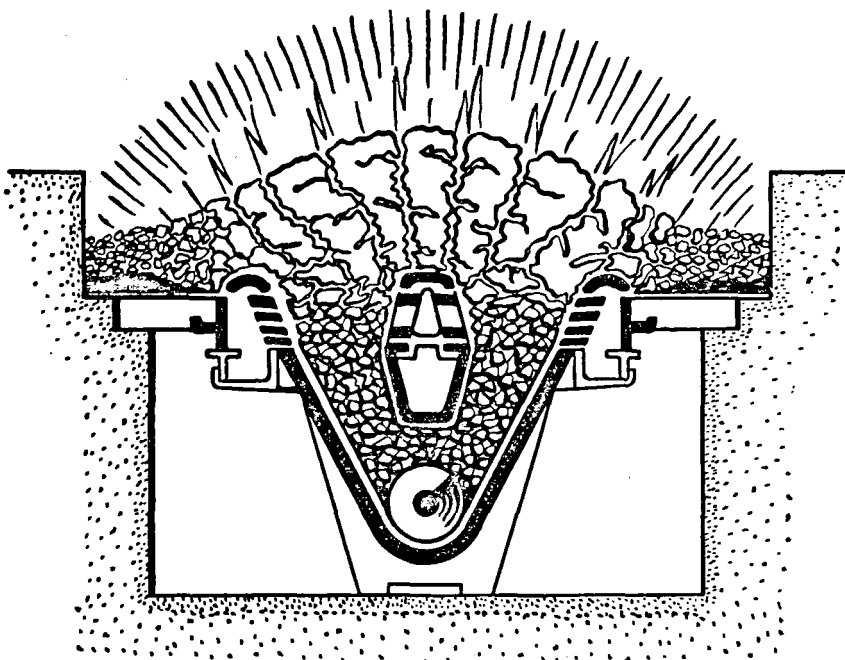


FIG. 19



Reproduced by permission of Prior Stokers, Ltd.

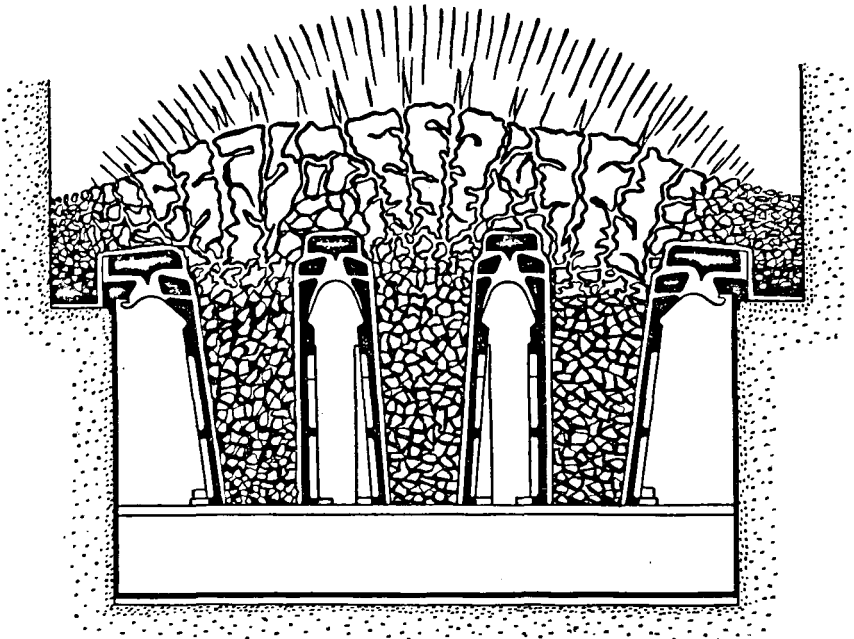
FIG. 20

distance between the inner tuyere ports, as this would render impracticable the fulfilment of principle (a) and a black centre would result ; this is particularly liable to occur with small coals of high inert content or coals entirely devoid of caking properties.

The shape of the combustion chamber does not as a rule lend itself to a solution of the problem by lengthening the retort, and apart from this it is difficult to ensure uniform fuel distribution throughout the length of a long retort, and it may not be easy to clinker effectively.

The different ways in which this problem has been met by manufacturers will be evident from a consideration of Figs. 19, 20 and 21, all of which provide for feeding the coal upwards through multiple retorts.

These designs ensure a large area of uniformly incandescent, highly radiating fire-bed surface at a reasonably low combustion rate per unit area ; they are specially suitable for burning low-grade fuels. The larger grate area and an even distribution of low-pressure air reduce tuyere deterioration and prevent excessive clinker formation.



Reproduced by permission of Rimer Manufacturing Co., Ltd.

FIG. 21

One maker has produced a design in which the hopper base, coal tube, and retort base are flooded with water to a level slightly above the top of the coal tube. A constant water level is maintained by means of a tank and ball valve. It is claimed that the water provides a positive seal and that its cooling effect facilitates clinkering and increases the life of the tuyeres.

Whilst the general principles of retort design are equally applicable to stokers for horizontal shell boilers, a special construction is nevertheless necessary in order to adapt them to the flues which are usually of comparatively small diameter.

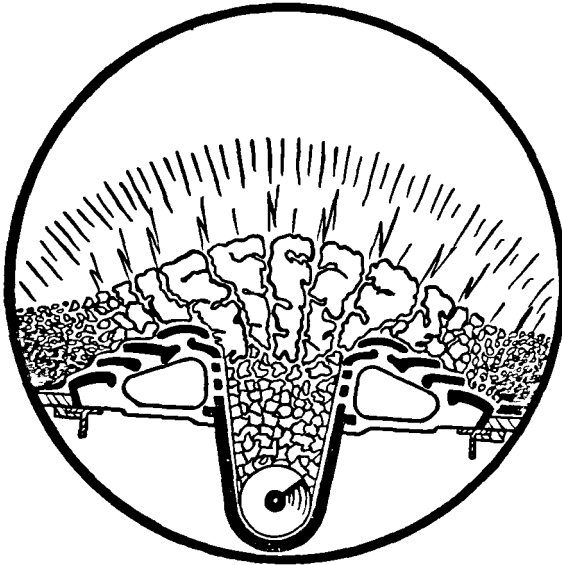


FIG. 22

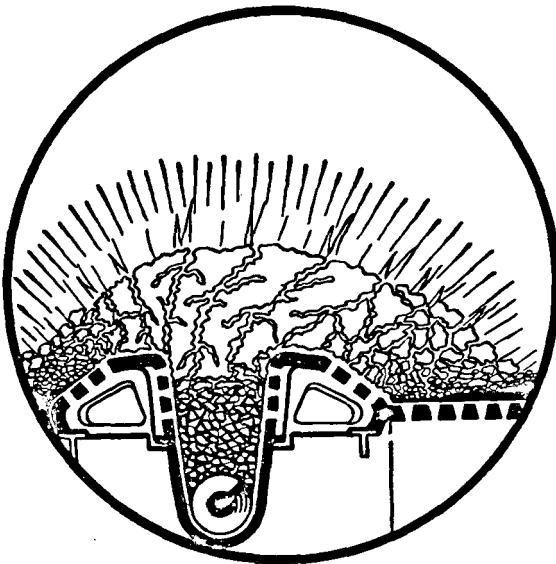
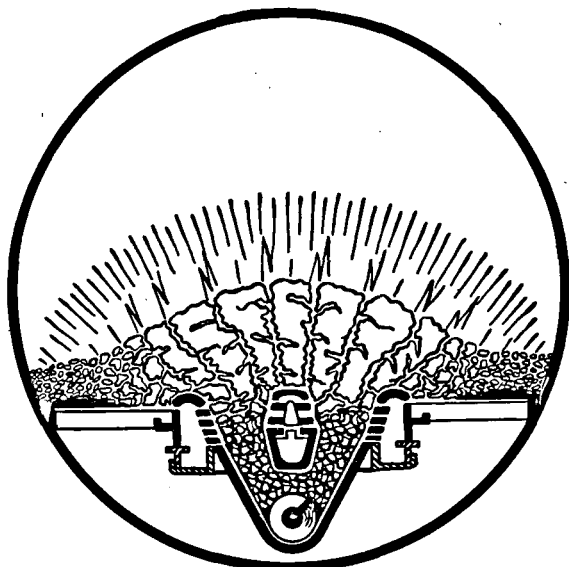


FIG. 23

The retorts of such stokers are consequently longer and narrower than those used for boilers which do not impose this restriction on width. Sections of typical retorts for flue tube boilers are shown in Figs. 22, 23 and 24, from which it will be seen they closely parallel those already described.



Reproduced by permission of Prior Stokers, Ltd.

FIG. 24

#### COMBUSTION CHAMBERS

In vertical boilers, the level of the stoker retort relative to the boiler is fixed with due consideration to flame clearance, combustion chamber volume, and the provision of clinkering facilities. The layout of refractories in the combustion chamber is a matter of considerable importance; the boiler shell, where it is not water-cooled, must be protected by a firebrick lining of ample thickness, and this brickwork must be carried up to a sufficient height to give adequate protection to the mud ring. Any openings which it may be necessary to leave in the lining for cleaning doors should be spanned by a sprung arch—slabs are not satisfactory as they are liable to crack and collapse under the effects of heating and cooling, and are more susceptible to mechanical damage.

The retorts of stokers for flue-tube boilers are terminated at a firebrick bridge wall and the front plates are lined with refractory material.

#### AUTOMATIC CONTROLS

Most of the underfeed stokers used for the firing of steam boilers operate on what is known as the "stop-start" principle. As already mentioned, the transmission unit usually includes a means of selecting one of a number of different rates of coal feed and this device is set so that the rate of feed, when the stoker is running continuously, is somewhat in excess of that required to meet the highest peak load on the boiler. A pressurestat mounted on the boiler is set so that at the desired working pressure it breaks an electrical circuit and stops the stoker motor; when the pressure has fallen by an amount depending on the differential for the instrument, the circuit is remade and the motor starts again. Thus the stoker runs for a period and then remains idle for a period, the relative length of these periods being varied according to the steam load on the boiler; the average rate of coal feed over unit time is,

therefore, infinitely variable between zero and the rate at which the stoker feeds when running continuously. The air-supply damper is set to suit the rate of coal feed. When the coal feed stops, the forced draught fan also stops.

Another system of control, based on intermittent coal feeding, is designed to preserve the correct air/fuel ratio. It comprises an automatic temperature or pressure control, which operates a standard automatically controlled air valve in the forced draught system, an air flow measuring equipment, and an automatic coal-feed controlling feature.

The air flow is measured by a differential diaphragm with a lever system which is in equilibrium for any particular value of the differential pressure corresponding to a given rate of flow. A change in air flow disturbs this condition of equilibrium, and the small movement of the lever system causes one of two electrical contacts to be made, according to whether the air flow has increased or decreased. As soon as contact is made, the servo mechanism modifies the position of the lever balancing system, and equilibrium is restored.

The position of the lever balancing system is used to operate an indicator which shows the air flow, and it is also coupled to the electric control equipment which operates the fuel feed. The variation in the rate of fuel feeding is carried out in one-minute cycles, that is to say, the feed is continuous for a portion of one minute and is interrupted for the remainder of the minute.

In this way an infinitely varying rate of coal feed between zero and the maximum is possible. By using so short a period as one minute for the time cycle, it is claimed that fluctuations in combustion conditions are smoothed out. A means is provided for varying the air/fuel ratio. A separate hand/automatic control panel is provided so that the operator can take charge of fuel feeding, which is an advantage during starting up or if the automatic control is put out of action.<sup>1</sup>

Other systems of controls are based on a continuously running stoker with equipment for automatically selecting a rate of coal feed (between limits) to suit the load condition. This may be accomplished by employing a pressurestat to operate a small pulling motor mounted on the gearbox and linked to the coal-feed selector mechanism and to a damper in the fan inlet or discharge.

An increase in load is indicated by a slight drop in pressure and this causes the pulling motor to move in a direction which increases the rate of coal feed and air supply ; a decrease in load is followed by the opposite effect. A second pressurestat, set to operate at a somewhat higher pressure than the one which normally takes control, stops the stoker if the lowest rate of coal feed is more than sufficient to meet the load.<sup>2</sup>

Another method of control, also based on a continuously running stoker, provides a constant air/fuel ratio by means of interconnected air and coal metering devices. A pressurestat operates a coal-feed selector mechanism and the rate of air flow is regulated by a valve in the air system.

A slight change in the velocity of air flow is measured by a pitot tube and transmitted to a control valve, which makes the required readjustment of the air regulating valve. The control valve is connected hydraulically to the coal-feed selector gear so that the velocity which it maintains in the air duct is suitably readjusted every time there is a change in the rate of coal feed. A weight of air appropriate to the weight of coal burned is thus automatically



supplied. The air/coal ratio can be adjusted to suit the requirements of the fuel which is being burned.

Indicators showing the weight of coal fed in lb. per hour and the air flow in cubic feet per minute are supplied, and these, with the control valve and ratio adjustment, are housed in a casing which can be remotely situated from the stoker.

The automatic air control can be independently fitted to stokers operating on the "stop-start" principle, without automatic coal feed selection.<sup>3</sup>

In one stoker of the continuously feeding type, the quantity of fuel delivered to the screw is regulated by a small modulating motor, which is set in motion in the required direction by a potentiometric steam-pressure controller, working through electrical relays. The modulating motor is also linked to an air control valve in the fan inlet. This valve consists of a number of vanes, radially disposed, and each capable of rotation on its radial axis. The whole equipment constitutes a "floating" control which supplies air and coal according to variations in boiler load.<sup>4</sup>

#### SAFETY DEVICES

High steam-pressure and low-water safety controls should always be included as part of the equipment of automatically-fired boiler installations. The former stops the stoker in the event of steam pressure rising above the normal limit of control, and the latter if the water level falls below the normal low limit; in some cases it is necessary to include a device which gives audible warning if either of the safety controls comes into operation.

The low-water safety control should be valved so that it can easily be blown down and tested, and regulations should be made to ensure that this is done at frequent intervals.

The driving motor is protected from damage due to excessive loads by thermal or magnetic overload releases, but these are not sufficient to protect the transmission gear from the effects of a sudden jam caused by an obstruction in the coal-feed screw. Mechanical damage of this kind may be guarded against by incorporating an easily replaceable shearpin or a slipping clutch in the transmission.

#### FUELS

The factors which influence the suitability of fuels for burning in underfeed stokers used for steam raising will now be discussed.

(a) *Grading.*—Closely graded and cleaned fuels are not necessary for underfeed stoking; on the contrary, it is often an advantage to have fuels which contain a proportion of "fines". There is an upper limit of size determined by the largest piece of coal which can be passed through the screw without crushing. This may vary a little in stokers of different makes, but generally speaking, stokers feeding from 200 to 350 lb./hr. will take fuel up to 2 in. size, and larger machines up to 2½ in. A certain amount of oversize fuel can be tolerated, as the feed screw will break it down. The proportion of "fines" through a ½-in. mesh which is acceptable depends on the nature of the installation and on the characteristics of the fuel, but 30 to 35 per cent. may be taken as a safe average.

(b) *Volatile Content.*—Bituminous coals, moderate to slightly caking, 33 to 36 per cent. volatiles, are the types most generally favoured for underfeed stoking; they include many coals from Scotland, Northumberland, Yorkshire, and the Midlands.

Heavily caking coals, 30 per cent. volatiles or thereabouts, are liable to be troublesome in underfeed stokers to an extent depending on their caking properties.

Coking coals, 16 to 28 per cent. volatiles, are not generally suitable. Semi-bituminous coals, 13 to 16 per cent. volatiles, including Welsh "Navigation" coals, may be used, but their caking properties may cause a drop in the rated output of the boiler.

Welsh hard steam coals, 11 to 13 per cent. volatiles, are usually unsuitable, but varieties such as Phurnod and Ocean coals will give satisfactory results.

Anthracites and semi-anthracites, 6 to 11 per cent. volatiles, are, in general, unsuitable for firing in underfeed stokers, unless the machines are specially designed for the purpose, and such machines are available in this country.

(c) *Caking Properties.*—Bituminous coals with slight to moderate caking properties are very suitable for underfeed firing. Coals which exhibit highly caking and swelling propensities, such as Kent coals, most of the coals from the Durham coalfields, and some from South Wales, are not satisfactory for underfeed stoking. Such coals form massive lumps of coke which present a low superficial area and so prohibit effective contact between coal and air. Coals of this kind can be burned in underfeed stoker, but only when given the manual attention of breaking down the coke bed periodically, and this necessity, of course, largely offsets the advantages which would otherwise be derived from automatic firing.

(d) *Ash.*—The ash content should be limited to 12/15 per cent. if operational difficulties are to be avoided. Generally speaking, ash with a fusion temperature of about 1,150° C. will be satisfactory from the clinking point of view; fusion temperatures as low as 1,050° C., or as high as 1,250° C., may be satisfactory, according to the temperature of the furnace.

#### BLENDING FUELS

Anthracite and semi-anthracite may be used with satisfactory results if they are blended with bituminous or semi-bituminous fuels. The percentage of each used in the mixture depends on their characteristics. Welsh hard steam coals and semi-bituminous coals may also be suitable if mixed with bituminous coal. Coke and coke breeze are not satisfactory as straight fuels, as their abrasive qualities cause rapid wear of the feed screws and tubes. They can be burned in an emergency, but it is preferable to mix them with 50 per cent. bituminous coal, slack or graded, in order to reduce wear to a minimum.

#### CONCLUSION

In addition to new features of underfeed stoker design, there has been a good deal of detailed modification, resulting in a cleaner and more compact appearance, with the provision of better facilities for operation and maintenance. Adaptations of stokers based on the original hopper model and applied to particular boiler types are giving place to more specialised designs, each more suited to its purpose.

The obvious advantages of bunker feed models, and their increased reliability resulting from improvement in design, has caused them to gain

considerably in popularity, and, where the site conditions are favourable, they are now generally preferred to hopper models.

A development of great importance is the application of combustion control systems to underfeed stokers. The problem involved does not present any serious technical difficulty, and a number of devices incorporating air/coal ratio control are already available, or are in the experimental stage; the real difficulty which confronts the engineer is to provide an accurate and reliable control at a price sufficiently low to ensure its general adoption.

When new plant is being selected and arranged, unity of design and the best adaptation of equipment to the duty it has to perform can only be achieved by close collaboration throughout between architect, consulting engineer, and manufacturer. Unfortunately, it too often happens that the selection of boiler-firing equipment is left until all other details have been irrevocably settled, with the result that the stoker maker's freedom of choice is hampered to the detriment of the installation.

During the war and since, underfeed stokers have been called upon to burn fuels variously described as "low grade", "unfamiliar", and "small coals of high inert content", all more or less unsatisfactory, but on the whole these fuels have been handled successfully.

Reference has been made to the blending of fuels, and it has been shown that by this means fuels can be burned which would otherwise be difficult or entirely unsatisfactory. This mixing of fuels for underfeed stoking is not likely, however, to become a general practice; the technical and economic difficulties are too great for it to be regarded more seriously than an expedient to be resorted to in an emergency.

It must be emphasised that the full benefits of automatic underfeed stoking can only be realised when fuels lying within the range of suitability can be supplied, and it is unfortunate that in many cases the non-availability of such fuels has been responsible for the persistence of much less economical methods of firing.

Efficient combustion appliances are capable of effecting considerable economies in fuel consumption; thus, an extension of their use will do much to bridge the gap which exists between fuel production and utilisation.

Underfeed stokers, by virtue of the basic principle on which they operate, are able to burn bituminous coal without smoke, and their use, therefore, will do much to eliminate the atmospheric pollution which is so frequently attendant upon steam raising.

It is, therefore, in the national interest, both from the points of view of economy and cleanliness that a fuel supply and distribution policy, ensuring that available fuels are allocated to the appliances which can make the most efficient use of them, be implemented without delay.

#### *References*

- 1 Wellman-Lindars Furnace Control. The Wellman Smith Owen Engineering Corporation, Ltd.
- 2 The Riley Stoker Co., Ltd. Prior Stokers, Ltd.
- 3 Unicalor-Metronic Air Control. Joshua Bigwood & Son, Ltd.
- 4 Colostat Combustion Systems, Ltd.

APPENDIX. Results of Tests.

Test No.	I	II	III	IV	V
Date of Test	4th February, 1943	19/20th May, 1943		20th August, 1946	24th November, 1943
PARTICULARS OF PLANT— Boiler	Vertical multi-tubular, 15 ft. × 7 ft. dia. Cochran	Vertical multi-tubular, 4 ft. 6 in. × 6 ft. 6 in. dia. Cochran	Galloway, 30 ft. × 7 ft. dia., 2 flue each with 2 cross tubes	Dry back economic, 14 ft. × 8 ft. 6 in. dia. (Danks)	Spearing R.T.
Method of firing	Prior No. 9 "Duplex" underfeed stoker	Rimer trifurcated dual ram underfeed stoker	Iron Fireman automatic underfeed stoker	2 Unicalor Class "F" underfeed stokers	3 Riley No. 12 underfeed stokers
Draught	Steel chimney, natural draught	Natural draught	Brick stack, 120 ft. high	Natural draught	Induced
DATA FROM OBSERVATIONS— DURATION OF TEST . . . . . hrs.	6·07	24	55	4	6·35
FUEL : Description	Bituminous coal, washed $\frac{1}{2}$ -1 in. size	Washed slack, 40 per cent. through $\frac{1}{2}$ in. mesh	Ellistown D.S.Nuts	Hilton Main D.S. Nuts	Welsh steam coal, Phurnod No. 5 Washed Nuts
Proximate analysis as weighed— Moisture . . . . . per cent.	10·7	3·5	17·60	9·6	—
Volatile matter . . . . . per cent.	32·28	12·3	31·54	24·6	—
Fixed carbon . . . . . per cent.	48·07	78·2	45·54	57·5	—
Ash . . . . . per cent.	8·95	6·0	5·32	8·3	—
Gross calorific value as weighed . . B.Th.U./lb.	11,520	14,180	10,514	12,820	14,525
Net calorific value as weighed . . B.Th.U./lb.	11,024	—	9,965	—	13,420
Fuel fired per hr. . . . . lb.	346	155	—	287·8	2,875

<b>ASH AND CLINKER—</b>					
Collected during test . . . . lb.	139.5	227.6	—	92	756
Percentage of fuel fired . . . per cent.	6.65	6.11	6.84	7.91	4.14
<b>WATER—</b>					
Temperature entering economiser . . ° F.	—	—	160	—	88
Temperature entering boiler . . . ° F.	186	60	268	191.7	346
Evaporation per hr. . . . . lb.	2,910	1,291	6,615 day, 330 night	2,806	27,970
Evaporation per lb. fuel as weighed . lb.	8.42	8.33	9.1	9.75	9.73
<b>STEAM—</b>					
Gauge pressure . . . . . lb./sq. in.	56	48	115	104	180
Heat per lb. above feed temperature B.Th.U.	1,028	1,145	960.69	1,029	1,140
<b>FLUE GASES—</b>					
Temperature leaving boiler . . . ° F.	741	600	573	322	—
Temperature leaving economiser . . ° F.	None fitted	None fitted	368	None fitted	—
CO <sub>2</sub> content leaving boiler . . . per cent.	13.3	8.7	12	10.66	—
CO <sub>2</sub> content at base of stack . . . per cent.	—	—	8	—	—
<b>DRAUGHT—</b>					
Suction over fire . . . . . in. W.G.	0.02	—	0.2	0.21	—
Suction leaving boiler . . . . . in. W.G.	0.11	—	0.6	—	—
Suction at base of stack . . . . . in. W.G.	—	—	0.65	0.35	—
<b>AIR—</b>					
Temperature of air supply . . . . ° F.	69.5	—	—	80	—
Static pressure in air duct . . . in. W.G.	1.28	—	0.8	—	—
			in plenum chamber		
<b>POWER CONSUMPTION—</b>					
Power consumption of stoker motor	2 kW.	—	2.92 amps.	4.4	—
Rated capacity of stoker motor . . B.H.P.	5 B.H.P.	—	Two 3 B.H.P. motors	Two 3 B.H.P. motors	—
<b>RESULTS—</b>					
Overall thermal efficiency on gross calorific value of fuel . . per cent.	75.0	67.73	79.75 68.00 Net efficiency of boiler	78.26	76.5

## 6. The Firing of Shell Boilers with Pulverised Fuel

By P. G. RYDER, A.C.G.I., M.I.E.E., M.I.MECH.E.

### INTRODUCTION

In the following paragraphs the general principles of pulverised fuel firing are referred to, particularly in relation to shell boilers.

Pulverised fuel, due to the degree of fineness employed, has a very large surface area compared with fuel used in lump form. In consequence, the particles of fuel are more easily brought into intimate contact with the oxygen necessary for combustion. This action is assisted by the fact that the fine particles of fuel are conveyed in an air stream to the burner by what is termed the primary air. At the burner the remainder of the air necessary for complete combustion is brought into contact with the "primary" air and fuel to an extent depending on the type of flame required.

Because of the high degree of aeration and surface area of the fuel, combustion takes place in a very similar manner to liquid fuel, and the use of the pulverised fuel results in the continuous attainment of a high rate of heat release and a high combustion efficiency with absence of smoke and smell.

Operating labour is a minimum, as full automatic control may be used.

A properly installed and maintained installation can be entirely clean in operation. For this reason the plant should not be placed in some dark corner but in a well-lighted building where any leakage can be easily detected and put right.

### BOILERS

Although the bulk of pulverised fuel used for boiler firing is in connection with water-tube boilers, a number of Lancashire, Cornish, and Vertical boilers are being successfully fired by this method. Central-heating boilers of the sectional type with automatic control and a fuel consumption of as little as 50 lb. per hour is another satisfactory application.

The evaporation possible when using pulverised fuel greatly exceeds the maximum obtainable with hand firing, and in certain circumstances has been doubled.

The overall efficiency is high and can be maintained indefinitely, provided the flues, etc., are kept free of dust. Including superheater and economiser the efficiency is about 80 per cent.

### FUEL

For firing shell boilers suitable fuel is limited to bituminous coal and hard pitch. The size of fuel before pulverising should not exceed  $\frac{1}{2}$ -in. cube for a small plant and  $1\frac{1}{2}$ -in. cube for a large plant. There is nothing to prevent the use of a much larger fuel, provided the cost of the necessary crusher can be justified, as a graded fuel is unnecessary and the presence of a high percentage of fines is beneficial.

Low surface moisture is most important unless the pulverising plant is suitable for dealing with it, and then an ample supply of hot air is essential. High moisture lowers the flame temperature and increases the chimney losses.

Low ash is also important, particularly with the high-speed type of pulveriser. Its presence, especially where pyrites is a substantial part of the ash, causes increased wear and a reduction in the fineness of the product, unless the pulverising plant includes a classifier.

Fuels with high ash content can be used and burnt more efficiently in the pulverised condition than in solid form, but the maintenance of the plant is higher.

Almost any fuel can be burnt, provided the volatile matter is sufficient to maintain combustion, but in the shell boiler, due to the smallness of the combustion chamber and absence of refractory walls, the volatile content should not be less than 25 per cent.

The degree of fineness is also important, particularly with shell boilers, for the two reasons just given. The fineness is usually stated as the percentage residue after sieving a known weight, usually 50 or 100 grammes, on a British Standard sieve.

The sizes of sieves used and the permissible residues on these are as follows :

Residue on 200 B.S. sieve . . . . .	15·0 per cent.
"    " 100 "    " . . . . .	3·0 "    "
"    " 50 "    " . . . . .	trace

#### FIRING SYSTEMS

There are two systems used for the preparation and firing of pulverised fuel, namely, the "unit" and the "storage".

With the "unit" system the fuel is pulverised as required and delivered direct to the burner at a rate to meet the instantaneous demand of the boiler or furnace.

With the "storage" system the fuel after pulverisation is stored until required. The pulverising plant is therefore distinct from the firing system.

#### "UNIT" SYSTEM

With this system there is no storage of pulverised fuel at any point. The fuel, either wet or dry, of a size suitable for the particular type of plant, is fed into the pulveriser at one point with the primary air and as it is reduced to the required degree of fineness passes out of the pulveriser with the air direct to the burner.

The rate of feed is regulated to suit the moment by moment requirements of the plant, and this may be done either by hand or automatically.

It is usual to provide hot primary air, and this is essential where the moisture in the fuel exceeds 5 per cent. The amount of primary air is generally between 25 and 30 per cent. of the total theoretical air required for combustion, but this varies considerably, depending on the moisture in the fuel, the temperature of the air available, and the conditions required at the combustion chamber.

Drying of the fuel is not so important with the "unit" system as with the storage system, as the fuel is in an aerated condition from the moment it enters the pulverising chamber until combustion takes place at the burner. The chief consideration is to see that the quantity and temperature of the air is sufficient to prevent the fuel caking in the pulverising chamber, so that proper size reduction can take place, and to ensure that condensation cannot occur once the surface moisture in the fuel has been taken up by the air. In practice no difficulty is experienced, provided the air conditions are suitable for the coal which has to be used.

In some "unit" pulverisers the primary air is generated by the elements used for pulverising, in others this action is assisted by a fan or is provided by the fan only.

The secondary air is usually provided by a separate fan, but in certain small "units" everything necessary for feeding and pulverising the fuel,

providing both primary and secondary air, and distributing of the fuel to several burners, is combined in one machine driven by a single motor.

The "unit" plant requires much less space, is more simple to operate and maintain, and cheaper to instal than a "storage" plant. The fuel is delivered regularly to the burner, so "flushing" cannot take place as occurs with a "storage" system when the fuel is not dried sufficiently.

There is a very slight time lag with the "unit" system before any change in the rate of feed is noticeable at the burner, but in practice this does not cause any operational difficulty.

#### "STORAGE" SYSTEM

In practice this system is used in three distinct ways, known as :—

1. "Bin and feeder" system.
2. "Ring main" system.
3. "Bulk distribution" system.

*"Bin and Feeder" System.*—The fuel after pulverising is stored in a bin until required, when it is extracted by means of a screw or other device for delivery into an air stream which conveys it to the burner. Usually there is a separate feeder for each burner.

It is important that the pulverised fuel does not contain more than 2 per cent. moisture, otherwise over-heating takes place in the bin with the possibility of fire and explosion.

This system is now almost exclusively used for firing large water-tube boilers and will therefore not be referred to again in detail.

*"Ring Main" System.*—This system employs the bin and feeder system as the primary means of delivering the pulverised fuel to a number of burners. Actually, the feeder delivers more fuel than is needed at the burners into a ring main which includes in its circuit a fan and cyclone.

By means of a special valve some of the air with the pulverised fuel it is carrying is diverted from the main stream so as to supply a burner. As many as a dozen such valves and burners may be used on a single ring main. The surplus fuel due to excess feed and closing down of any burner is returned to the storage bin by means of the cyclone collector.

It will be appreciated that the pulverised fuel can never be perfectly distributed in any cross-section of the air stream, also, the finer particles are more easily diverted from the normal direction of flow in the ring main than are the coarser particles ; there is therefore some uncertainty as to the fineness of the fuel delivered to any burner, with the tendency for the last few burners on the ring main to get the coarser fuel.

*"Bulk Distribution" System.*—In this system the preparation plant is of relatively large capacity located in a district from which a number of consumers can be supplied.

The pulverised fuel is conveyed in bulk by rail or road tank wagons and is pumped pneumatically, in a manner similar to oil, from the tanks to the storage bin at the place where the fuel is to be used. It therefore possesses the chief advantages of fuel oil, but without the objectionable smell associated with the latter.

The consumer's plant consists of storage bin, extracting and feeding equipment of simple design which delivers the pulverised fuel into the burner pipe where it is mixed with the necessary primary and secondary air supplied by duplex fan. The whole equipment is comparable in size to that of an oil-fired installation.



The fuel distributed in this way is usually sold to a guaranteed specification, the calorific value being not less than 14,000 B.Th.U. per lb., with moisture and ash not exceeding 3 per cent. and 4 per cent. respectively.

This system is used for firing shell boilers, central-heating boilers of the sectional type, etc., and meets the need of the small consumer and those who do not want to operate their own pulverising equipment.

#### PULVERISING PLANT

There are a considerable number of types of pulverising plant and most of these can be used for either the "unit" or "storage" system. A general classification of these plants is as follows:—

1. Ball and tube mills.
2. Ring roll mills.
3. Beater mills.

Whatever type of mill is used it is very desirable to have a classifier somewhere in the system so that the fineness of the pulverised fuel is constant, irrespective of the condition of the mill, which is subject to wear.

Except in the case of the "storage" system, a separate dryer for the fuel is rarely used and is unnecessary even for this system, where the plant incorporates adequate means of drying the fuel at the same time as pulverising takes place.

*Air-swept Ball or Tube Mill.*—This represents the simplest form of plant, as the primary air in passing from one end of the mill to the other through the hollow trunnion bearings dries and classifies the fuel, but it has very definite limitations. The velocity of the air through the outlet trunnion must not exceed about 2.5 ft./sec. if the fineness is to be kept within permissible limits. Therefore the volume of air, whether hot or cold, is strictly limited by the size of the outlet trunnion. This in turn limits the moisture in the fuel to about 7 per cent. as a maximum. Any increase above this figure is immediately shown by a falling off in output which becomes progressively greater as the moisture increases. Apart from these limitations the plant is reliable and maintenance low.

Usually the mill has one compartment, but sometimes it is divided into two, with larger grinding media in the compartment nearer the inlet than in the compartment at the outlet end.

*Air-swept Ball or Tube Mill with Classifier.*—These types of mill are often fitted with either an external or internal classifier. Those with internal classifier provide only a means of separating the fuel of finished fineness from the oversize.

With an external classifier there is in one design a means of pre-drying and pre-classifying the fuel before it enters the mill. This system has the advantage that any fuel in the feed already of the required fineness does not pass through the mill. It is dried before separation and the mill has dried fuel to deal with, all of which requires size reduction.

*Ball Mills with External Classifier and Drying System.*—This system of ball mill employs a mill either of the shaft or trunnion type arranged usually with one compartment.

With the shaft mill the discharge is through a diaphragm at the opposite end to the feed and either the whole of the mill drum or the discharge end of it is enclosed in an outer stationary casing. Where the whole mill is enclosed it acts as a very good sound and temperature insulator. Pre-drying and subsequent classification of the mill product is essential. This is usually

arranged in the manner described in the last paragraph under the heading "Air-swept Ball or Tube Mill with Classifier".

*Ring Roll Mills.*—There are a great variety of types under this classification. Some have the grinding ring with the working face horizontal, in others this is vertical, and some have it in an angular position. The rollers are, of course, arranged to suit, and the number of these is generally three. In some machines the ring is fixed and the rollers are caused to rotate by means of a rotating head which carries them. In another type one roller is driven which in turn drives the ring and this in turn drives the other rollers.

Under this same classification may be included those mills in which the rollers are replaced by large balls.

Whether rolls or balls are used the action is generally similar, and on both types it is usual to use spring loading so as to keep the rolls or balls in contact with the ring and so follow the varying thickness of the fuel between the two grinding surfaces.

In general terms, mills of the above type are able to deal with slightly more moisture than can be used in a ball or tube mill. The amount of superfine flour is less than in a ball or tube mill.

Some form of classification is essential, as in one pass through the mill only a portion of the feed is reduced to the required degree of fineness.

The classifiers are sometimes superimposed on the mill or are arranged as part of an external system. When externally arranged the system of pre-classification and drying may be used as with other types of mills.

*Beater Mills.*—In this type of pulveriser the grinding action is partly by impact and partly by attrition of the particles of fuel one against the other and between the particles and the grinding elements.

These machines run at high peripheral speed and are therefore subject to comparatively heavy wear of the grinding elements.

The grinding elements consist of either a set of rotating arms with beater heads, driven from a central shaft with stationary grinding ring, or a series of fixed and rotating pins and blocks against which the fuel is driven centrifugally and is drawn out of the pulverising chamber by a hot air current induced by a fan either integral with or external to the pulveriser.

It is important with these high-speed mills that a classifier system is incorporated, as otherwise, owing to the relatively high rate of wear, the fineness cannot be maintained.

As with certain other types of mill the induced hot air is used for drying the fuel as it is reduced.

#### COMPARATIVE POWER CONSUMPTION

Most of the published figures for power consumption are difficult to compare as so many of the relevant factors are either not stated at all or are not on the same basis.

The grindability of the fuel varies enormously; for instance, hard North-East coast coal is very much more difficult to pulverise than Kent coal, and the latter, when treated in the same machine as the hard coal, will contain a higher percentage of superfine coal even though the sieving analysis may be the same.

Other important factors are the initial moisture in the fuel, the fineness of the product, and the amount of primary air and the pressure against which it is delivered.

The following comparative figures are based on hard North-East coast coal ground to a residue not exceeding 15 per cent. on the 200 B.S. sieve when delivering 30 per cent. of primary air against a static resistance of 2-in. w.g.

<i>Type of pulverising plant</i>	<i>kWh per ton of fuel as fed</i>
Air-swept ball mill . . . . .	36·0
Ball mill with external classifier and drying system . . . . .	26·5
Ring roll mill with classifier . . . . .	24·5
Beater mills . . . . .	33·5

#### BURNERS

When firing shell boilers with pulverised fuel it is most important, owing to restricted combustion space, that the primary air and fuel is brought quickly into intimate contact with the secondary air so as to produce the shortest flame possible and ensure complete combustion in the shortest time. This is done in a variety of ways such as dividing the primary air and fuel stream and the secondary air stream into a number of parallel layers or by causing turbulence. Turbulence is produced by such means as causing the primary and secondary air to leave the burner in tangential streams having opposite directions of rotation or by forcing the secondary air through a series of jets or holes at right angles to the primary air stream. The amount of refractory lining in the combustion zone should be the maximum possible in order to assist early ignition of the fuel.

#### DUST BLOWING AND COLLECTION

On all shell boilers except those of small output or where systematic cleaning can be arranged for, it is most important that all surfaces and flues are kept free of deposited dust. For this purpose sootblowing equipment should be provided with means of collecting the dust when the sootblowers are in action.

#### CONCLUSIONS

(1) As with other mechanical means of firing fuel proper, consideration must be given to all the relevant factors which ensure a proper and satisfactory application.

(2) Pulverised fuel firing requires a minimum of operating labour, and full automatic control can be applied where this is necessary.

The plant is simple to instal and maintain, and all parts subject to wear are usually cheap and easy to replace.

(3) The application of pulverised fuel to shell and other type boilers is a practical means of burning efficiently a very wide range of volatile fuels. The size of fuel and the presence of a high percentage of fines is immaterial, provided the maximum size is not greater than the plant can deal with.

#### APPENDIX

Pulverised fuel preparation and firing is not subject to any statutory requirements, but attention is drawn to the recommendation issued by H.M. Chief Inspector of Factories, Form 831, May 1937, entitled "Precautions for the Construction, Working and Repair of Coal Drying and Pulverising Plants". These recommendations do not apply to "Unit" plants of 30-cwt. capacity per hour or less.

## 7. The Installation of Steam Boilers

By P. A. EVANS, M.A., M.INST.F.

In the earlier stages of the war, when the Ministry of Fuel and Power commenced the drive to secure more efficient use of fuel, it was stated by several authorities that 60 per cent. of the boiler plant in industry was operated at less than 60 per cent. efficiency. Many of these cases were reputed to be due to bad brickwork.

The Association of Boiler Setters, devoting themselves to determining causes for such performances, suggested that these might be put, roughly, into three categories :—

1. Design of settings, flues, etc.
2. Personnel engaged in construction, both operative and supervisory.
3. Conditions affecting purchase in the first instance.

The divisions are not absolute and are somewhat inter-related, but serve, nevertheless, as a useful basis for more detailed consideration.

Taking these headings in reverse order, there existed, unfortunately in no mean numbers, factory owners and even engineers who regarded boiler brickwork as a mere "something" to enclose a boiler and then forget for life. Furthermore, they believed that the more cheaply one could acquire such enclosure the more clever one was. Boiler makers, often, of course, responsible for installation, were often obliged by stress of competition to concur in such a view. The producers of mechanical stokers or of mechanical draught apparatus were given practically no opportunity of influencing the matter and had to carry out their part of the work with the pious hope that the volumes of flue gas, the available draught, and so on finally obtained would somehow square with their design calculations.

The second cause for unsatisfactory brickwork is more insidious, as it arises, not from parsimony but from failure to appreciate the subject fully. Boiler settings are often regarded as coming within the category of building work and, as such, treated like any other building operation by entrusting them to the general building contractor. Although the specification might be perfectly satisfactory the final result might not be so. It should be realised that there exists a body of craftsmen, bricklayers and others, who spend all their working time on the construction of furnaces, retort settings, coke ovens, and boiler settings. These men are specially skilled in the laying of firebricks and with the effects of high temperatures and the means of dealing with those effects. It is perhaps proper to mention that they command a rate of pay which recognises such skill and which, therefore, has some bearing on the price to be paid for the work.

The body of specialised labour is, in general, fully employed by specialist firms with competent engineers as supervisors. This fact is understood when the question is that of erecting a steel furnace but not so well understood when a boiler installation is involved.

The correction of inefficiency due to these causes is almost entirely in the hands of the user ; that of design is a different matter and has, during the last few years, received a great deal of study. The British Coal Utilisation Research Association, through the R/16 Committee, has been able to co-ordinate the work of the technical committees of the Shell Boilermakers' Association and the

Association of Boiler Setters. Dr. Ritchie has presided over a study panel drawn from these associations and from the manufacturers of economisers. This panel has been at work on the efficiency of boilers as affected by the manner of installation and has made a number of recommendations on the design of boiler settings and flues. The Ministry of Fuel has asked the British Standards Institution to undertake the preparation of Standard Specifications for these matters and the work of the R/16 Panel has been made available to the B.S.I.

The main improvements to be expected as a result of this work may be briefly indicated as follows :

Foundations should be proportioned in accordance with the nature of the subsoil and should be limited in extent. The object of the limitation is to avoid failure due to temperature stress which frequently occurs with large concrete rafts. The concrete should be protected with insulating bricks to limit the surface temperature and also to reduce the loss of heat through the foundation. For example a 3-in course of suitable insulating bricks would serve to reduce the heat loss to about two-thirds of that obtaining with an uninsulated raft and, perhaps more important, would reduce the surface temperature from say, 1,000° F. to 700° F. Concrete, when heated above 900° F., begins to disintegrate and this, of course, starts failures in the setting. The figures given can be taken as approximate only, for the results in any given case depend upon the shape of the foundation. That is to say on the relation between length and breadth quite apart from depth, so that a battery of boilers would differ in this respect from a single one.

The side walls and the tops of the settings should be insulated and changes made in the more usually accepted methods of bonding in order to reduce the loss of heat and also to increase the resistance to infiltration of cold air. The infiltration of cold air into boiler brickwork of many installations is much higher than it need be.

The total heat losses from settings are in some cases as high as 10 per cent. of the heat supplied as fuel to the boiler. With a modern insulated setting these may be reduced to 3 per cent. or less.

It will be appreciated that a reduction of heat loss will be accompanied by a fall in the temperature of the outside brickwork ; this in turn means less temperature stress at this point and therefore less tendency to crack from this cause, and hence less air leakage.

It is suggested that the sizes of the various flues should be reduced. Increased gas velocity means increased transfer of heat from the gas to the boiler. It is not intended to imply that flues should be reduced in size without limit, for the frictional losses must not be too high. Flue gases cost money to move whether this be by fan or by natural draught. A shaft does not move flue gases for nothing : its cost is the value of the heat it exhausts to atmosphere. It is assumed, however, that with the improvements in mechanical stokers and boiler brickwork a high CO<sub>2</sub> figure will be more consistently maintained, so that the volume of gas to be handled will be less than formerly.

The foregoing observations are mainly concerned with shell boilers, but the provision of insulation and high resistance to air leakage are equally necessary with water-tube boilers. This type of boiler presents less difficulty as far as heat loss to the foundation is concerned.

Water-tube boilers, more particularly the smaller ones used in industry, have " dry " fireboxes in which the walls are directly exposed to radiant heat

from the fire and also in the lower parts are in contact with the fuel and its resulting ash. This is a condition not obtaining in shell boilers and puts greater demands upon the firebricks to be used for lining such fireboxes. A brick to be satisfactory for this purpose should be highly refractory, possess good resistance to spalling, and be resistant to chemical attack from the metallic oxides and salts present in the ash of the fuel—ash frequently in a state of fusion. Furthermore, it is essential that the bricks should be of good shape and uniform in size, for, if not, it is difficult to lay them with an extremely thin joint. It is at the joints that failure generally commences.

The most generally suitable bricks for fireboxes are made from Scotch fireclays and have an alumina content of over 40 per cent. They are among the more expensive refractories, but, fortunately, at present relatively less so than formerly. In spite of many price increases during recent years the cost of these bricks is only from 35 to 40 per cent. above that prevailing before the war. During the same time the less refractory bricks used for shell boiler settings and other purposes and drawn principally from the Midlands have increased in price by approximately 120 per cent.

The present high cost of firebricks with an alumina content of up to about 30 per cent. has directed attention to the properties most desirable in bricks to be used for boiler settings. Such bricks should be of good shape and uniform in size; a far higher standard of uniformity than has been customary in the past should be insisted upon. They should be strong mechanically and be properly burnt so as to be well vitrified and therefore more resistant to damp. A surprising number of bottom flue linings fail because they have been allowed to become damp, and the number of sources of such damp, quite apart from wet subsoils, is equally surprising. Damp subsoils should, of course, be considered when designing the foundations and should not be a continual source of trouble. Lastly, the bricks should be reasonably refractory, bearing in mind that only in exceptional cases will they have to withstand a temperature in excess of 1,000°C.

In most parts of a boiler setting, and particularly in main flues and economisers, the temperature will rarely be above 550°C. This temperature is so low as to be well within the safe temperature range of a good common "red" brick. It is already standard practice to construct economiser settings without firebrick linings and it may well be sound to extend this omission to main and by-pass flues. The saving in cost would go far towards paying for the insulating bricks so necessary in other parts of settings.

In conclusion, it should be remembered that efficiency and economy are not the same thing and that the cost of obtaining higher efficiency may result in a reduction of economy. The R/16 Panel has made recommendations only for forms of construction which will increase both economy and efficiency.

## 8. Automatic Control of Solid Fuel Fired Steam-Raising Plants

By H. C. OUGHTON and R. W. TOWERS

### GENERAL

In considering the application of automatic control to apparatus heated by combustion of solid fuel and air, it is necessary to realise that whilst the range

of instruments available for this purpose is large the manner in which they may be employed (i.e. the mode of control) is limited by the nature of the fuel and the mechanical devices so far developed for regulating the fuel feed in response to the impulses from the controlling device.

In the larger steam-raising plants complete automatic combustion control can be satisfactorily achieved, as the fuel is fed at exactly the required rate to maintain the desired output, and the air is automatically proportioned to give maximum combustion efficiency, but the controlling equipment required to achieve this is generally more elaborate and therefore more costly than is warranted in small units.

For small plants the simplest method of control is to be preferred, and the simplest are unquestionably the "on-off" or "two-rate" systems. In the former the fuel feed is on so long as the demand is not being met and off so long as the demand is being exceeded. In the latter the fuel is fed at a pre-set minimum rate so long as the demand is being exceeded, and at a pre-set maximum rate so long as the demand is not being met, the controlling instrument causing the change in the fuel feed rate immediately the supply exceeds or drops below the demand.

The mechanical device controlling the fuel fed to the boiler usually consists of a motor-driven rotating "worm" feeding coal from a hopper to the fuel bed, the driving motor also driving a fan for the supply of the air necessary for the efficient combustion of the fuel. When the motor stops, both fuel feed and air stop and steam production falls. When the motor runs, fuel and air are fed and steam production increases. The rate of coal feed while the motor is running being practically constant, so that the rate of steam production is constant irrespective of the rate of steam demand, the mechanical device or stoker may have two effective speeds which are selected by the controlling instrument in accordance with the balance existing between demand and supply.

The two-rate system is achieved by having the fuel feed worm-driven from a two-speed gear-box which is operated independently of the main driving-motor, the change-of-rate mechanism embracing both fuel and air supply, so that both are changed together to maintain the correct balance for efficient combustion. In neither the on-off nor the two-rate method of feeding coal to the boiler does the output of steam exactly balance the demand, as with both methods steam is raised in a series of impulses which are large enough to over-ride the demand, and so compensate for the intervening periods when the fuel feed is stopped in the case of on-off control, or running at its pre-set lowest speed in the case of two-rate control.

It is obvious that the two-rate system is capable of giving the most constant combustion and generating conditions, particularly where the demand is reasonably constant, because under these conditions the low rate of feed can be pre-set to just a little below that required to maintain the desired output, and the high feed rate can be pre-set to just a little above that required to maintain the output, and the two rates employed are close to the average rate actually required to establish an exact balance between supply and demand.

Where, however, the demand is liable to fluctuate, considerably wider difference in setting between the minimum and maximum fuel feed rates must be employed, since the minimum rate must always be low enough to keep

steam generation below the lowest rate likely to be demanded, and the maximum fuel feed rate must always be sufficient to generate steam at a greater rate than is likely to be demanded.

One of the questions to settle when considering the application of automatic control is the variable in respect to which the control is to be applied. In small steam-raising plants there are three alternatives: (1) steam pressure, (2) steam temperature, (3) combustion-chamber temperature, the latter only being applicable where demand is likely to be absolutely constant.

#### PRESSURE CONTROL

If pressure is to be the controlled variable then a pressure-sensitive device is the first link in the chain of components forming the complete controlling equipment. The device usually employed is an electric switch responsive to changes in pressure.

In the on-off mode of control the pressure switch closes the electrical circuit to the driving-motor starter when the steam pressure falls below the required value, and opens the circuit when the pressure reaches the desired value. In the two-rate method of control two pressure switches are used, one to control the main driving motor, the other to control the change-speed device. The steam pressure required to operate the main driving-motor switch is higher than that required to operate the change-speed mechanism switch.

When the demand for steam is greater than the supply the change-speed control is in the "high-speed" position and the main motor-control switch is in the "on" position. When the output exceeds the demand and the steam pressure rises to the value set on the change-speed switch, the switch operates to reduce the rate of fuel feed. If the output of steam still exceeds the demand even at the reduced rate of coal feed the pressure will continue to rise until it reaches the value set on the driving-motor control switch, which will then operate and stop the main driving motor, reducing the fuel feed to zero.

The pressure switch is a variable device capable of being altered at will to suit the changes required in the boiler operating conditions; for instance, the pressure at which the switch opens can be pre-set on site to any value within a fairly wide range.

The pressure switch has a second variable, namely the operating differential or difference between cut-out and the cut-in pressures. Both pressure and differential settings can be varied over their whole range independently of each other so that the plant can be arranged to operate at any pressure within the range of the instrument, and the differential can be chosen to suit the boiler operating conditions.

The basis of the design of the pressure switch is a snap-action switch, operated by the bellows unit, responsive to changes in steam pressure. The device can be fixed directly to the boiler or other device, or it can be fixed on a wall or panel and be connected by suitable piping to the steam space.

#### TEMPERATURE CONTROL

If temperature is to be the controlled variable then a temperature-sensitive device is the first link in the chain of components forming the complete controlling equipment. When controlling in terms of steam temperature the sensitive element should be of such construction that whilst being robust it will respond almost immediately to changes in the temperature of its surrounding medium. A suitable thermocouple is illustrated in Fig. 25.



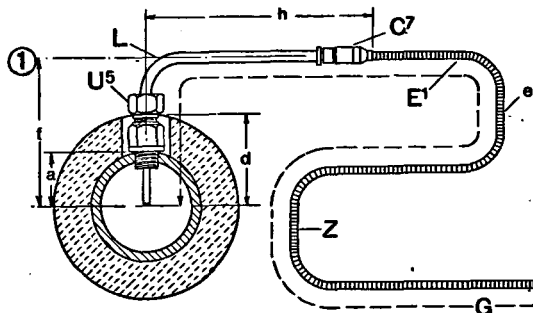


FIG. 25.—Concentric type thermocouple in steam line.

When controlling in terms of combustion-chamber temperature the sensitive element takes the form of a radiation-receiving tube which is sighted through the chamber wall on to one of the interior surfaces thereof. The intensity of radiation therefrom being the measure of the temperature. The receiving tube contains either a mirror or a lens which focuses the heat rays entering the tube on to the hot junction of a small and sensitive thermocouple mounted inside the receiving tube. See Fig. 26.

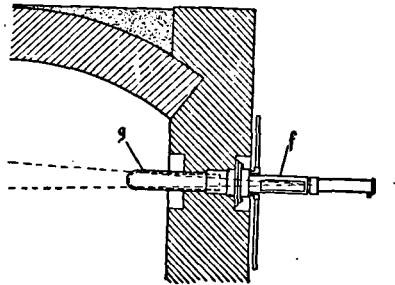


FIG. 26.—Radiation-receiving tube sighted into furnace.

The second link of the chain of control components is the cable connecting the sensitive element to the controller ; this should be of the type recommended for the installation by the instrument maker, and should, of course, be installed and protected as carefully as the cable of the power and lighting supply.

The third link in the chain is the measuring-and-controlling instrument ; this may be of the indicating or recording type, and in both cases the instrument may be either of the deflectional (millivoltmeter) or of the potentiometric type. In the former type the permanent magnetic moving-coil system carries a pointer or pen-arm which moves over a graduated scale or chart. The position of the pointer or pen-arm relative to the scale or chart indicates the instantaneous temperature of the associated temperature-sensitive device.

In the potentiometric type of instrument the moving-coil system is employed in such a manner as to bring into balance the electromotive force developed by the temperature-sensitive element and an e.m.f. tapped from the standardised source in the instrument. When these two e.m.f.'s are out of balance mechanical or electronic action causes the e.m.f. drawn from the standard

source to be varied until it balances that from the temperature-sensitive element, at the same time moving an index across the scale or chart so that when the galvanometer stands at zero indicating complete balance between the opposing e.m.f.'s the index shows the temperature at which this balance is achieved, i.e. the temperature of the sensitive element.

Incorporated in an instrument operating on the on-off principle is a pair of contacts or a switch which is closed so long as the temperature is below the desired figure, and open so long as the temperature is above this figure, while in the case of the instrument employing the two-rate system of control there are two pairs of contacts or a two-way switch, one circuit being closed so long as the temperature is below the desired figure, the alternative circuit being closed so long as it is above this figure.

The final link in the chain of control equipment is a mechanical device which regulates the fuel feed, this device invariably being motor-operated.

In on-off control the motor is switched on by the controller whenever the temperature is below the desired figure, the rate of feed being more than sufficient than is required to raise the temperature to the desired level, and when the desired level is reached the stoker motor is switched off and the fuel feed ceases until such time as the output drops to, or a little below, the desired level.

In two-rate control the stoker motor has two alternative speeds, hence fuel may be fed at two alternative rates. One below that required to maintain the output at the desired level, the other above that required. When the temperature or output is below the desired level the controller causes the high fuel feed-rate to be established, conversely when it is above the desired level the low fuel feed-rate is established. The effect of these alternative rates is probably best explained by the diagram Fig. 27, and the following remarks:—

Fig. 27 is a time-temperature graph arranged in the manner usual in continuous chart recorders, the earlier times being at the bottom and the later times at the top, while the low temperatures are to the left and the high temperatures to the right. The thick black line represents the steam temperature, the dotted line the temperature of the sensitive element (which naturally always lags behind the former), and the broken black line represents the rate of fuel feed to the plant.

At time 1 the heat input is at its pre-set minimum (which is insufficient to maintain the temperature at the desired level), consequently the temperature of the steam is falling (heavy black line), the temperature-sensitive element (dotted line) lagging slightly. Every automatic control system has some minute amount of dead space within which the controlled variable may change without the controller "doing anything about it"; in this case the "dead zone" has been assumed to be  $2^{\circ}$  ( $\pm 1^{\circ}$ ) wide. We therefore have to wait until time 3 before the temperature of the sensitive element has dropped below the lower limit of the dead zone before the controller can cause an increase in the rate of fuel feed. Since the instrument itself may possess some inherent time-lag the actual increase in the rate of feed does not occur until time 4, the pre-set maximum rate being reached at time 6. In consequence of the higher combustion rate developed the fall in temperature is arrested (time 7) and converted into a rise, the arrest and conversion lagging behind the change in rate of fuel feed because of the lag inherent in the plant. The rise in temperature persists until after the instrument reading reaches the upper limit of the dead zone (time 13), when subsequently the controller causes the fuel

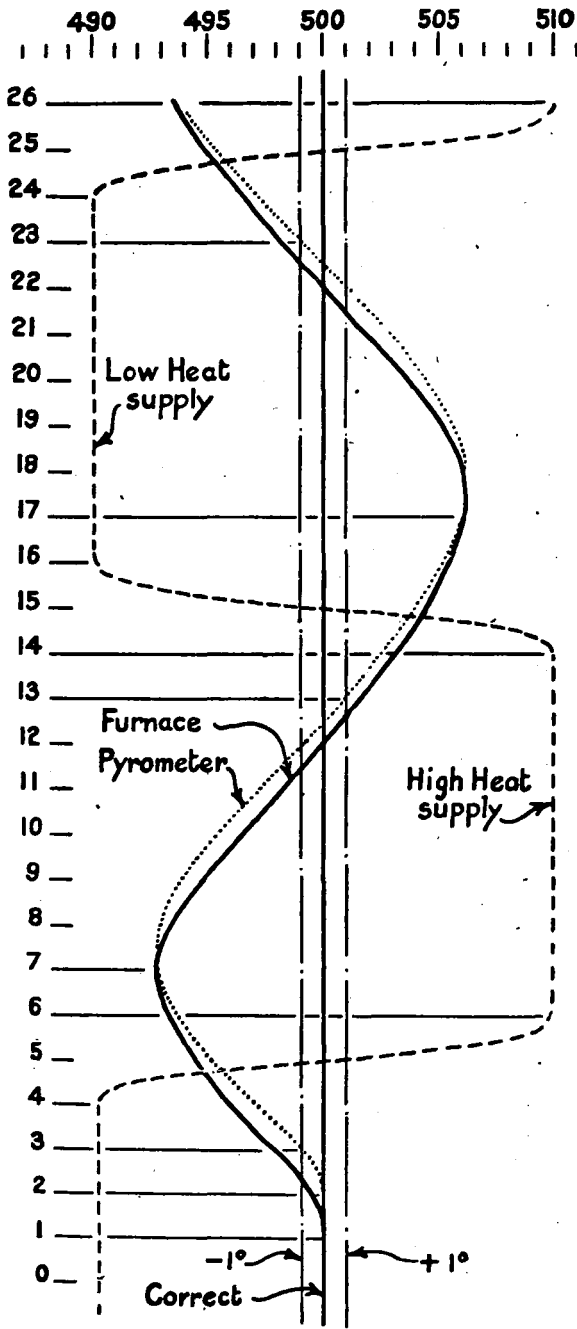


FIG. 27

feed-rate to be reduced to its pre-set minimum (times 14-16). Consequently the rise in temperature is arrested (time 17) and subsequently reversed, falling to the desired value at time 22, thus completing one whole cycle which is repeated indefinitely, thus maintaining the mean temperature at the desired level.

Coupled to the fuel-feed action may be dampers or other devices for regulating the air to the combustion chamber. The regulation of the air is more important in the case of on-off control, where there is a wide difference in the rate of fuel feed to the combustion chamber, than is the case for two-rate control where the best results are usually obtained where the minimum rate is set only a little below and the maximum rate only a little above the rate actually required to maintain the desired output. This, of course, is only practical when the load is reasonably constant. If it is likely to vary considerably then the minimum and maximum fuel feed rates must be wider apart in order to accommodate the variation in load.

#### FEED-WATER CONTROL

The boiler feed-water to the type of steam-raising plant under consideration is usually supplied through a steam-driven or electrically-driven pump.

To complete the automatic control of this type of plant it is usual to instal a feed-water regulator, arranged to maintain the water level in the boiler within close limits. In addition to the advantages of automatic control, the maintenance of a constant water level assists in steaming the plant at its highest efficiency, for by maintaining the level at the height determined by the boiler-makers it is easier to maintain a constant steam pressure and the danger of priming is considerably reduced.

Where the feed-pump is steam driven it can be controlled by a regulator in one of two ways. In the first the regulator, which is fixed to the boiler shell at or about the water-level, controls directly a steam valve in the supply line to the feed-pump. In the second the regulator, similarly installed, can be of the electric-switch type and used to operate an electrically-driven steam valve in the supply line to the feed-pump.

A regulator similar to the last type described can be used when the feed-water pump is electrically driven, and in this case the control operates on the pump-motor starter.

The electric-switch type of regulator usually incorporates a second switch which comes into operation to stop the stoker motor, irrespective of the steam pressure, and to energise an alarm circuit if the water level falls below a pre-determined amount.

## 9. Industrial Steam-Raising Plant

*Units up to 20,000 lb./hr. Developments in Coal Handling, Ash and Clinker Removal and Disposal, Developments in Flue Gas Cleaning Plants including Cyclones, Spraying and Absorption, and Electrostatic Methods*

By H. D. WATSON, A.M.I.C.E., M.I.MECH.E., M.A.S.M.E., etc.

In this paper the emphasis will be laid upon those steam-raising plants in which the boilers are coal fired either by mechanical means or by hand. Hand firing is employed for coal consumptions up to about 1,500 lb./hr., but it may

be deemed expedient or economical to consider the installation of mechanical firing equipment for coal consumption lower than the above. The present tendency is to eliminate or minimise unskilled labour ; the use of mechanical equipment, therefore, whilst reducing the number of attendants required for a given size of plant, involves the employment of a higher quality of labour ; indeed it is generally agreed that maintenance costs as well as fuel costs can be kept down by the exercise of the ability of well-trained operators.

#### MECHANICAL STOKERS

Mechanical firing when reasonably operated is more efficient than by hand, and as both systems are discussed in other papers before the Session it is unnecessary to labour the point here.

#### COAL-HANDLING PLANT

In considering coal-handling plant for small boiler installations it must be borne in mind that the amount of coal to be handled is relatively small, and so the plant should be as simple and inexpensive as possible, but it is not to be inferred from this that it should be as cheap as possible. It must be efficient, reliable, and available at all times, and this can only be guaranteed by sound design and first-class materials and workmanship. The recurrent expense caused by involuntary outages will be serious if these are scanted in an effort to secure a low first cost.

It is often overlooked that the coal-handling plant is an integral part of the boiler installation itself, and as much consideration should be given to its design as to the design of the boiler itself. Where site conditions are sufficiently flexible, it is sound practice to give considerable attention to the coal-handling system and avoid those higher operating costs which will be a constant charge during the entire life of the plant. Some attention should be given to the degradation which a fuel may suffer in handling and to the advantages of one design over another in this respect.

In designing handling and storage systems it is worth while to go to some trouble to avoid segregation. The demand that fuel should be of uniform quality, whether this be high or low, can hardly be justified if the user takes no care to preserve it in this condition right up to the combustion stage.

The possibility that the plant may need to be enlarged at some future time should be kept in mind, and a system which will then demand complete replacement should be avoided at the outset. It is not of extreme importance that the handling and storage plant always be operated at 100 per cent. of its capacity.

The general layout of the coal-handling plant is determined mainly by site conditions, and is influenced to a large extent by the method of delivering the coal in bulk to the site, i.e. whether by road or rail, and also to the disposition of the road or railway siding relative to the location of the boilerhouse and coal pile.

The modern trend is to introduce mechanical stokers whenever possible, and to introduce these and retain man-handling of coal and ashes appears to be an anachronism, since mechanical handling of coal and ash is always financially justified providing the equipment is correctly designed for the conditions under which it will have to operate.

*Fig. 28.* In this installation coal is brought to the site in road vehicles and is discharged into ground hoppers in front of each boiler. From each hopper the coal is fed to an inclined elevator, the feed being controlled by a roller

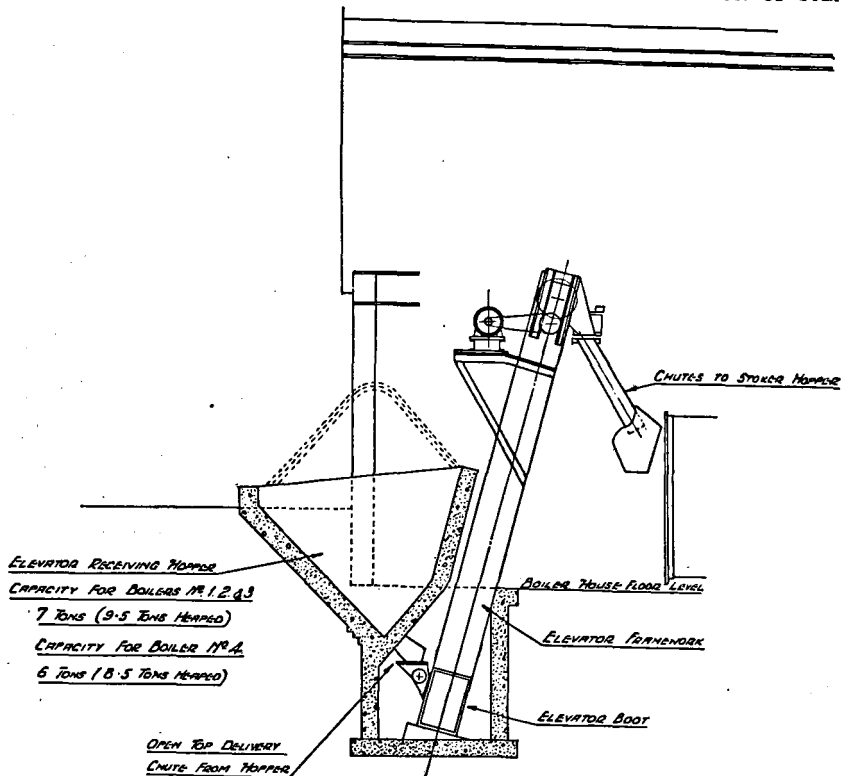


FIG. 28.—Proposed Arrangement of Elevator.

eeder driven by the tail shaft of the elevator. At the head of the elevator a chute is provided to discharge the coal to the stoker hopper.

The operation of the elevator is entirely automatic, the driving motor being started up by a switch in the stoker hopper when the coal falls to a pre-determined level, and being stopped by a further switch when the coal level rises to the top of the elevator chute.

Capacity : up to about 3 tons per hour.

Cost : delivered and erected, but excluding foundations, about £450 for each elevator.

Fig. 29. Where coal storage at ground level in front of the boilers is not available, storage bunkers can be provided in the boilerhouse as shown on the drawing.

The coal is discharged from road vehicles into a ground receiving-hopper at one end of the boilerhouse and is conveyed and elevated to the overhead bunkers by means of a gravity bucket conveyor. This conveyor is fitted with automatic dumpers to enable the coal to be discharged into the appropriate section of the bunkers. During the loading operation an attendant is required on the top walk-way alongside the conveyor to set the dumpers to tip the coal at the correct point.

Plants of this type have a capacity of 20 tons per hour upwards.

Cost : delivered and erected, but excluding foundations, about £4,000.

Note.—Prices given were at the date of the paper, October, 1946.

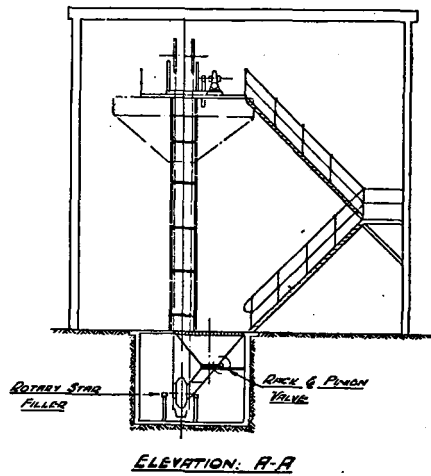
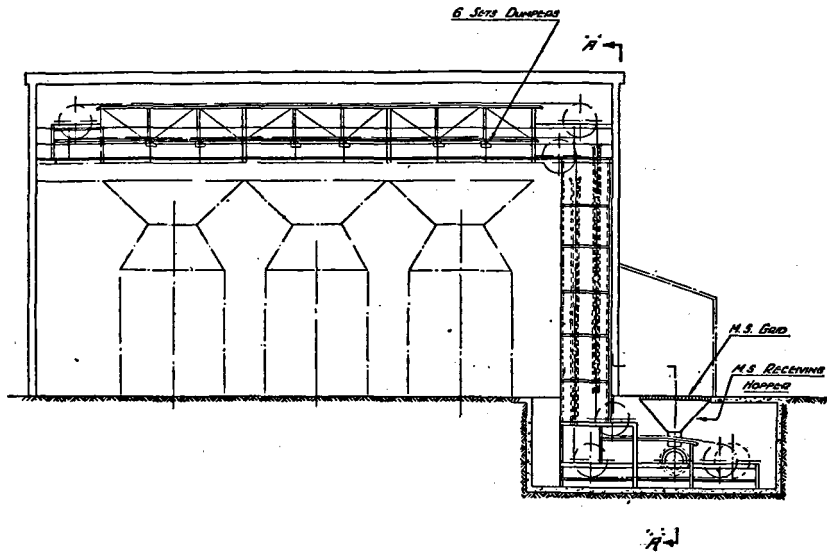


FIG. 29.—Arrangement of Coal Handling Plant.

*Fig. 30.* This installation is somewhat similar to that described above with the exception that the gravity bucket conveyor is superseded by an elevator and a “U” link conveyor, the capacity of the plant being too small to warrant a gravity bucket conveyor.

Capacity : about 10 tons per hour.

Cost : delivered and erected, but excluding foundations, about £1,250.

Fig. 31. Where coal is brought to the site by rail, the railway wagons can be conveniently unloaded by means of a hand-operated wagon tilter as illustrated on this drawing. With this the bulk of the coal flows out of the wagon by gravity through the side doors, only a small proportion being required to be raked out by hand. This tilter can be incorporated in most coal-handling schemes and is very effective in saving labour as 3 to 4 wagons can be unloaded in one hour.

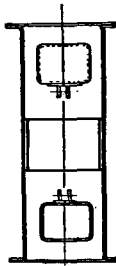
The particular coal-handling plant illustrated on this drawing comprises a wagon tilter, a ground receiving hopper, an elevator and a "U" link coal conveyor which discharges the coal to the stoker hoppers.

As the conveying plant is automatic in action, the only manual labour required is for discharging the wagons.

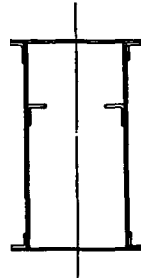
In this scheme a bifurcated chute at the head of the elevator enables coal to be delivered to ground level so as to form an emergency store.

Capacity : about 20 tons per hour.

Cost : delivered and erected, but excluding foundations, about £1,800.

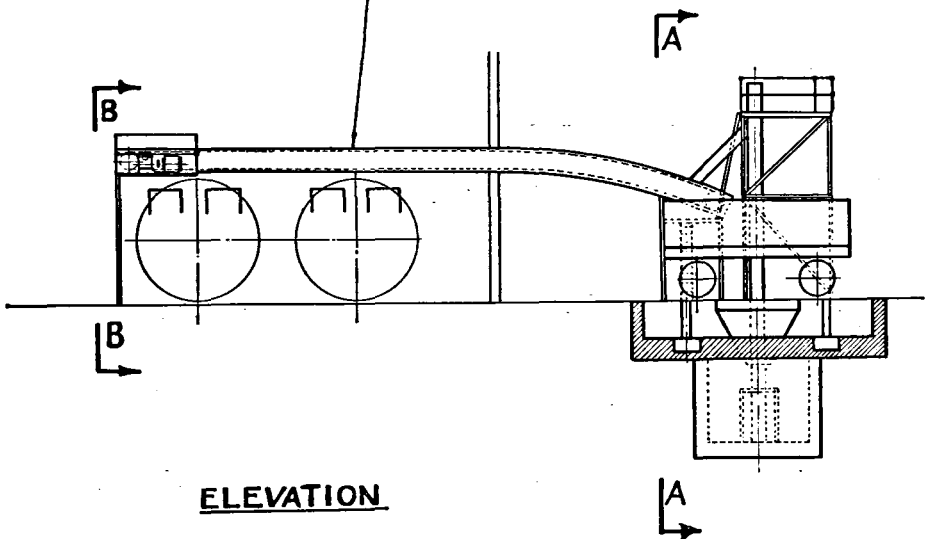


**TYPICAL SECTION  
THRO' BUCKET ELEVATOR**



**TYPICAL SECTION  
DRAG LINK CONVEYOR  
CASING.**

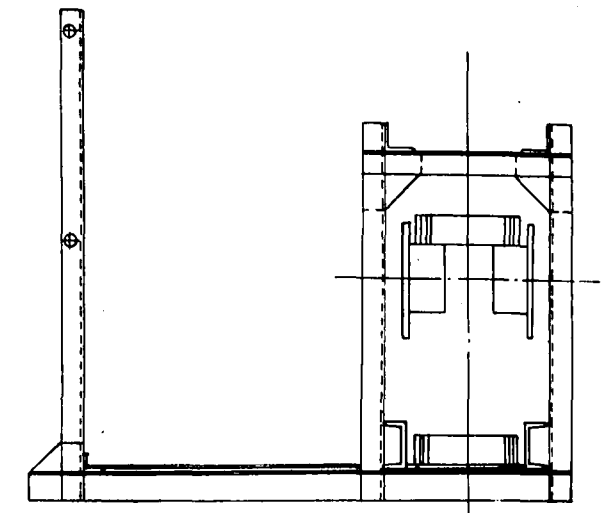
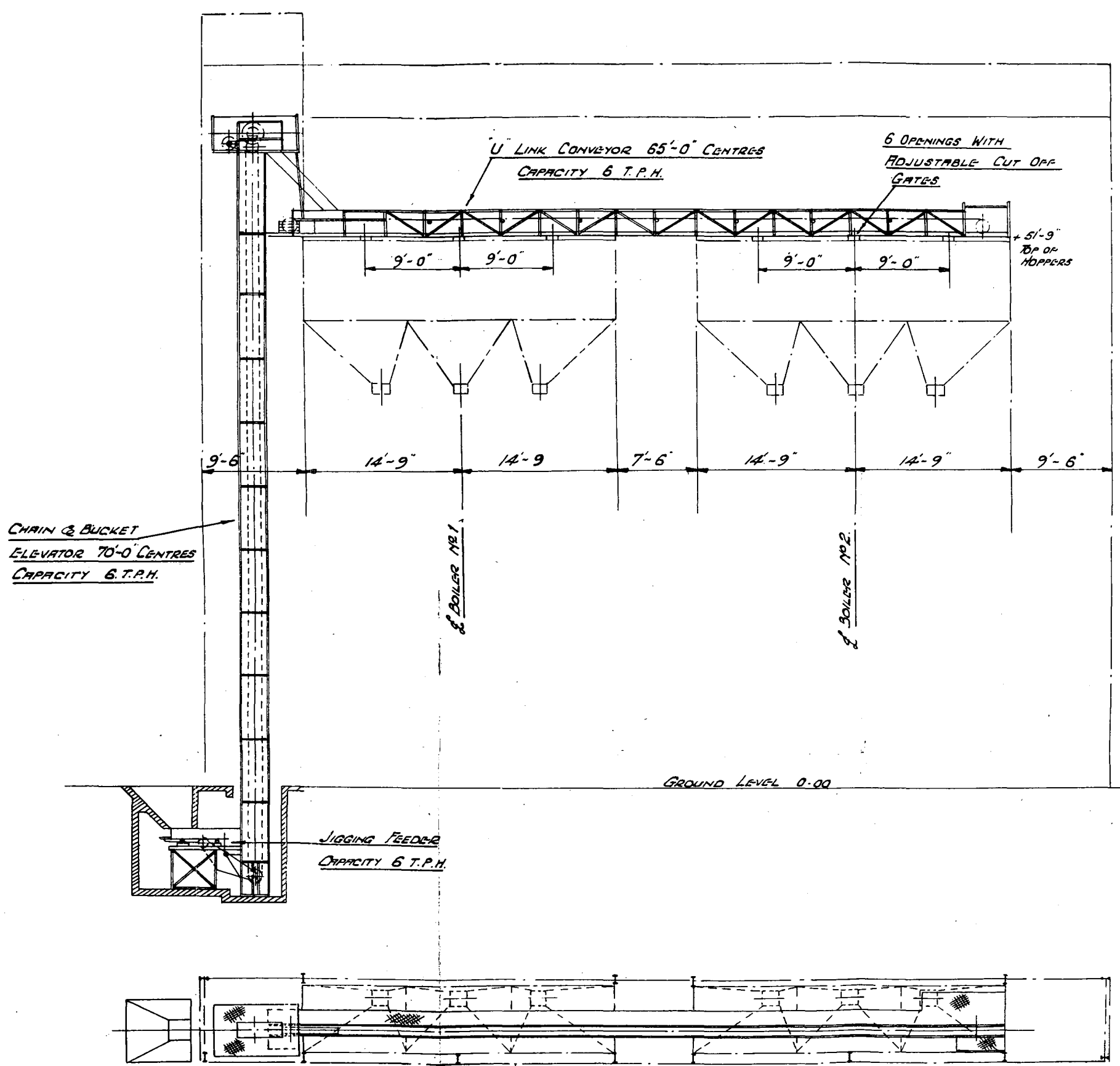
**DRAG LINK COAL CONVEYOR**  
46° CHAIN CRS.  
CHAIN SPEED 10 F.P.M.



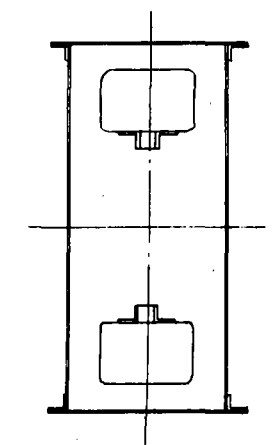
**ELEVATION**

FIG. 31



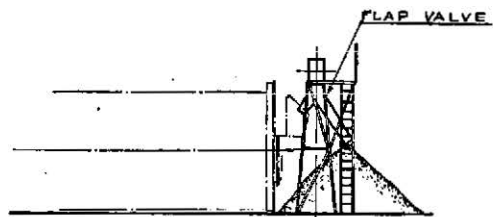


SECTION THROUGH CONVEYOR

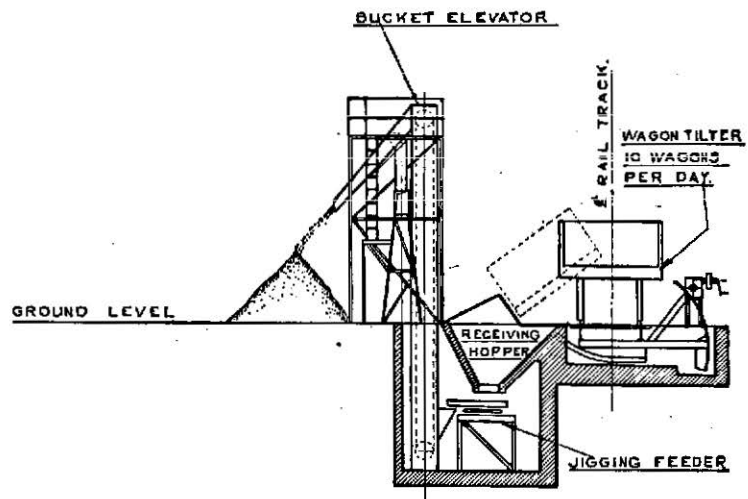


SECTION THROUGH ELEVATOR

FIG. 30. ARRANGEMENT OF COAL-HANDLING PLANT.



VIEW ON "B.B."



SECTIONAL ELEVATION "A.A."

FIG. 31—*contd.*

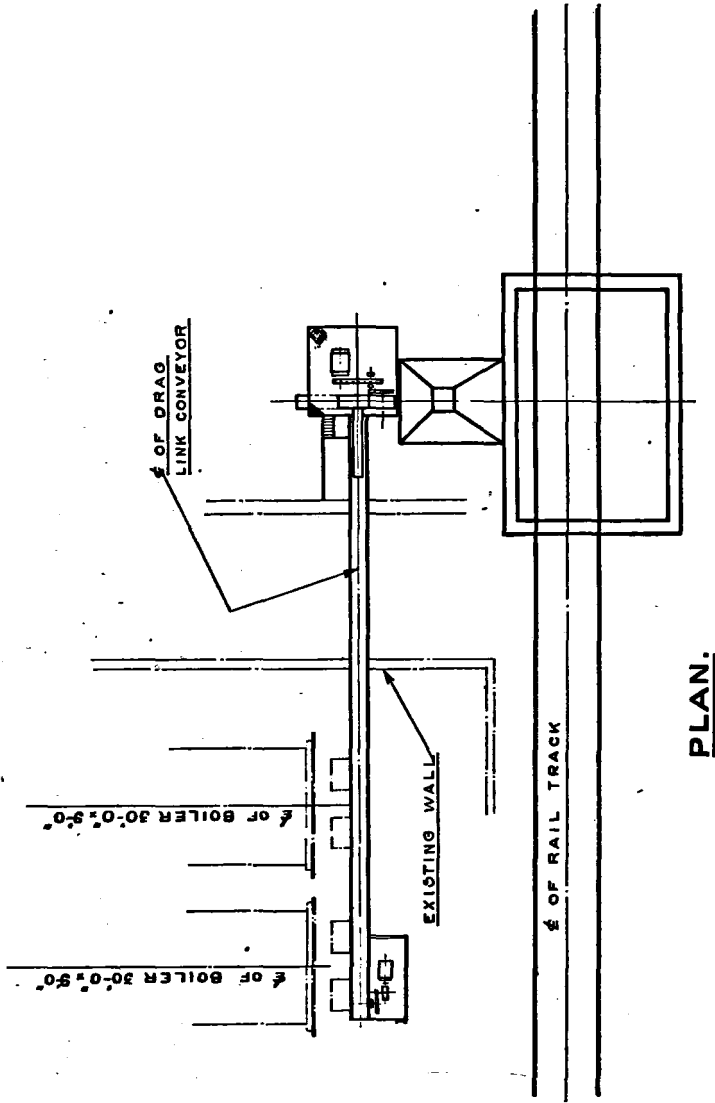


FIG. 31—contd.

## ASH HANDLING PLANTS

*Fig. 32.* Generally speaking the amount of ash discharged from small boiler installations is insufficient to warrant a continuous ash-handling system, but it is essential to elevate the ashes so that they can be delivered to road vehicles or railway wagons.

A simple type of ash hoist is illustrated on this drawing. The ashes are loaded by hand into small trucks operating on a small-gauge track and are pushed outside the boilerhouse to a position adjacent to the hoist where the tub is locked to a lifting cradle. An electrically-driven winch at the head of the hoist is then started up by the attendant, and the tub is raised and automatically inverted and stopped so that the ashes can be discharged to a waiting vehicle. When the tub is empty the attendant reverses the winch operation and the tub is lowered to ground level for return to the boilerhouse. Electrical limit switches are incorporated to prevent over-hoisting and over-lowering and to prevent the cradle being raised until the tub is securely locked in position. The usual size of tub is 10-cwt. capacity.

Cost : delivered and erected, but excluding foundations, about £1,300.

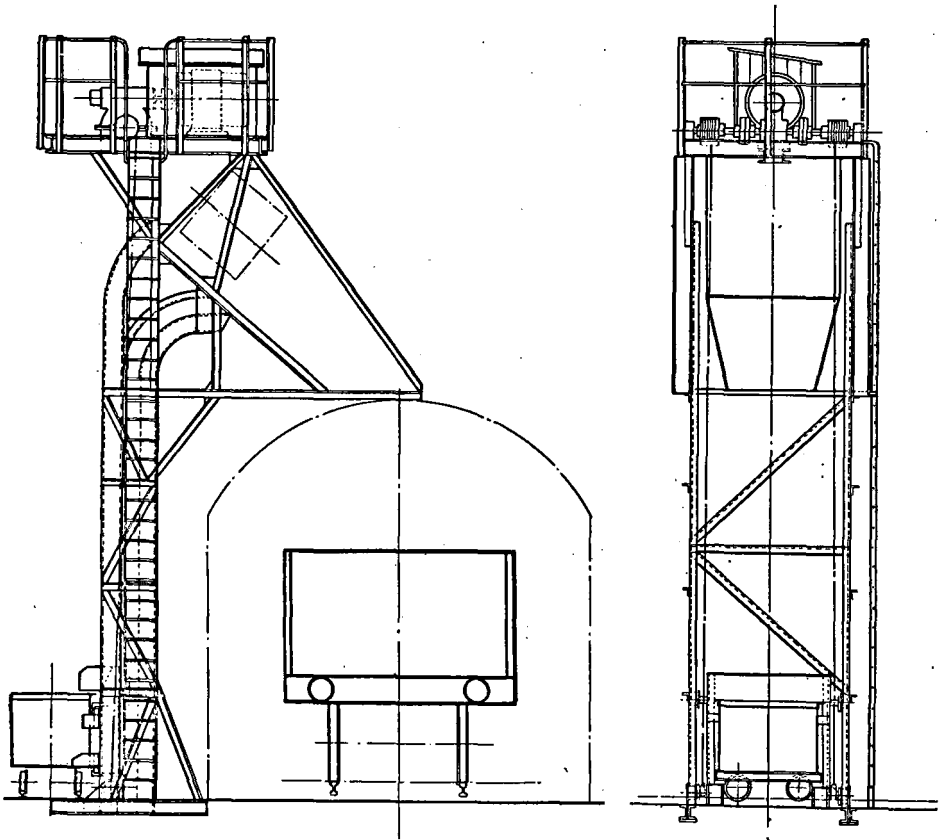


FIG. 32.—Arrangement of Tub Hoist.

Fig. 33. In the event of storage being required for the ashes the hoist can be combined with a storage bunker generally as shown.

The tub, however, can be of any desired size or shape to suit the working conditions.

Cost : delivered and erected, but excluding foundations, about £2,000.

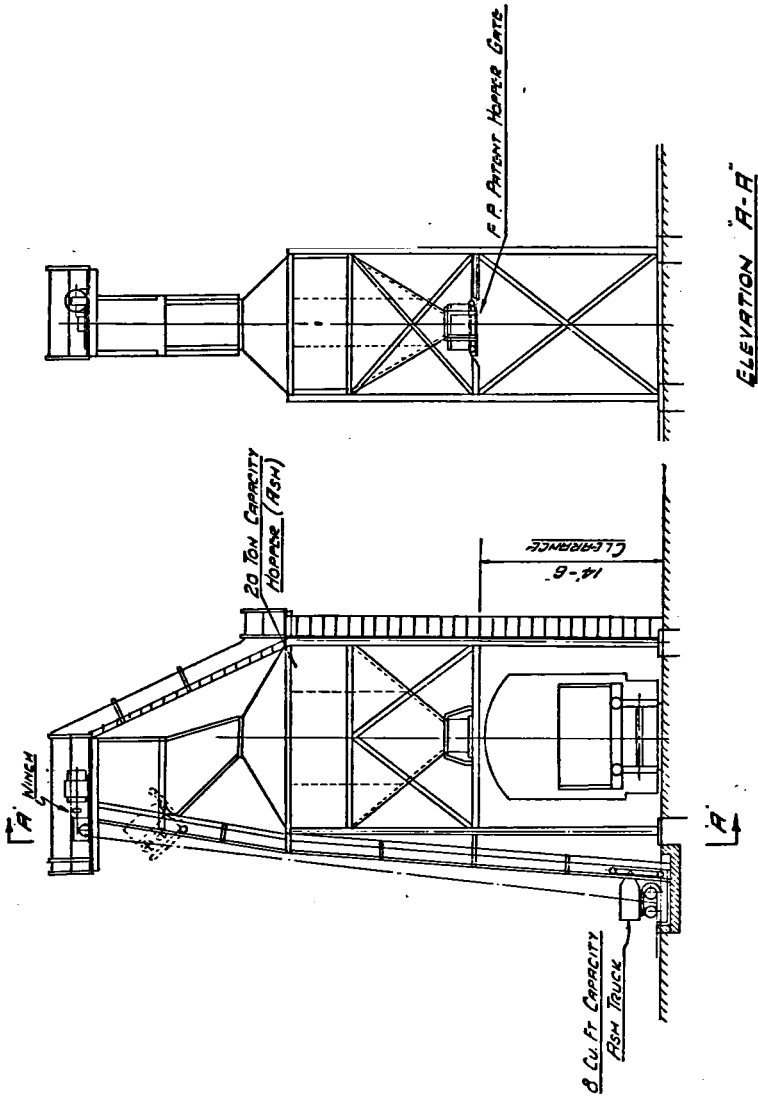
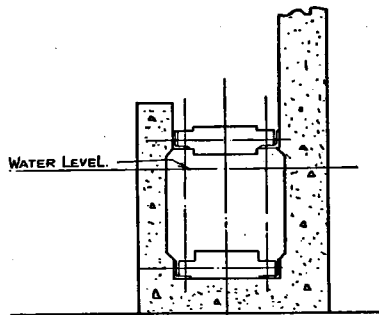


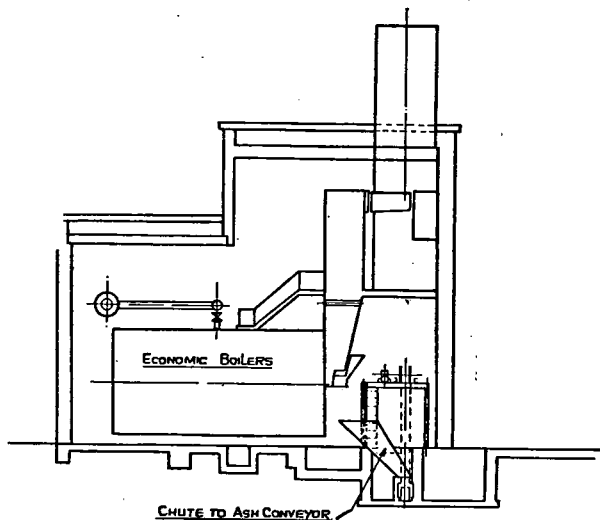
FIG. 33.—Arrangement of Skip Hoist.

*Fig. 34.* Where it is not convenient for the ashes to be loaded directly by hand from the ashpits to the tubs a drag-link conveyor can be arranged below ground level in front of the boilers. The ashes can be raked into this conveyor, which will convey them outside the boilerhouse and elevate them so that they can be discharged into tubs. The tubs can be emptied by being hoisted by the ash hoist already described.

Cost : delivered and erected, but excluding foundations, about £1,000.\*



TYPICAL CROSS-SECTION  
THRO' SCRAPER CONVEYOR  
TROUGH.



SIDE ELEVATION.

FIG. 34.—Arrangement of Ash Handling Plant.

\* These illustrations are reproduced by permission of Mitchell Engineering Co., Ltd.

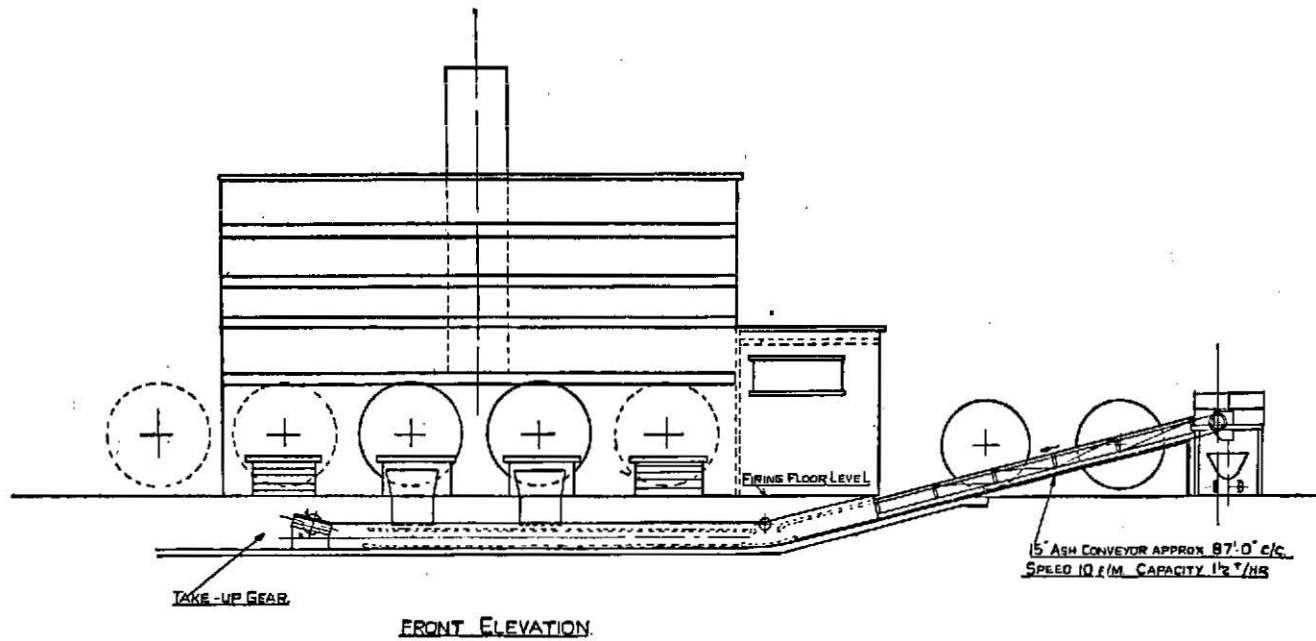


FIG. 34. *contd.*—Arrangement of Ash Handling Plant.

## FLUE GAS CLEANING

This may be achieved by one of several methods, such as :—

- (1) Settling chamber.
- (2) Shunt suction cyclone collectors.
- (3) Cell type collectors.
- (4) Multi-cell collectors.
- (5) Gas washing.
- (6) Electrostatic precipitation.

(1) *Settling Chamber*.—The flue gases are led into a large chamber so designed that the gas speed falls to about 1 ft. per second. The larger particles are deposited, and only fine dust and smoke are carried away. The settling chamber is generally built with bricks, and can be worked with natural draught.

(2) *Shunt Suction Cyclone Collectors*.—The dust-laden gas stream in the induced-draught fan is tapped from the point of maximum dust concentration in the main collector and led to a secondary vortex collector ; centrifugal action is used to extract the grits, the cleansed gas being returned to the main collector inlet, whilst the grits are collected in the hopper at the bottom. An induced draught fan is required since the resistance is about  $1\frac{1}{2}$ -in. w.g. The efficiency of collection is about 75-80 per cent.

(3) *Cell Type Collectors*.—These work on the same principle as the secondary mentioned above. Usually there are four or more collectors arranged in pairs so that the collector efficiency may be maintained with either rising or falling load, by increasing or reducing the number of collectors in circuit and thus maintaining that gas speed essential for efficient collection. The efficiency of collection is about 85 per cent., and the resistance is generally about  $2\frac{1}{2}$ -in. w.g.

(4) *Multi-Cell Collectors*.—A large number of comparatively small tube collectors, of diameter varying with type from about 2 to 10 in., are arranged in the gas stream, and the efficiency of collection has been found to be about 90 per cent. The draught loss incurred for the usual designs is about  $1\frac{1}{2}$  in. to  $2\frac{1}{2}$  in. w.g. depending upon the type.

(5) *Gas Washing*.—This is usually employed when it is necessary to remove sulphuric acid and other harmful products as well as the grits from the gases. Notable instances of employment are at the London Power Company's Battersea power station and also the Howden I.C.I. patented process used at Fulham, Swansea, and elsewhere. The cost is high for small industrial power stations.

(6) *Electrostatic Precipitation*.—For power station work this method is employed for collecting grits from pulverised fuel fired boilers. The grit-laden gases are made to pass through circular or rectangular collector electrodes. The particles are charged by means of wire or rod discharge electrodes which are maintained at about 70,000 volts, and the charged particles move to the collector electrodes, then give up their charge, and fall into suitably arranged hoppers. Rapper gear is employed periodically to shake the dust from the collector electrodes.

While it is not likely that the cost of electrostatic precipitation will permit it to be used with industrial units of the size to which this paper is confined, special considerations connected with the location of the plant and the zoning system may require to be given consideration.



*Discussion*

**Mr. Lupton** said that he was not sure whether low steam pressures should not be prohibited by law. If the grid system of heat distribution were developed the use of the heat pump should be fully considered. The high-grade heat should be used to develop electrical energy and the low-grade heat used for space heating. The internal combustion engine and the gas turbine had great possibilities for the production of power and an efficiency of 35 per cent. could easily be obtained. In this country we should develop the methods used in other countries where fuels had long been scarce and only low-grade fuels were available.

Referring to the papers, Mr. Lupton asked Dr. Ritchie how the ideal efficiency curve was obtained and what was its meaning. Mr. Peacock's paper suggested to him that there should be more co-operation between electricity supply undertakings and consumers. There were far too many different tariffs for electricity. Shell boilers were generally favoured for most industrial work because of the greater quantity of energy stored in them as compared with the water-tube boiler. More care was necessary with the treatment of water used in water-tube boilers. While Mr. Peacock's paper was unanswerable the variability of coal quality had been and still was a grave deterrent to efficiency. Consistency of fuel should be the aim. The boiler stoker usually secured a constant steam pressure but not economical working. Bonus schemes for economy were therefore very desirable.

The speaker was in favour of buying coal on a calorific value basis and was doing that today. He suggested that the effectiveness of the tumbler mill pulveriser was not fully appreciated, and that the cost of power and upkeep of pulverising plant was not always correctly set against the cost of steam raising. Referring again to Dr. Ritchie's paper he asked what part of a Lancashire boiler should be anchored.

**Mr. Dudley** observed that when raising 10,000 lb. steam an hour the stoker handled 11 cwt. of fuel an hour, whereas a miner, with a working time of only five hours, handled 10 to 12 tons a shift. The stoker therefore had time to put the fuel on properly and was not hard-worked.

**Mr. Griffin** believed that with proper use of instruments a fuel economy of 20-30 per cent. could still be obtained. He felt that it should be compulsory for boiler makers to fit the requisite instruments to new boilers.

**Mr. Bagshaw** said that underfeed stokers attached to hot water boilers, if properly worked and controlled, could handle low loads satisfactorily. In practice, however, flue gases with 3 per cent. CO<sub>2</sub> were common. The practice of lowering only the side flue damper nearest to the furnace being cleaned, when operating Lancashire boilers, was wrong; both dampers should be lowered and the CO<sub>2</sub> would then not fall perceptibly. Properly operated, a Lancashire boiler could be as economic as a water-tube boiler.

**Mr. I. M. Stewart** (Commonwealth Coal Commission, Australia) wrote:— It was very interesting to me to hear a set of papers written from the British background of shell boilers for industrial steam-raising. In Australia such boilers are relatively few. Boilerhouses generating less than about 10,000 lb. of steam an hour are mostly equipped with "Colonial" type externally-fired multitubular boilers, while water-tube boilers predominate for factories larger than this.

Ease of transport, low first cost and the flexibility with regard to grate area, stressed by Mr. Peacock, are the predominant factors in this choice.

I would be interested to know the excess air which was carried in the particular tests plotted by Dr. Ritchie in Figs. 9 and 10. On spot tests we have not found such high boiler exit gas temperatures as shown in Fig. 9; this may be partly due to the higher flame radiation from our high-volatile coals, but I can claim no great accuracy for our results.

I hope that we shall be able to initiate some work similar to that carried out by Dr. Ritchie on small colonial and water-tube boilers, but I am particularly interested in the overall performance since flue gas losses play only a small part of the efficiency loss particularly when the boiler is not operated 24 hours per day. The externally-fired boiler has a large area of brickwork exposed to furnace temperature and in small units the radiation losses and air leakage (in the most vulnerable place) are considerable. Even greater is the loss of stored heat in the furnace brickwork. Attempts to retain this by close dampering during the banked period frequently result in blowing of the safety valves one or two hours after shutting down with complaints from all the neighbouring residents.

To avoid excessive furnace temperatures the small externally-fired boiler cannot be operated at better than about 10 per cent.  $\text{CO}_2$  at full load without excessive maintenance. With boiler exit temperatures at  $500^\circ$  to  $600^\circ$  F. this does not represent an unduly high loss, but, since the boiler must be well draughted to secure this, the excess air at low loads can be simply appalling, e.g. less than 5 per cent.  $\text{CO}_2$ , unless the firemen control the dampers exceptionally well.

The "on-off" type of controller described in Paper No. 8 has won great popularity for small boilers fired with screw-underfeed or spreader stokers because it releases the fireman for other duties. As most firemen set the stoker and fan at the highest possible speed the "off" periods are frequently of long duration, the pressure fluctuations are large, flue gas losses are high, clinking tendencies, smoke and grit emission are increased and the effect on the furnace brickwork and boiler shell of the large temperature fluctuations between the on and off periods cannot be good.

The two-speed control is much better, but I am convinced that the proper solution for the small industrial boiler is to drive the stoker and fan from a common variable speed drive, preferably a small steam engine exhausting to process main or feed heater. A very simple controller would keep steam pressure just as steady as any "on-off" controller, and for any one setting of dampers and coal feeder a fixed air-fuel rate would be obtained over quite a wide range of speeds. The principle is, of course, similar to the Metrovick D.C. control device for large boiler installations, except that mechanical linkage to a common drive shaft is proposed instead of electrical linkage to common D.C. busbar. This mechanical linkage could be quite neatly installed on most small boilers with forced-draught stokers, though admittedly it would require considerable ingenuity where induced draught only is fitted.

The prime difficulty in the way of any improvement in the small industrial boiler plant has been outlined by Mr. Evans—works managers and directors don't like to spend money on the boilerhouse and tend to buy on first cost rather than on annual cost. I believe that discussions such as this coupled

with the excellent work which has been started by your research associations will provide us all with further ammunition in the campaign for economical and efficient boiler plants for the small industrial plant.

Mr. A. F. Webber wrote that it was not essential to abolish the usual setting before considering a steaming economiser. The scope for heat recovery by a non-steaming economiser was limited when low boiler pressures were associated with high feed-inlet temperatures. On an installation working at 120 lb./sq. in. with feed-inlet temperature of 180° F., the maximum permissible rise in the economiser was 120°-130° F. and the final gas temperature could not fall below 480° F.; with a steaming economiser, the water outlet temperature could be 350° F. and the outlet gas temperature 350° F. The difficulty was that the steaming economiser must have steel tubes, but cast iron was desirable on the gas side, resulting in an expensive double construction.

The main point on which the writer joined issue with Dr. Ritchie was upon the economical rating of Lancashire boilers. The "nominal rating" of a 30-ft. × 9-ft. boiler was given at 11,000 lb./hr. "from and at 212° F." and a recommendation was made in Dr. Ritchie's paper that boilers should normally be installed on the basis of 70 per cent. of this rating. This led to very substantially increased capital costs and extra ground area was required. From the Woolwich Arsenal experiments it would seem that a boiler having an efficiency of 78 per cent. at an output of 60-70 per cent. of 11,000 lb./hr. (i.e. 7,150 lb./hr.) could not be expected to have an efficiency of more than 65-66 per cent. at outputs of about 15,000 lb./hr. Figures were quoted by the writer (a) from Fuel Economy Review for 1944 (Messrs. Mandleberg's works) and (b) from *ibid* for 1933 (Port Sunlight) of boiler tests on industrial plant which showed efficiency figures at high outputs far above what would be deduced from Dr. Ritchie's results. The basis of Dr. Ritchie's recommendation to de-rate Lancashire boilers was that high efficiency and high output could not co-exist. Published figures showed that they could co-exist, and the problem therefore was to see that the required conditions were secured.

The side flue temperatures in the Woolwich tests appeared high. Temperatures as high as 1,000° F. in the side flues usually meant that combustion was being completed in the bottom flue. The paper gave a formula (67° F. rise for each 1,000 lb./hr. duty) from which the side flue temperatures in the Mandleberg and Port Sunlight plants should have been over 1,200° F.—they were 800°-850° F. and 854° F. respectively. The Woolwich tests should not be accepted as a valid reason for reversing the present trend in design of high-duty, high-efficiency Lancashire boiler plant.

As a footnote to Mr. Peacock's paper it should be noted that a works having shell boilers was not precluded from developing power generation from process steam; there was very considerable scope for this without exceeding a steam pressure of 250 lb./sq. in.

Mr. Pearsall was quite right in claiming that very substantial economies in both coal and labour would result from converting from hand firing to mechanical firing. Since existing mechanical stokers were generally applied to boilers having the higher capacities and more steam was raised in boilers having economisers, Mr. Pearsall's estimate of a possible saving of 2½ million tons of coal in this way was likely to be high. The statement that in a Lancashire boiler with economiser the outlet gas temperature rose 15° F. for each 10 per cent. excess air was probably true only of a low gas-speed vertical

economiser with heating surface small by modern standards. With a modern high-speed, gilled-tube economiser the curve for temperature rise against excess air should be as flat as that for an Economic boiler. Doubts were expressed whether the lines in Mr. Pearsall's first figure should be straight since if extended to 220 per cent. excess air (5·8 per cent.  $\text{CO}_2$ ) impossible temperatures resulted. It had hitherto been the writer's opinion that even with mechanical firing an average of 12 per cent.  $\text{CO}_2$  in the side flues was as high as it was wise to attempt.

The high capital costs associated with p.f. firing and the low fuel, labour and maintenance costs caused high load factor to be the most likely field for it. The tentative suggestion was offered that a yearly total of 5,000 hours at a fairly high proportion of full load was requisite if the high cost of the plant was to be recouped by its low running cost. There was no reason why a p.f. fired boiler should not operate continuously from one annual inspection to the next since the whole process of steam generation was entirely mechanised. Mr. Ryder was a little pessimistic in giving 7 per cent. as the maximum economic moisture content of coal for ball mills with hot primary air ; he would put the figure at 10 per cent.

Insulation over the rafts of settings was more effective than Mr. Evans suggested. An instance was quoted when  $1\frac{1}{2}$ -in. of insulation backing 3-in. of firebrick caused the concrete raft immediately under the insulation to rise to a stable temperature of 600-620° F. with downtake temperatures averaging 1,350-1,400° F. Would insulating brick, applied to side walls, be strong enough mechanically to provide a good bond between the firebrick and the common brick ? It would be most desirable if completely insulated settings could be specified. Insulation on the side walls might increase the temperature stresses in the walls due to the greater temperature difference between the inner and outer surfaces.

Dealing with the heating surface of Lancashire boilers, Mr. Webber did not approve the suggestion made by Mr. Evans that the size of the flues should be reduced. This would only be effective if heat transfer were by convection, whereas in the bottom and side flues radiation was the principal method. Boiler efficiency had not been found to be improved when flues were half-full of grit and the gas speed doubled. According to Fig. 13 of Mr. Pearsall's paper, with 20 per cent. excess air the temperature drop from downtake to boiler exit was 510° F. ; with 140 per cent. excess air, giving approximately double the weight of flue gas, the temperature drop was 180° F.—less than one-third. In fact, heat transfer in the bottom flue seemed to be reduced by 60 per cent. when the gas speed was doubled, while that in the side flues was substantially unaltered ; this was due to the pre-dominant effect of radiation in the hotter flue ; the temperature in Fig. 13 for the Economic boiler showed a substantial increase in heat transfer for a doubled gas speed ; here convective heat transfer was the dominating factor at these lower temperatures. Dr. Foxwell's analysis of heat transfer in Lancashire boilers (J. Inst. Fuel, XVI, 168) confirmed the importance of radiation in the flues of this type of boiler.

Although formerly advocating the elimination of brick settings from Lancashire boilers, the writer had now reversed his opinion. The bottom flue heated the water in the bottom of the boiler, an important factor in reducing strains in view of the tendency of the bottom water to remain cold. Retention of the bottom flue only would have the disadvantage of bringing the gases to

the front of the boiler where they would be more difficult to handle. A balance must be struck between reliability and efficiency, since both were important. Mr. Webber doubted whether tube heating surface was much more efficient than shell heating surface, "efficiency" being defined as "rate of heat transfer/sq. ft./hr./° F. temp. difference between gas and water." Analysis of Figs. 11 and 12 in Dr. Ritchie's paper yielded the following evidence :

The total heating surface of a standard 15 ft. 6 in.  $\times$  9 ft. 6 in. diam. Economic boiler is 1,825 sq. ft. That of the 14 ft.  $\times$  9 ft. 6 in. boiler would be about 1,640 sq. ft. of which 230 sq. ft. would be accounted for by the furnace flues, leaving 1,410 sq. ft. for the tubes and end plates. As this boiler was brick-set, there would be about 280 sq. ft. of shell heating surface. The ratio : 'tube H.S./shell H.S.' is therefore 5. At nominal rating of 7,500 lb./hr. the tubes are responsible for 43 per cent. of the total useful heat transfer and the shell for 49 per cent.—a ratio of 8.8. It would seem, therefore, that tube H.S. is nearly twice as useful, but the tubes contain gas which enters at 1,580° F. and leaves at 700° F., an average of 1,140° F. which is not, of course, the true mean temperature but will serve as a measure of the temperature head available. The shell has to deal with gas entering at 700° F. and leaving at 580° F., an average of 640° F. As the boiler water is presumably at about 350° F., the temperature head in the tubes (1,140-350 = 790° F.) is  $2\frac{3}{4}$  times the temperature head across the shell heating surface (640-350 = 290° F.). It would seem, therefore, that on the basis of heat transfer/sq. ft./hr./° F. the despised shell heating surface is *more* efficient than tube heating surface. While I do not believe this, I think it shows that shell heating surface is not necessarily *less* efficient.

Mr. Webber considered the real advantage of the Economic boiler was that it was possible to get much more heating surface in the same space, not that this heating surface was more efficient.

Mr. J. R. Edwards wrote that in addition to the aspects of heat transfer dealt with in Dr. Ritchie's paper, two others should be considered, namely the draught available at the fires and the ratio of grate surface to heating surface. Draught had a bearing on rate of firing which in turn bore on the velocity of the gases over the surfaces. The ratio of grate to heating surface in a Lancashire boiler without superheater or economiser was low, of the order of 1.26 or 1.28 ; this caused high flue-gas temperatures leaving the side flues of the boilers ; he had positive proof that the best ratio was about 1.75 in plants that included superheater and economisers but not air heaters. Economisers in the past had often been installed of much too small a size ; his own practice was to use for each 30-ft.  $\times$  8 ft. 6 in. Lancashire boiler in a battery, 120 pipes 11 ft. 6 in. long. If this did not give the 1.75 ratio, the length of the grates should be reduced accordingly.

Even with high draught (e.g. a suction of  $1\frac{1}{2}$ -in. w.g. in the side flue and 1-in. w.g. over the fires) settings could be air-tight, with CO<sub>2</sub> between 12 and  $14\frac{1}{2}$  per cent. Very high efficiencies could be maintained from Lancashire boilers with low rates of firing ; but high efficiencies could also be obtained from very hard-worked Lancashire boilers. For this reason it would not be wise to advise the installation of over-capacity operated at low load to secure high efficiency.

The writer instanced a works with 105 Lancashire boilers at which the average rate of firing was increased from 15.3 lb. to 38.7 lb. fuel per sq. ft. of grate area per hour and the cost of steam production was decreased from £331,000 to £97,600 with reduction of the number of boilers working from 95 to 36. The thermal efficiency at low output was 59 per cent. and at high output 78.1 per cent. Two other cases were quoted from the writer's experience in which the performance of the plant was much improved when the rate of firing was very much increased.

Disagreement was expressed with Fig. 9 of Dr. Ritchie's paper in that the high temperature of the gases at the downtake (1,520° F.) and the boiler exit (1,020° F.) suggested that the heating surfaces were not clean and the grate area was too large. Because of stratification, great care should be observed when taking temperatures in flues. There was no danger in working Lancashire boilers at very high ratings, provided the heating surfaces were kept clean and the feed water properly treated. The writer considered the most efficient average rate of firing to be about 42 lb. of fuel/sq. ft. grate area/hr., but the maximum rate might be up to 60 lb.

It was disconcerting to hear from the Minister that better grade fuels were not likely to be available for 5-7 years. Using low-grade fuels more boilers would be required for a given steaming capacity, but those who installed larger boiler capacity now would be left with surplus capacity in 5-7 years' time, which—the writer maintained—would consequently be operated at a lower efficiency.

**Mr. Felsner** referring to Mr. Hayward's paper on the chain-grate stoker for Lancashire boilers asked for a full description of the coal and its caking and swelling properties, and also for particulars of the rates of combustion per sq. ft. of grate area that could be obtained with various fuels.

**Mr. F. H. Allman-Ward**, referring to Mr. Tinley's paper, expressed doubts whether the original simplicity of the stoker described had not become buried under the "Modufeed" control, which was added later. The features of the original design had all been retained in the commercial machine. The stoker remained the least sensitive of any to variations in coal grading as it threw out oversize which, in practice, was hit with a shovel and returned to the hopper. It could feed directly from the bunker. It could be constructed to handle and mix two or more fuels in a pre-determined ratio, e.g. coke breeze and bituminous fines. Use of a conveyor instead of forcing the fuel through a tube by a screw resulted in the reduction of wear to the minimum. A simpler mechanism for doing the work could hardly be devised. The "Domestic" development was of interest as by rocking the hopper and holding the feeder with its forks stationary and fixed to the conveyor tube, an efficient stoker had been designed with two moving parts—the spiral and the hopper—and a single swinging linkage.

In reply to the discussion, **Dr. Ritchie** wrote as follows :

Mr. Lupton asked for an explanation of 'ideal' efficiency. This is merely the heat absorption efficiency of the heating surface as determined from the results obtained on the complete plant.

Mr. Webber and Mr. Edwards both object to the findings of the R/16 Committee, i.e. that the heat absorption efficiency of a shell boiler decreases with increase in rating. Without going into detail, the decrease of

2 per cent. for each increase in evaporation of 1,000 lb./hr. mentioned in the paper has been established beyond doubt for two different sizes of Lancashire boiler, i.e. 30 ft. × 8 ft. and 30 ft. × 9 ft. with hand firing and mechanical firing over a range of ratings from 2,000 to 12,500 lb./hr., while precisely the same relationship has been established by an independent authority for a 28 ft. × 7 ft. 6 in. powdered-coal fired Lancashire boiler over a range of ratings from 3,200 to 16,800 lb./hr. All figures are f. & a. 212° F. These investigations were carried out on Lancashire boilers alone without an economiser. The influence of an economiser has been discussed with the economiser manufacturers, as a result of which it has been concluded that in the complete plant, boiler and economiser, the heat absorption efficiency would vary with rating in almost exactly the same manner as that established for the boiler itself. Experimental work by the R/16 Committee on an Economic boiler yields substantially the same result, while tests carried out on locomotive boilers in U.S.A. showed that with this type of boiler, a similar general relationship exists between heat absorption efficiency and rating.

The above remarks relate to the efficiency of the heating surface itself under more or less ideal conditions, and not to the complete plant under operating conditions, a point which was made quite clear in the paper. The efficiency of the plant *as a whole* depends to a large extent on the efficiency of the firing appliance, but even so, over a wide range of ratings, the efficiency increases with decrease in rating. The evidence, following a considerable amount of investigation, would seem to show the wisdom of endeavouring to have the operational load average approximately 70 per cent. of the standard rating. In point of fact, a large number of industrial boiler plants in this country where the load is fluctuating generate up to 70–80 per cent. of their total output of steam at about this rating.

As to the economic aspect of rating in relation to efficiency, each case must obviously be considered on its merits, having regard to the present very high cost of coal. A steam demand of 24,000 lb./hr. could, for example, be met by two 12,000-lb./hr. units working at full normal output, or three such units de-rated to 8,000 lb./hr. With three boilers as opposed to two, the evidence shows that the saving in fuel cost would be of the order of £1,000 per annum with single shift working, and £2,000 per annum with double shift operation. This would much more than justify the installation of the extra boiler and would, at the same time, provide for stand-by capacity, as in emergency two boilers could carry the load.

Mr. Webber produces no evidence to support his contention that the findings of the R/16 Committee are wrong, basing his case on two commercial tests at a single high rating, without giving any details. In making a comparison with the efficiency figures given in the paper, he omits to take into account the fact that the latter refer to the heating surface alone under ideal conditions, while the former refer to the complete plant. Mr. Edwards compares the performance of a group of obsolete boilers with a group of modern boilers in relation to rating, which is manifestly unsound.

The facts are that the results given in the paper are based upon a series of tests conducted with meticulous care in co-operation with the

owners of the plant and the manufacturers. They have been thoroughly scrutinised by an independent body of competent steam engineers and the deductions approved. Apart from this, the results have been confirmed by similar investigations in this country and in the U.S.A.

Both Mr. Edwards and Mr. Webber refer to the fact that the exit gas temperatures in the R/16 tests are considerably higher than they would anticipate. This question of flue gas temperature has been studied by the R/16 Committee and it has been proved beyond question that errors of very high magnitude can be made in attempting to make this measurement. The ordinary commercial pyrometer is subject to large inherent error. It is impossible within the scope of this reply to deal with the matter in detail but it will be discussed exhaustively in a report which the R/16 Committee is about to publish. Quite possibly, the statements of Mr. Edwards and Mr. Webber are based upon wrong measurement of flue gas temperature.



## SECTION A. THE GENERATION OF STEAM—*continued*

### SESSION IIIa. Shunting Locomotives

*Chairman of Session* : SIR WILLIAM STANIER, F.R.S.

• SCIENTIFIC ADVISER TO THE MINISTRY OF SUPPLY

#### 1. Trends in the Development of Design of the Direct Fired Steam Locomotive.

By R. E. KETLEY, A.M.I.LO.C.E.

The continuation in service today of many industrial steam locomotives over 40 years old would suggest wrongly that there has been little advance in design. Is not this long life due in large measure to their simplicity, and the fact that they have been carefully maintained? Complications in design that are intended to increase the efficiency of industrial steam locomotives are particularly liable to failure. They are seldom maintained in good order, and unless specialised labour is devoted to their maintenance, they become a drag on the efficiency of the locomotive. This has been particularly apparent in wartime, yet it is a principle proved time and again on the railways of the world. Care of maintenance, always desirable, is not always given.

Requirements of the efficient modern industrial locomotive may be listed as follows:—

Efficient production of steam.

The minimum loss of steam and pressure between boiler and cylinders.

Efficient employment of the steam in the cylinders.

Efficient transmission of power from the cylinder to the wheels.

The 0-6-0 steam shunting locomotives built in numbers for the War Department may be taken as a good example of how simplicity and these requirements may be achieved by modern design. Many of these locomotives have earned an excellent reputation for fuel and water economy combined with high power output and efficiency in traffic.

The basis of any locomotive is the main frame. This frame is massive (Fig. 35) and is thoroughly braced by the mass of the inside cylinders, which can be very securely bolted in place without weakening the frame plates. These cylinders have never been known to loosen. This cannot be said for earlier designs with outside cylinders (Fig. 36) which involve a large cut-out in the frame for the steam chest to pass through, while the presence of the valves between the frames precludes the use of a complete frame centre casting, as access to the valves must be considered. Besides the weaker construction, the boiler cannot be secured directly to the cylinders as in the former example.

#### EFFICIENT PRODUCTION OF STEAM

This is a difficult matter within the limits of a locomotive, and nowhere in the world has any design been found to be more successful than the modern examples of the accepted locomotive type of boiler, the highly developed successor to Stephenson's boiler for the Rocket. Today, a very careful balance is maintained between damper area, grate area, the air space through the grate, the firebox proportions, the controllable extra air that may enter through

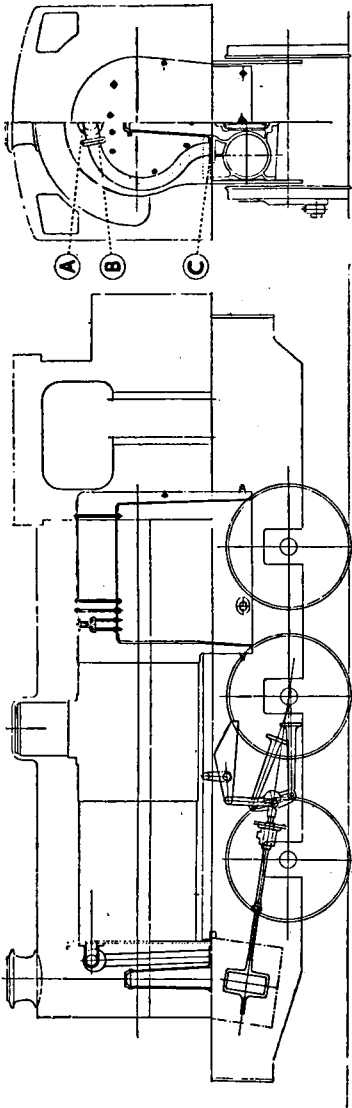


FIG. 35

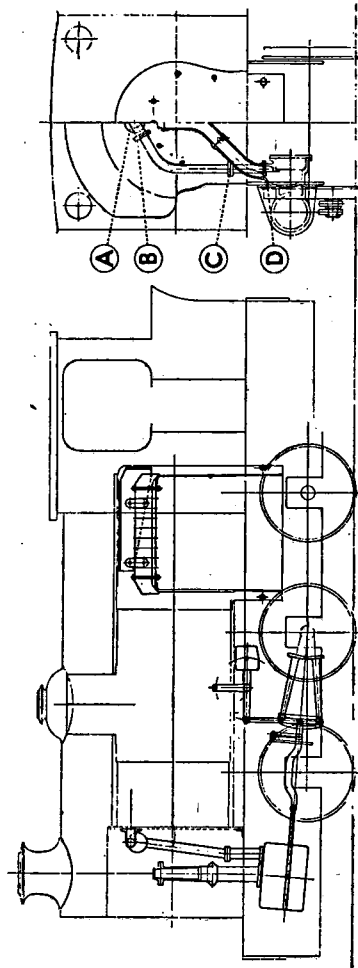


FIG. 36

the firedoor, the area through the tubes, their length, and the proportions of smokebox and chimney. On the water side must be considered the careful proportioning particularly of the firebox water spaces. However, first class design of these factors may rapidly be nullified by scale accumulations which may quickly cause serious failures. In the design in question (Fig. 35) large wash out plugs and doors are carefully placed to enable easy cleaning of the water spaces, this being further facilitated in the case of the firebox crown by the direct method of staying rather than by roof bars as shown in Fig. 36.

**THE MINIMUM LOSS OF STEAM AND PRESSURE BETWEEN BOILER AND CYLINDERS**

This requires firstly that the steam should have as direct and unobstructed a passage as possible; secondly that there should be the minimum liability to

leakage in service. In the modern design there is a single large steam pipe with a well radiused elbow near the boiler outlet followed by a sweeping curve, to connect directly on to the steam chest of reasonable capacity serving both valves. We have already noted the rigidity of the frame and cylinder construction, and how the front end of the boiler is secured ; this, combined with the fact that there are only three steam pipe joints, A, B and C, assures the minimum liability to leaks. In the earlier outside cylinder design (Fig. 36) the steam has to pass down two smaller pipes, through more complex bends, to two independent steam chests. It will be appreciated that the flow in this last described system is more restricted besides being an intermittent, rather than a continuous flow. It will be seen that there are no less than seven joints, A, BB, CC and DD, the liability of which to leakage is greatly increased by the less rigid frame construction and the possibility of cylinder and boiler movement.

It is not out of place to point out here the exhaust layouts in these two cases. That shown in Fig. 35 has the blast pipe mounted directly on the cylinders, and there are but two joints subject to no movement and only exhaust steam pressure. Leakage at these joints is almost unheard of. The arrangement in Fig. 36 however, entails five joints and four of these are prone to leakage in the event of any movement taking place in the front end assembly.

Efficient steaming is quickly affected by leakages at the front end. This is well known to all persons who have been connected with steam locomotive operation. A locomotive loses efficiency if there is any leakage of steam pipes or exhaust pipes inside the smokebox, or any entry of air there through unwanted channels. A comparison of the two designs will quickly indicate which will be the most efficient as least liable to leakage in hard service.

#### EFFICIENT EMPLOYMENT OF THE STEAM IN THE CYLINDERS

Both designs lend themselves to similar valve events giving similar efficiency of steam utilisation in the cylinders when in new condition. However, the outside cylinder design with greater exposed surfaces on the cylinders, steam chests and steam pipes, has greater heat radiation losses.

The inside cylinder design profits by rigidity enabling the designed valve events to be maintained, this being aided by the directness of the valve gear in which wear may cause less lost motion with consequent inaccuracies. The earlier outside cylinder designs may have valve events interfered with by lack of rigidity with more potential lost motion, so causing inaccuracy in steam distribution by the slide valves.

#### THE EFFICIENT TRANSMISSION OF POWER FROM CYLINDERS TO WHEELS

There is little to say under this heading. The steam locomotive, though little changed in this particular in the last hundred years, has vindicated time and again the use of a direct drive to the wheels, without the interposition of gearing or chain drives. Different designs of locomotives having such indirect drives have been used from time to time in the past, though few have stood the test of years.

The ability to maintain efficiency is a true criterion of industrial locomotive design. Individual engineers may be prepared to take special care of individual accessories in which they are personally interested, but these can add little to the all round efficiency of the locomotives in service if the efficiency of steam generation and steam utilisation cannot be readily maintained at optimum figures. How far the modern locomotives used to illustrate these remarks have succeeded in doing this can best be judged from the experiences of those who

have operated them. It should be mentioned that where outside cylinders must be employed, as is usually the case with four-coupled types, modern designs have followed railway practice in placing the valves above the cylinders, permitting a strong front end construction. This eliminates many of the disadvantages of earlier designs, and gains accessibility, though at the expense of vulnerability to dirt and to mishap, points where the inside cylinder design scores heavily. Superheating has little to recommend it for industrial locomotives on short runs, adding cost and complication for a slight thermal gain soon lost once maintenance is required, through wear and tear.

## 2. Notes on Diesel Electric Shunting Locomotives

By F. A. HARPER, M.A., M.I.C.E., M.I.E.E.

Apart from any over-riding national considerations it can presumably be taken that the objective is to do the shunting with the necessary expedition at the lowest possible total annual cost. That is, the type of locomotive to be used in any particular case is decided largely by economic factors which include capital charges, renewal provision, operating costs and maintenance costs, related to the hours of traffic requirements at the place concerned. There will always be certain other factors which it will be difficult to assess in monetary terms and some element of judgment will always be necessary. Each case must be treated on its merits and the type of locomotive found most suitable in one case will not necessarily provide the best solution in others.

In the experience of the L.M.S. Railway, the Diesel-electric shunter has proved to be technically and economically sound for certain duties and as this company is the largest single user of such locomotives in the country, it may be worth while to examine this case.

There are at present 40 units in use, mostly with engines of 350 H.P. and weighing some 50 tons. But for the war, this number would have been substantially greater as 42 have been transferred to the allied armies for use overseas. Several different types have been built but they all meet the same general specification and very complete accounts of their development, use and maintenance have been published.<sup>1, 2, 3</sup> Briefly, they are able to handle complete trains up to 1,000 tons in weight and to break up or marshal trains of this size, either by flat or hump shunting. These duties require a high, steady and readily controlled tractive effort but speeds rarely exceed a few miles per hour. In flat shunting rapid acceleration to 4 or 5 miles per hour is desirable to keep the number of reversals as low as possible, while in hump shunting accurate control of speed between  $\frac{1}{2}$  and  $1\frac{1}{2}$  miles per hour is necessary.

These different requirements and the rapid reversals and changing conditions in a busy shunting yard require a simple yet flexible system of control and the automatic protection of the Diesel engine against abuse. This can readily be provided with electric transmission but it must be mentioned that it is not the intention in these notes to present a brief for any one form of drive. The electric drive is certainly believed to be the best for the particular conditions to be met on the L.M.S. system but other forms may well be justified in other cases, when all factors are taken into account.

The crux of design is a good engine, conservatively rated and running well within its power. Any increased cost in the first place will be amply repaid in

reliability, low cost of maintenance and long life. The L.M.S. engines have a top speed of 680 r.p.m., but much of their running is done at lower speeds. The transmission comprises a single generator supplying power to either one motor with double reduction gearing and jackshaft drive or, in the latest type, to two axle-hung motors, also with double reduction gearing. This transmission equipment is a simple application of well established electric traction practice so designed that, within certain limits of speed, the full power available from the engine may be utilised to produce either a high tractive effort at low speed or a lower tractive effort at a correspondingly increased speed. In effect, the equipment constitutes a foolproof automatic drive with a gear ratio continuously variable over the limits required. The importance of the electrical losses involved can easily be exaggerated as they are largely offset by the gains resulting from the fact that the engine always runs at an economical speed in relation to the power that it is delivering.

All components must be of simple and robust design. Equipment which meets the requirements of road transport is generally unsuitable on a locomotive, partly because in railway service a longer life is expected and partly because the duty is more severe. Operations normal in a shunting yard would be considered a series of minor accidents on the road.

Regarding maintenance work as distinct from overhauls, the only logical target is its elimination. This can never be achieved but it can continually be approached. The first step is good design and the second is the careful control of such attention as is unavoidable. The more the work is intelligently planned and carefully carried out, the less need there will be for maintenance and a failure in service must be treated as a major catastrophe requiring thorough investigation and energetic steps to avoid its recurrence. A good example of what may be termed preventive maintenance is the periodical checking of crankshaft alignment to detect any incipient trouble with the main bearings. The necessary maintenance examinations can generally be carried out at times when the locomotive is not required for traffic and so they do not reduce its actual availability for service. In present L.M.S. practice some small mechanical examinations are made at weekly or fortnightly intervals, but most of the work is done at monthly, three-monthly or six-monthly intervals. They are scheduled to occupy 316 hours per annum. In practice, including the time needed to rectify all faults discovered and minor breakdowns experienced in traffic, the time actually spent, as shown by careful records, averages 510 hours per annum, corresponding to an actual availability of 94 per cent. This figure does not, of course, imply that the locomotive duties can be arranged to take complete advantage of this availability.

Little can be said about major overhauls—it has already been mentioned that this point has been fully dealt with elsewhere. When the number of locomotives required is not sufficient to justify a spare unit the matter may present some difficulty, especially since in such cases, workshop staff and plant are likely to be limited. With a large intensively organised shop, it is possible to reduce the time needed for an overhaul to 14 days or less and the matter presents no great difficulty to the larger user. The L.M.S. locomotives are at present overhauled only after every three or four years of practically continuous duty, corresponding to about 30,000 hours in service. When certain alterations in shed maintenance procedure which are now being introduced have had time to take effect, it is expected that this period will be considerably extended.

Most of the engine parts subject to wear are small and can easily be reconditioned or replaced. The crankshaft presents a more awkward problem as it is almost the only component which cannot be attended to without the complete dismantling of the engine. Usually the transmission does not require much attention, even at major overhauls of the locomotive, but advantage is taken of the opportunity to dismantle it for a thorough inspection and, if necessary, for the re-turning of the commutators.

Turning now to the economics of Diesel-electric shunting, some figures have recently been published by D. B. Hoseason<sup>4</sup> which, in general, appear to line up with L.M.S. experience. A predominant factor is the high capital cost of the Diesel locomotive. In 1939, a 50-ton steam shunter cost about £3,500 and a Diesel of the same weight about £10,000, but at present, in U.S.A. a Diesel locomotive costs only 2 to 2½ times as much as a comparable steam unit, and there is a tendency for this ratio to decrease. There seems to be no reason why a similar reduction should not be effected here if the Diesel manufacturers are able to undertake the building of standard types in reasonable quantities. Account must also be taken of the greater availability of the Diesel and in some cases its greater speed of working, which may normally be expected to effect a reduction in the number of units required as compared with steam. As a rough guide, seven Diesel-electric units can replace ten steam units. For the ascertainment of costs, the Diesel-electric shunting unit is taken by the L.M.S. to have an economic life of about 30 years and that of a steam unit some 50 years.

In all running charges Diesels show savings and their successful economic exploitation is therefore the easier the greater the number of hours of useful service they perform per annum.

As regards labour costs, only one man is needed on a Diesel locomotive working in a shunting yard. The basic efficiencies of the two types affords little guidance regarding fuel costs owing to the constantly varying and frequently interrupted power demands of shunting work. The average power output over a shift may be no more than 50 h.p. although maximum tractive effort has been required frequently during the period. Under such conditions the steam locomotive is clearly at a disadvantage. In a recent check the consumption of a Diesel unit and a steam unit engaged in the same work was compared over some hundreds of hours. The steam locomotive burnt coal at the rate of 112 tons per 1,000 hours and the diesel locomotive used oil at the rate of 2,060 gallons per 1,000 hours, corresponding to relative fuel consumptions of 14 to 1 in terms of weight and 8 to 1 in terms of B.Th.U. In terms of cost, the ratio may be between 2 to 1 and 3 to 1. The small bulk of the Diesel's fuel may be commented upon; there is no difficulty in building shunting locomotives which carry sufficient fuel for two or more weeks continuous service, thus avoiding the not inconsiderable unproductive time which the steam locomotive spends in coaling as well as the carriage and handling of the coal.

Repair costs of Diesels are not yet stabilised, largely owing to the small numbers in use. If the steady production of standard types can be achieved it may confidently be expected that spares will be both cheaper and more quickly forthcoming. Hoseason gives the maintenance cost of the Diesel as little more than one-third of the steam unit. Such figures might be obtained in a comparison on equal terms but when the comparison is between a small

number of diesels and a large number of steam locomotives maintained by the same organisation it is by no means so favourable.

In a brief summary of the present position of the Diesel-electric shunting locomotive, it may be said :—

(1) As a working instrument it is a well proved proposition and it can be adopted with confidence.

(2) If its running maintenance is soundly established, it takes little time and presents no difficulty to reasonably intelligent men with a little special training. The policy should be to leave well alone so far as experience and observation show this can safely be done. Nothing can be gained by the unnecessary dismantling of equipment.

(3) With proper design and facilities, overhauls present no great difficulty and are needed only at long intervals. Six to eight-year periods are a practicable aim with a good unit, the first essential of which is a good engine working well within its capacity.

(4) Its availability for service is high and, as compared with steam locomotives, it may make possible a reduction in the number of units needed.

(5) Its engine operates at a high thermal efficiency over a wide range of load and it can readily be shut down during idle periods, whereas the thermal efficiency of the coal-fired steam locomotive, when used for shunting, is necessarily very low.

(6) It is, therefore, a sound economic proposition for intensive shunting. The L.M.S. locomotives are used in yards which are in continuous operation for three shifts per day, but investigation shows that they could still present a good case if they were in operation for only two shifts per day. For single shifts, the working costs, plus the higher interest and renewal or depreciation costs at present, make the Diesel-electric less economical than steam units. In the case of industrial yards employing light, general utility units, the Diesel may still show to advantage when the work calls for only a few hours of duty per day, if the alternative is to keep a steam unit continuously under steam.

(7) It is clear then that on steam-operated railways the Diesel shunter as an adjunct has come to stay. Its position as a complement to main line electrification would be no less important, as its use would obviously be advantageous in certain places in order to avoid the cost of overhead electric equipment on lines where movements are few.

Finally, I should like to mention the question of the efficiency of electrical transmission. With a constant-running prime mover, the efficiency of any system of transmission is necessarily zero at starting. At 1 mile per hour, that of the 350 h.p. electric unit lies between 40 per cent. and 50 per cent., depending upon the tractive effort required ; at 2 miles per hour, it lies between 53 per cent. and 63 per cent. ; at all speeds over 4 miles per hour, it exceeds 60 per cent. and lies between 70 per cent. and 80 per cent. over most of the usual working range. These figures are admittedly lower than those claimed for mechanical, if not for hydraulic systems, but it must be pointed out that the lowest figures are largely associated with low power output, and so cannot greatly effect the daily fuel consumption. Further, the electrical system must be credited with certain appreciable gains in engine efficiency. Owing to the flexibility of the system, the engine speed under any conditions of loading need be no greater than that required to produce the

power demanded. Thus its mechanical losses are kept to a minimum, and combustion conditions are always satisfactory. In practice, there can be little difference between the fuel consumptions of locomotives with mechanical and electrical transmissions.

#### *References*

<sup>1</sup> Diesel Shunting Locomotives. C. E. Fairburn. *Journal of the Institution of Locomotive Engineers*, Vol. XXXI, No. 161, May-June, 1941.

<sup>2</sup> The Maintenance of Diesel Electric Shunting Locomotives on the L.M.S. Railway. *Ibid.*, Vol. XXXIV, No. 179, May-June, 1944.

<sup>3</sup> L.M.S.R. Diesel Electric Shunting Locomotives. *Railway Gazette*, 27th Nov., 4th and 11th Dec., 1942. Reprinted.

<sup>4</sup> Chairman's Address. East Midlands Sub. Centre. D. B. Hoseason. *Journal of the Institute of Electrical Engineers*. Vol. 93, Part I, No. 65, May, 1946.

### 3. Straight Diesel Shunting Locomotives

By JOHN ALCOCK, M.A., M.I.MECH.E., M.I.LOCO.E.

"Straight Diesel Locomotives" refers to the locomotive equipped with a Diesel engine as its power unit, with mechanical transmission, consisting of either a friction clutch or hydraulic coupling followed by a gearbox giving generally 2, 3 or 4 speeds, which can be operated in either forward or reverse gear. Such locomotives in various sizes are operating today in thousands, and they are the most efficient and economical type available to the industrialist at the present time.

Some 20 years ago small Diesel locomotives began to come on to the market at prices comparable with steam locomotives and today the smaller sizes of Diesel locomotives are considerably cheaper than the steam locomotive. Add to this the fact that the Diesel engine has an overall efficiency higher than any other power unit, that a straight mechanical transmission has a higher overall efficiency than any other form of transmission, and that the unit can operate 24 hours a day, if need be, or alternatively only half-an-hour a day with less waste or labour than in any other unit, it is not surprising to find a very considerable number of manufacturers selling between them hundreds of these locomotives every year.

The smaller Diesel units are generally made as standard types with horse-powers of 40, 60, 80, 100 and up to 150, the weights of the locomotives varying accordingly from about 10 tons up to 25 tons. This range covers the average factory sidings, the smaller units handling 250 to 350-ton trains on level track, while the larger units can handle up to 600 to 700-ton trains under similar conditions. Above these sizes the steam locomotive is still cheaper in first cost and consequently the bulk of locomotives built today weighing over 25 tons in weight are still steam driven.

Those engineers, however, whose directors allow them to look beyond first cost find the larger straight Diesel locomotive the solution to their shunting problems. These larger Diesel locomotives are still, unfortunately, built only in small numbers and it is very largely for this reason that they are expensive. I firmly believe that in the years ahead larger quantities will be built at less cost, and that before long the straight Diesel locomotive will supersede all other types for shunting and marshalling work. Today a heavy steelworks' steam locomotive weighing about 50 tons would cost approximately £7,000, a straight Diesel locomotive of the same weight about £12,000, and a similar Diesel-electric locomotive somewhere about £18,000.



Straight Diesel locomotives have now been in service from 15 to 20 years and their cost of maintenance compares most favourably with steam locomotives. Even a major overhaul would not cost nearly as much as a boiler repair and, where day-to-day maintenance is well carried out, reliability is excellent. By far and away the most important item on a Diesel locomotive are its filters—air filters, lubricating oil filters and fuel filters—and these must have regular first-class attention. Nearly all the troubles experienced with Diesel locomotives are due to neglect of this rule.

In performance, the geared Diesel locomotive is ideal for producing real power at low speeds. For starting heavy loads from rest, particularly on curves or gradients, high tractive power is essential and as the speed is low the actual work done in foot-pounds per minute is extremely small. The geared Diesel is the only type of locomotive which can produce such high torques easily and well within its capacity. The steam locomotive makes very "heavy weather" of a difficult start and it is not until it attains something like 5 miles per hour that a steady maximum tractive effort is produced. The Diesel electric locomotive gets the results satisfactorily, but only by generating a great deal more power than is necessary and dissipating the excess power in heating up the traction motors. Furthermore, the Diesel locomotive is so much less liable to wheel slip than the steam locomotive that a 40-ton Diesel can handle trains which a 50-ton steam locomotive would find difficult.

In spite of post-war difficulties straight Diesel locomotives are being built today developing 500 b.h.p., weighing up to 50 tons and capable of developing over 35,000 lb. tractive effort. They will be able to equal the largest 8-wheel-coupled steam locomotives in performance on shunting and marshalling work at about half the annual running cost, and in spite of all this they can be built on a 9-ft. wheelbase, which means that for the industrial user, whose sharp curves demand the shortest possible wheelbase, they will be by far the most powerful locomotive of any type available.

## 4. Fireless or Steam Storage Locomotives

By C. D. HANNA, M.I.LOCO.E.

The fireless or steam storage locomotive is, as its name implies, a heat storage machine and derives its power from the heat stored in the water in the receiver which gradually evaporates part of the water as the steam pressure falls. The receiver is first charged with water to approximately 50 per cent. to 60 per cent. of its capacity and is then charged with steam, bringing the whole of the contents, steam and water, up to pressure.

As steam is drawn off to do work in the cylinders, the pressure falls and more steam is formed in the receiver with characteristics corresponding to the lower pressure. In dropping from a pressure of 300 lb. per sq. in. to 160 lb. per sq. in. the amount of steam formed per 1,000 lb. water follows almost a straight-line law, but the amount formed below 160 lb. per sq. in. increases much more rapidly and thus provides more steam, and at a greater volume, for use in the cylinders. The greater the water capacity of the receiver the larger the amount of steam formed.

The driving mechanism of the fireless locomotive follows the usual steam locomotive practice, but the receiver supplied by steam from an outside source is substituted for the steam-generating boiler. The receiver itself is a cylindrical vessel with dished ends, built up in accordance with usual boiler practice or, where deemed necessary, fusion welded. A steam dome is fitted in which the steam regulator is situated and this dome also serves as a manhole for inspection purposes. There are no smoke tubes, firebox, stays, foundation ring or firehole ring and these possibilities of trouble are thus absent.

The receiver is charged through a shut down check valve fitted to a seating from which pipes are led to a position at or near platform level on both sides of the locomotive where, by means of special quick-coupling flanges having spherical metal-to-metal joints, connection is made to the outside charging column pipes. The locomotive can thus be charged from either side.

When the locomotive is designed to use receiver pressure, the fittings consist of a steam regulator, pressure gauge, water gauge, safety valve, blow-off cock, and hand-operated bell or, if desired, a steam whistle. When, however, the receiver pressure is higher than that for which the locomotive is designed, a reducing valve with a safety valve on the low-pressure side is fitted.

Owing to the expansion and contraction of the reservoir, the pipes leading to the cylinders should have some flexibility and modern practice has led to the use of steel pipes and flexsteel joints.

Exhaust steam is carried up the back of the cab in most cases and the condensed steam runs off from a top chamber on to the track.

As the amount of heat available is limited it should be conserved as much as possible, and the receiver is therefore lagged with a mattress and covered with the usual clothing plates. The steam pipes and cylinders are also lagged.

A mechanical brake in the form of a toggle or hand screw is the natural fitment for fireless locomotives as these make no demand on the power supply, but both steam and vacuum brakes have successfully been fitted. The power for the steam brake is based on a pressure of 50–60 lb. per sq. in., obtained by means of a reducing valve, while the ejector is designed to work at a low pressure of 35–60 lb. per sq. in., also obtained through a reducing valve.

Electric light equipment consisting of battery, head, tail and cab lamps with necessary switches and fusebox has also been supplied. The equipment can be made flameproof if necessary.

Without knowing the conditions as to load, grade, curve, and the duty generally, it is only possible to lay down general principles which govern the successful working of fireless locomotives.

If the run is long, the load hauled is determined by the pressure available at the end of the run, and this must be sufficient to return the locomotive to the charging point.

There is a progressive diminution of the pressure from beginning to end of run and, to take the extreme case with the throttle full open and motion in full gear, i.e. maximum cut off, the run, in *time*, would be the same with the engine running light or with load. The excess power running light would be absorbed in accelerating to a higher speed than with load and consequently the run, in *space*, would be longer. That is wasteful.

The economic use of steam is the aim and this is done by matching the load and power at a uniform speed. This is achieved by "linking-up" the

valve gear and so reducing the cut-off, or throttling the steam at the regulator and thus reducing the pressure. The former reduces the amount of steam allowed into the cylinder and the latter takes advantage of the lower density of steam at lower pressures. A combination of both methods may be necessary.

Where the run is short, large loads can be hauled and where loads are light, much longer runs can be made.

The largest fireless locomotives built in this country are, in the author's belief, two 0-8-0 type locomotives built in 1942 and 1945 for South Africa by Messrs. Andrew Barclay, Sons & Co., Ltd. They have the following particulars: Cylinders 24 in.  $\times$  20 in., wheel diameter 38 in., working pressure 140 lb. per sq. in., with a receiver pressure of 260 lb. per sq. in. and a capacity of 630 cubic ft. The weight empty is 51 tons and in working order 64 tons, the water content being therefore 13 tons. The tractive force at 140 lb. per sq. in. pressure is 36,000 lb.

These were designed to haul:—

(a) 335 tons up a gradient of 1 in 33 from a standstill at the bottom of the grade.

(b) 535 tons at a speed of 8 m.p.h. over a level straight track for a distance of  $2\frac{1}{2}$  miles when the receiver was charged at commencement of journey to 80 per cent. of its maximum pressure.

This indicates that the performance of a fireless locomotive is not limited to very light loads. At the other end of the scale a fireless locomotive has been built with cylinders  $5\frac{3}{8}$  in.  $\times$  8 in. and 16 in. diameter wheels working at a pressure of 160 lb. and weighing 4 tons in working order. In Vienna an experimental fireless locomotive built some years ago with a storage pressure of 1,700 lb./sq. in. and a working pressure of 215 lb./sq. in. has been followed by a large number with similar characteristics as regards storage and working pressure. Thus the scope for the use of fireless locomotives is very wide indeed.

When haulage is required and steam is available at a pressure of 150 lb. per sq. in. or upwards, good use can be made of it in a fireless locomotive.

The life of a fireless locomotive is long and it is a remarkable fact that out of all the locomotives supplied by my firm not one receiver has had to be replaced; repairs have been of a minor character. From 1913 to date, 102 fireless locomotives have been or are being built by this firm.

The availability of the fireless locomotive is high as the recharging can generally be done at a convenient time to suit its working schedule. The time taken in recharging varies from 15 to 30 minutes, varying with the size of the receiver and the pressure. Stand-by losses are small, amounting to  $1\frac{1}{2} \times 3$  lb. per sq. in. per hour. No provision is necessary for the storing and handling of fuel on the loco. There are no fires to be lighted, nor does the boiler require to be washed out. The danger of fires is eliminated and the absence of smoke allows the locomotive to operate inside buildings or around plants where cleanliness is essential.

Maintenance costs on the wearing parts will vary with the amount and nature of the work performed but on the whole are very light as the locomotive works for a great proportion of its time at a much lower pressure than that for which the parts have been designed. The amount of spares carried can therefore be small.

The cost per lb. of charge, taking coal at 45s. per ton, is approximately 0.036 pence, which for a charge of 1,000 lb. works out at 3s.

## 5. Experience in the Operation of Shunting Locomotives

By A. C. THIRTLE, A.M.I.C.E., A.M.I.E.E.

Fireless locomotives have been used for the shunting of coal wagons at the Carlisle Willow Holme Electricity Generating Station since 1926. The first machine, purchased from a Government Ordnance factory where it had previously been in service, went into regular use at the Power Station in 1926 and fulfilled all the duties required in the handling of coal trucks until 1943. At this date a major extension of the power station justified the purchase of a second locomotive which went into service in September, 1943. A third locomotive was put into commission in June, 1945, when a second extension of the power station further increased the quantity of coal required to be handled.

The satisfactory results of the operation of the first locomotive were so convincing that the engineers had no doubt in selecting this method for the shunting of the further tonnage of coal trucks which were required by the extensions to the power station. The following is a brief description of the type of locomotive used, the methods of charging, and the duties performed :—

### *Description of Locomotives.*

Type .. .. .	6-wheeled fireless outside-cylinder locomotive.
Diameter of cylinders .. .. .	17 in.
Length of stroke .. .. .	18 in.
Diameter of wheels .. .. .	3 ft. 5 in.
Wheel base .. .. .	10 ft. 9 in.
Gauge of railway .. .. .	4 ft. 8½ in.
Steam pressure in reservoir .. .. .	160 lb. per sq. in.
Weight of locomotive empty .. .. .	24 tons
Weight of locomotive in working order .. .. .	31 tons

} 7 tons water  
and steam

*Method of Charging.*—The locomotive reservoirs are charged with steam to a pressure of 160 lb. per sq. in. A steam pipe operating at 600 lb. per sq. in. runs from the power station boilerhouse to the locomotive charging house. In this charging house is situated a steam receiver operating at 250 lb. per sq. in., and a steam header operating at 160 lb. per sq. in. The 600 lb. pressure steam main can be used to charge, through a reducing valve, either the 250 lb. pressure steam receiver or the 160 lb. steam header. The steam header is then used with suitable valve control and flexible pipe to charge the locomotive reservoir. The time required for withdrawing the locomotive from duty, charging it and returning it to duty is 15 minutes.

*Duties.*—Locomotives are used for shunting full and empty wagons between the railway receiving lines and the coal wagon tippers. The usual haul is three full wagons and the haulage of full and empty wagons can be comfortably handled down to a reservoir steam pressure of 50 lb. per sq. in. Over the operating range of 160 lb. per sq. in. to 50 lb. per sq. in., 30 wagons, containing 450 tons of coal can be moved through the

discharge cycle. The following is a table of the average duties performed per locomotive charge :—

Steam pressure start	..	..	..	..	160 lb. per sq. in.
Steam pressure finish	..	..	..	..	50 lb. per sq. in.
No. of wagons handled	..	..	..	..	30
Average tare weight	..	..	..	..	8 tons
Average coal weight	..	..	..	..	15 tons
Average loaded weight	..	..	..	..	23 tons
Average haul (full)	..	..	..	..	450 yd.
Average haul (empty)	..	..	..	..	320 yd.
No. of starts per 30 wagons handled	..	..	..	..	100
Ton-miles per charge :—					
(a) Full wagons	..	..	..	..	176
(b) Empty wagons	..	..	..	..	44
					220

#### COST OF STEAM PER RUNNING PERIOD

Calculations have been made of the heat input required to charge the locomotive reservoir from a cold condition to its working pressure of 160 lb. per sq. in. and also the heat required for the service charging between pressures of 50 lb. per sq. in. and 160 lb. per sq. in. The calculations have been checked by weighed tests and may be considered as reliable.

*From Cold Conditions 65° F.*

Heat required to charge to working pressure  
of 160 lb. per sq. in. .. .. . 4,200,000 B.Th.U.

Allowing for a 10 per cent. heat loss in the charging line and 80 per cent. boilerhouse efficiency, this represents 526 lb. coal of C.V. 11,000 B.Th.U. per lb. With coal costing 45s. a ton, the cost is thus 10·58s. a charge. It is to be noted that this cost is in respect of charging from cold and experience shows this to be only necessary about once a month.

*Daily Service Charging from 50 lb. per sq. in.*—The heat input required to restore the reservoir to a working pressure of 160 lb. per sq. in. is 1,250,000 B.Th.U. With the foregoing assumptions this represents an expenditure of 156 lb. coal of C.V. 11,000 B.Th.U. per lb., which, with coal costing 45s. a ton, amounts to 3·14s.

As the energy of this charge is expended in the handling of 30 coal wagons of an average coal content of 15 tons a wagon, the cost can be expressed as 1·25 pence a wagon handled.

#### MAINTENANCE

The No. 1 locomotive, which has been in continuous use for 20 years, has had a remarkably good record for low maintenance costs. Apart from the necessary work involved by the annual insurance inspections, no costs were incurred until this year (1946) when a complete overhaul was undertaken involving a cost in materials of £195. On the Nos. 2 and 3 locomotives, which have been in use for 3 years and 1 year respectively, no maintenance costs have been incurred.

#### PERFORMANCE

From the record of experience in the use of fireless locomotives at an electricity generating station over a period of 20 years their performance can be regarded as entirely satisfactory and they have proved to be extremely economical in operating and maintenance costs.

## 6. Shunting Locomotives for Iron and Steel Works

By E. L. DIAMOND, M.S.C.(ENG.), A.M.I.C.E., A.M.I.MECH.E., M.I.LOCO.E.

The steam locomotive is used practically universally in iron and steel works in this country. Only for certain special duties of a short repetitive nature, such as the movement of charging and quenching cars on coke-oven plant, are electric locomotives normally used. There are, however, the beginnings of a tendency to consider an increasing number of regular haulage duties on an *ad hoc* basis, and to substitute electric haulage of one kind or another including conveyors, or alternative types of locomotive. Apart from the possibility that this procedure might ultimately lead to an undesirable multiplicity of types of machine, a piecemeal approach to the problem suffers the very serious disadvantage that, especially at the present time, no locomotive manufacturer is prepared to develop new types of locomotive for special haulage duties unless there is a good prospect of the new type being standardised for construction in large numbers.

The general question of the most suitable types of locomotive for iron and steel works is therefore under close study at the present time, and from the preliminary work already done some broad indications as to the possibility of fuel saving and reduction of overall cost in steelworks transport can be offered.

### NATURE OF HAULAGE IN A STEELWORKS

The general conditions under which locomotives work in the average steelworks are probably far more severe than in any other field of use, and are certainly more so than in railway shunting yards. The older the works, the more severe are the conditions, and there is no doubt that the greatest scope for saving lies in improved layout of the railways, and careful planning as a whole of all material handling movements, especially with regard to the use of conveyors and elevators where appreciable differences in level are necessary. The factors which make existing steelworks locomotive duties so difficult are :—

(1) Curves as sharp as 90 ft. average radius, with sharper bends in places, limit the rigid wheelbase to about 10 ft. or less, and the overall length to about 24 ft. or less. Only small locomotives can therefore be used.

(2) Gradients of 1 in 30 or even steeper are commonly employed for the inclines by which blast furnace gantries, open-hearth furnace stages, etc., are approached. Similar gradients are consequently tolerated at other places, such as slag tips.

(3) The loads to be taken on most regular bulk material movements, as distinct from general shunting, are limited only by the locomotive's power to move them. It is common practice to surmount gantry inclines by rushing them at the maximum speed the locomotive can attain within the available length of track at the foot.

(4) Ingot cars and hot metal and slag ladle cars are heavy units. Even the comparatively small ingot cars normally used weigh from 25 to 50 tons gross. Steel is generally poured into the moulds and left to solidify whilst they stand on the cars, and the resulting transfer of heat to the plain bearings normally in use practically destroys lubrication. Similarly overflowing slag frequently seizes up the bearings of slag ladle cars before

they are started. Even the limited number of such vehicles which can be moved have frequently to be started by shock, which throws great stresses on the entire structure of the locomotive.

(5) It is common practice to feed scrap metal to open-hearth steel plants in small charging pans carried on charging cars. Large pieces of scrap frequently fall across the rails and are run over, sometimes getting into the entrails of the locomotive.

(6) The condition of the track is generally poor, especially in the neighbourhood of blast furnaces and steel plants, due to the large amount of dust and sand which accumulates underneath it, and the damage caused by ingots and other heavy masses of metal falling across the rails.

#### METHOD OF WORKING OF THE LOCOMOTIVES

It will be clear that the locomotives must be worked to the limit of their power. The limitation of size mainly affects the boiler and firebox, but as little continuous steaming is required the cylinders need not be correspondingly restricted. Typical locomotives even of the four-wheeled type, weighing say 36 tons, carry 16-in. cylinders and 160 lb. per sq. in. boiler pressure, and can exert a maximum tractive effort at starting of over 10 tons. All their heavy work is done at full regulator opening, and expansive working is seldom if ever employed. Heavy hauls of any length are thus made by drawing on the steam capacity of the boiler, and pauses are not infrequently necessary to recover steam pressure. But the tractive effort of the locomotives would otherwise be quite unequal to the duties they have to perform.

The intermittent nature of the duties also enables continuous firing to be dispensed with in most cases. Many of the locomotives employed even have no provision for carrying a supply of coal, and where it exists it is often made little use of, the firebox being filled at the commencement of a shift and recharged again only when taking coal and water at the stage. This practice is directly associated with the fact that no firemen are employed on steelworks shunting locomotives, the staff additional to the drivers, though classed as locomotive staff and actually designated "firemen" in some cases, actually working practically the whole of their time as shunters. In comparing the costs of steam and other types of locomotive it is usual to assume that the steam shunting locomotive requires two men, as in railway practice, as against one man for other types, and it is important therefore to point out that this hypothetical saving cannot be set off against the increased capital cost of other types for iron and steelworks use.

#### POSSIBILITIES OF REDUCING LOCOMOTIVE DUTIES

From the foregoing it will be evident that it is the regular process movements of raw materials, hot metal, slag, and ingots which cause the highest rates of fuel consumption and the greatest wear and tear in the locomotives. These, however, are in part duties which are most suitable to be performed by conveyor mechanisms of one kind or another. Iron ore, coke and fluxing materials, for instance, will be transported to the blast furnace storage bins and hoppers by conveyor from the ore stocking grounds, coke ovens, etc., in works now being planned, thus eliminating the blast furnace gantries with their heavy inclines.

Similarly bulk materials for steel plants could be sorted and loaded into pans for charging at a point on ground level close to the furnace stage, and lifted thence by conveyor or elevator to a suitable position for charging. This is a more debatable proposal, both because of the danger of falling scrap putting

a conveyor out of action, and because the limitations of present types of furnace chargers may necessitate some movement of the charging pans on the stage itself. It is a worth-while objective, however, because all such regular movements involving a considerable difference of level can be made more efficiently by such means, if the quantities are large enough.

As regards the movement of slag and ingots, a considerable mitigation of the locomotive duties is possible by careful attention to design of the rolling stock. Roller bearings in a position sufficiently isolated from direct heat transfer or the possibility of spillage have already been tried with success. A modernised method of pitside casting might eliminate ingot casting cars.

Some stress has been laid on this negative aspect of steelworks shunting locomotives because there appears to be a much greater scope for fuel saving in careful planning of material handling operations as a whole than in the mere substitution of one type of locomotive for another.

Where locomotives of some kind are essential, as in the case of slag disposal and hot metal transfer (as well as, of course, all shunting operations), attention to track layout and maintenance and rolling stock design offers possibilities of savings at least comparable with those associated with alternative types of locomotives. The question of rolling stock design, in fact, is practically a necessary preliminary to consideration of the Diesel locomotive as it is particularly desirable to avoid excessively severe shocks to the frame in the case of locomotives of this type if they are to give a return on their higher capital cost.

#### MERITS OF ALTERNATIVE TYPES OF LOCOMOTIVE

Granting that the present cost of works transport per ton of steel is mainly due to conditions resulting from the gradual growth of old works, and that radical re-planning is the only method of reducing these costs wholesale, there nevertheless remains a great deal of general shunting and haulage work that must be done by locomotives, and it is well worth while considering what advantages could be secured by alternative types.

The main disadvantages of the steam locomotive are its low availability and its high fuel consumption. It is generally found that out of the 8 hours of each shift a steam locomotive is actually working for only 6 hours,  $\frac{1}{2}$  hour being taken up by a mealtime,  $\frac{1}{2}$  hour by service duties (oiling, etc.), 40 minutes by coaling and watering, and 20 minutes by traffic hold-ups. Of the lost period, approximately half could be saved by a locomotive which required no fuelling and the minimum of servicing by the driver. Most steelworks locomotives work two or three shifts a day except at the week-end.

As regards fuel, steam locomotives burn on the average about 2 cwt. per hour. It would be difficult to estimate the amount of work done for this consumption on shunting duties, but the main source of inefficiency is the wasteful use of the steam generated. It is doubtful therefore whether a steam accumulator or fireless type of locomotive would show a great saving of fuel, as the increase of efficiency of steam generation would be small compared with the low efficiency of its utilisation.

The advantages of electric locomotives on both these counts are obvious. Electricity is available throughout steelworks, and it is not surprising that for regular short hauls for which conveyors or cable haulage may be judged uneconomical, electric locomotives are being increasingly adopted. The one great difficulty is current distribution, especially in the proximity of covered shops. There is scope for ingenuity here, for if steelworks railways could be completely electrified, not only would the fuel efficiency of the locomotives be



the highest attainable, but they could be integrated with the general power requirements of the works, for which ever-increasing use is being made of the great quantities of untapped waste heat. Indeed, if all the available waste heat in a steelworks could be economically converted into power it would appear the height of wastefulness to use any kind of raw fuel for traction.

Since this is at present an ideal only, the use of internal combustion locomotives of one form or another requires consideration. Such locomotives will have a much higher fuel efficiency than the steam locomotive, and should also enable the lost time for fuelling and servicing to be reduced. They are, however, expensive in first cost, and would secure an overall saving only if of sufficiently robust construction to withstand the arduous conditions of a steelworks without excessive maintenance.

#### SUITABLE TYPES OF DIESEL LOCOMOTIVE FOR STEELWORKS

Consideration of the kind of Diesel locomotive likely to be successful in steelworks leads to some definite conclusions. In the first place, although the steam locomotives at present in use have a fairly high tractive effort/weight ratio for short hauls, they are under-powered for most duties other than miscellaneous shunting, and can only be used successfully because they stand thrashing to the limit of their capacity all their working life, and will continue to run even when the working parts have worn to the last degree of slackness. It must be emphasised that these conditions are very different from those prevailing in railway shunting yards or the average factory yard.

The experience of the L.M.S. Railway, who are the only employers on a large scale of high-power Diesel shunting locomotives in this country, has stressed that the Diesel engine should not be called upon to run at more than 60 per cent of the maker's rating for more than a few minutes at a time if reliability is to be ensured. On the other hand the employment of much larger locomotives in existing works is impracticable on account of curvature and other restrictions.

A further difficulty arises in connection with maintenance. The experience of the L.M.S. Railway has shown that success in obtaining a high availability factor from Diesel shunting locomotives depends on strict adherence to a regular schedule of maintenance. It is common practice for steelworks locomotives to be repaired in the general works engineering shops, and locomotive maintenance work is fitted in as convenient with other repair work. Repairs of actual production plant such as rolling mills, naturally have first priority, and the introduction of Diesel locomotives would undoubtedly require the setting up of a special section with specialised staff.

For gantry work and other of the more arduous locomotive duties in existing works, it would therefore appear to be preferable to aim, as suggested, at conveyor systems as the correct solution. For general shunting, however, and for haulage of bulk materials over lengths of track suitably laid out to carry Diesel locomotives of considerable size, the latter would undoubtedly effect substantial fuel saving, provided adequate provision for maintenance is made. Following the experience of the L.M.S. Railway, it is probable that electric transmission would be necessary for the power required, and a special design giving sufficient power combined with minimum rigid wheelbase, and great structural strength combined with three-point suspension of the power unit, will have to be developed. The standardised designs at present available in this country are generally under-powered and of too light construction for steelworks use.

## OIL-BURNING STEAM LOCOMOTIVES

As an immediate measure to meet the present coal shortage, experiments are being made to convert existing steelworks steam locomotives to burn tar, which is available as a works by-product. This may have the incidental advantage of providing more flexible adjustment of the rate of combustion to steam requirements, but great care is necessary in such conversions to avoid excessive local deterioration of the firebox.

## 7. Shunting Locomotives for Colliery Requirements

By J. STAFFORD, M.I.MECH.E., M.INST.F.

The locomotives in use at the large collieries in South Yorkshire are, without exception, orthodox direct coal-fired steam locomotives, chiefly of the 0-6-0 type, varying in cylinder size from 14 in. dia.  $\times$  20 in. stroke to 18 in. dia.  $\times$  26 in. stroke, in wheel base from 9 ft. to 14 ft., and, in working weight from 30 to 50 tons. In some collieries 4-wheeled locomotives, with a relatively short wheelbase, are used.

Colliery siding conditions vary greatly, from main line practice laid with heavy rails, to second rate contracting practice with lighter rails ; the standard of maintenance also differs considerably. Sharp curves and light track at some of the older collieries limit the size and weight of locomotives, but the newer collieries, without these limitations, are employing the larger shunting locomotives up to 50 tons working weight.

The number in use at individual collieries varies between 2 and 4, depending upon many factors, but mainly on the disposition of the colliery sidings and their relation to the main line railway system. At those collieries where the railway company places empty wagons in, and removes full wagons from the colliery marshalling sidings, the wagons gravitating in between, the colliery locomotives have only general traffic duties to fulfil, such as the transport of landsale coal, boiler fuel, colliery refuse, goods, etc. ; two working locomotives are then sufficient. Mechanical handling of boiler fuel and colliery refuse would often enable one working locomotive to deal with a large colliery's traffic requirements.

It is considered that the steam locomotive, with its simple construction and flexibility in power, has advantages over the Diesel locomotive, with all its gears and complications ; maintenance of the steam locomotive is within the capacity of the average colliery engineering staff.

Electric locomotives of either battery or trolley type are considered unsuitable for colliery shunting conditions, on account of maintenance, mobility, and the complications of power transmission.

A number of austerity locomotives, designed and constructed for the War Department and surplus to their requirements, have been acquired by colliery companies, who find them, although heavy, quite suitable for their conditions. They are of the saddle tank 0-6-0 type, with inside cylinders 18-in. dia.  $\times$  26-in. stroke, having a wheelbase of 11 ft., and a working weight of 48 tons.

If standardisation is contemplated, three sizes of locomotives should suffice for all colliery conditions, say :—

14 in. × 20 in., 0-6-0	· ·	9 ft. wheelbase, 30 tons working weight
16 in. × 22 in., 0-6-0	· ·	11 ft. wheelbase, 40 tons working weight
18 in. × 24 in./26 in., 0-6-0	· ·	11 ft. wheelbase, 48 tons working weight.

The riding qualities of the 0-4-0 type are considered to be so unsatisfactory that it should not be included as a standard type ; siding conditions should be modified, where possible, to accept the 0-6-0 type.

Many advantages will follow in the wake of standardisation of types and parts ; central stores could carry stocks of spare components such as complete boilers, cylinders, wheels and axles, axle boxes, springs, etc., and even complete locomotives, ready for emergency.

Whether the steam boiler should be coal or oil fired is a question better dealt with by those who are at the moment studying the problem on a large scale. The coal consumption of a colliery locomotive varies between 1 ton and 3 tons per working day, depending on the duty it performs ; the average weekly coal consumption for locomotive purposes at a large South Yorkshire colliery with an output of 20,000 to 25,000 tons of coal a week is about 30 tons, or 0·12 to 0·15 per cent. If it is assumed that the average consumption for the country as a whole is 0·20 per cent. of the coal output, then locomotives at collieries today are using up to 400,000 tons of large saleable coal a year.

There is much that should be done to use this coal more efficiently than at present ; the use of good boiler feed water, proper lagging of boilers and cylinders, adequate maintenance of boilers, cylinders, and valves, and good draught control, being a few of many factors contributing to efficient fuel utilisation.

## 8. Shunting Locomotives on Cement Works

By G. J. DAVIS

The duties of shunting locomotives on a cement works do not differ materially from those on any other works or quarries, but one cannot avoid being impressed by the amount of fuel which can be wasted in these locomotives.

The work is usually of an intermittent nature, yet at all times sufficient steam pressure must be maintained so that the locomotive is available every instant. The sudden change from no load to full load is bound to result in alternations of an excessive discharge of black smoke and the escape of surplus steam through the safety valve.

It has been possible to make an interesting comparison between the operation of three electric locomotives, each driven by two 47 h.p. 250-V. d.c. motors and an 0-6-0 steam shunting locomotive all working in one quarry

doing identical journeys. An analysis of the figures shows that for every £100 total cost of the steam loco. the driver's wages amount to £57·5, fuel £24·98 and repairs £17·52. If the costs of the electric locos. are reduced to the same basis, then the fuel cost is £19·31 and repairs £13·54.

The electric locos. are supplied with power from a third rail system which is fed by a motor generator. This third rail is probably considered a liability from the safety point of view by most operators, but after 17 years of service there has not yet been an accident. There is always, of course, the alternative of supplying power by means of an overhead trolley wire, and one quarry installation in Germany has run very satisfactorily on this system for many years. The trolley wire is set well to the side of the track where mechanical excavators load the wagons and the locomotive is supplied by power through a trolley mounted on a retractable arm at the side of the locomotive. For ordinary running the wire is situated over the centre of the track and a trolley fixed to the top of the locomotive is used. There is little doubt that in the interest of fuel efficiency the electric locomotive has a lot to offer.

Diesel-engined locomotives are frequently used but the power unit requires a lot more maintenance than an electric motor. There are a great many working parts which are subject to wear and require renewal compared with very few in an electric motor.

#### *Discussion*

A brief discussion followed the presentation of these papers in which Messrs. H. S. Dudley, G. Allison and G. T. Peat took part. The chief points raised were the desirability of using higher pressures for fireless locomotives, even up to 600 lb./sq. in. and the importance of proper treatment and control of water for steam locomotives.

Mr. K. M. Blauhorn wrote : A new type of high-pressure fireless locomotive has been developed abroad which is admirably suited for shunting service. It retains the basic simplicity of the old fireless locomotive and avoids its disadvantages. Fireless locomotives have been well known and they are characterised by the fact that the conventional steam boiler is replaced by a steam accumulator working on the varying pressure principle. Steam is stored in the accumulator in the form of water at a pressure of up to 200 lb. per sq. in. and at saturation temperature, and steam is discharged to the engines.

In the course of operation the steam pressure is constantly declining and therefore these fireless locomotives could only be used over modest ranges and for very limited loads.

The higher the charging pressure in an accumulator the greater is the storage capacity for a given volume of water. The high-pressure fireless locomotive also employs a steam accumulator in substitution for the conventional steam boiler. The charging pressure of the accumulator, however, is very much greater than the steam pressure at engine inlet. An automatic reducing valve is installed between accumulator and engines and provision is made to superheat the steam by passing it through a heating coil placed inside the accumulator and through which it travels after pressure reduction. The

principle by which superheating is effected is shown diagrammatically in Fig. 37, and where it is also made clear that the maximum charging pressure of the accumulator (1,200 lb./sq. in.) is very much higher than the steam inlet pressure (190 lb./sq. in.) to the engines. Therefore, there is no decline in pressure of the steam supplied to the engines during the operation of the locomotive.

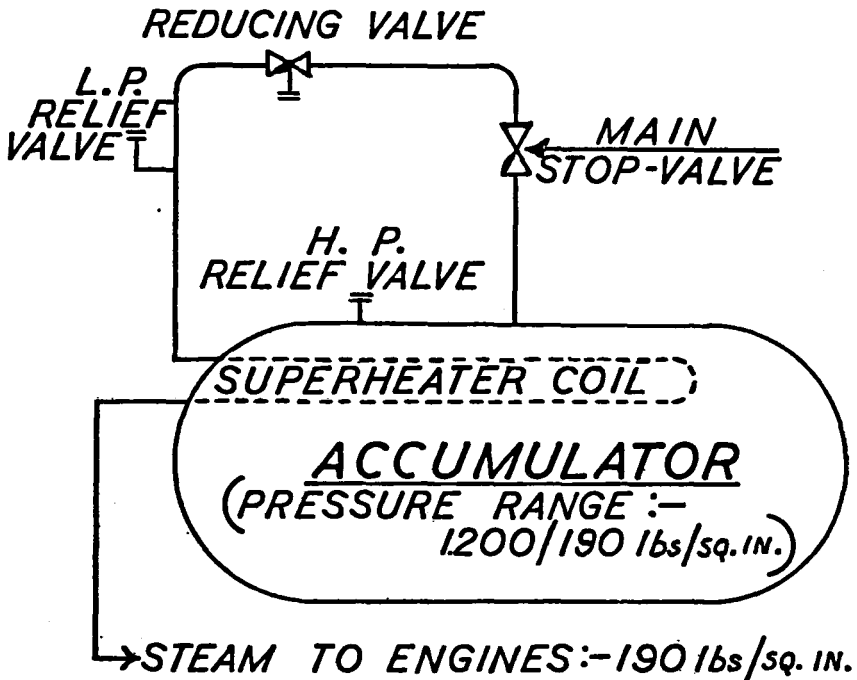


FIG. 37

The main advantages of the use of high pressures for steam storage in the locomotive accumulator are as follows :—

(1) The pressure of the steam entering the engines remains constant throughout the operational period of the locomotive, whereas its pressure is continuously declining during the operation of ordinary fireless locomotives.

(2) In consequence of (1) standard locomotive engines can be used in conjunction with the high-pressure fireless locomotive, whereas larger cylinder dimensions are required for the ordinary fireless locomotive.

(3) The pressure drop in the engines remains constant during the greater part of its operation and the steam consumption is very much lower than for ordinary fireless locomotives. Compared with a fireless

locomotive having a maximum charging pressure of 215 lb./sq. in. savings made with high-pressure fireless locomotives are :—

Charging pressure	Saving in steam consumption
lb./sq. in.	Per cent.
1,700	40
1,400	36
1,100	32
850	29
600	25

(4) The old fireless locomotives could only be designed for small loads and moderate ranges. The high-pressure fireless locomotives have been built for the biggest loads necessary in shunting services, and the range of these locomotives is very much greater than that of ordinary fireless locomotives. The increased working capacity of high-pressure fireless locomotives compares with a 215 lb./sq. in. fireless locomotive as follows :—

Charging pressure	Increased working capacity	
	Based on equal accumulator volume	Based on equal locomotive weight
lb./sq. in.	per cent.	per cent.
1,700	350	125
1,400	310	105
1,100	260	100
850	200	80
600	150	70

The first locomotive that was built on this new principle was designed to carry loads of 1,800 tons and has a capacity of 27,000 ton-miles. It has 1,100 h.p. engines and the locomotive weight is 82 tons. This locomotive has been in continuous service in Vienna since 1934, and although it was experimental, no trouble whatsoever has been experienced.

About 60 more high-pressure fireless locomotives of various sizes and duties have been built during the war. Particulars of these locomotives are given in the table below :—

	Type A	Type B
Locomotive weight (empty) (tons)	59	28
Locomotive weight (full) (tons)	69	35
Accumulator pressure (lb./sq. in.)	1,200	1,200
Engine inlet pressure (lb./sq. in.)	195	195
Maximum service load (tons)	1,650	1,100
Capacity (ton-miles)	24,000	11,000
Engine power (b.h.p.)	1,000	450
Length (ft.)	36	20
Accumulator volume (cu. ft.)	450	270
Steam required for one charge from 30 lb. per sq. in. (lb.)	9,000	5,500
Accumulator construction	Welded	Welded
Maximum speed (m.p.h.)	30	25

High-pressure fireless locomotives are charged from stationary plants. If boilers at 600 lb./sq. in. steam pressure, or more, are available, it is best to use these boilers, otherwise high-pressure charging boilers would have to be provided. These can, of course, be designed to utilise any fuel which may be available. Electrical charging can also be applied and patents have been developed whereby it is possible to use electric charging devices up to a pressure of 1,700 lb./sq. in.

As the advantages of the high-pressure fireless locomotive are very obvious as compared with ordinary fireless locomotives, it is very interesting to compare its merits for shunting service with those of conventionally fired locomotives.

(1) There is only one operator required for fireless locomotives.

(2) The steam for the fireless locomotive is generated by a stationary boiler where the efficiency is much greater than in a locomotive boiler.

(3) Waste of steam and fuel for heating up and during standstill periods are avoided. There are no losses through blowing off steam through the safety valve.

(4) The main costs are very much reduced as there are neither boiler, stoker, nor furnace which require extremely high costs of upkeep.

The Austrian Federal Railways have made an investigation of the comparative cost of shunting yard operation by means of high-pressure fireless locomotives and fired locomotives alternately. They have established that the operational savings with the high-pressure fireless locomotives are so high that the extra cost for charging boilers can be written off after  $1\frac{1}{2}$  years.

The manufacture of extra-high-pressure fireless locomotives offers no difficulties. Ordinary locomotive under-carriages and engines can be used. The accumulator can consist of one or more cylindrical shells which are of welded construction, or forged from the solid for pressures above 1,400 lb./sq. in. Charging the boilers is simple. If existing high-pressure boilers are not available, quick steaming charging boilers or special charging accumulators will be installed.

Proved designs are available for the method of charging the locomotive at high pressure.

The British rights for extra-high-pressure locomotives have been received, and it is hoped that locomotives of this new design will soon be built for use in this country.

**Mr. R. M. Macfarlane** wrote commenting upon statements that oil fuel was unsuitable for firing shunting locomotives. He ascribed the difficulties and damage that had arisen to the use of unsuitable equipment allowing the heat release to be too great and uncontrolled. It was a common experience to find small shunting engines equipped with oil-burning gear capable of steaming a main line "Pacific" engine, the oil burner being indifferently erected and so situated that the fireman could operate it only with great difficulty.

Where oil-firing gear, of capacity in keeping with the requirements of a locomotive, was fitted and used in conjunction with control gear which could control it as required, effective and efficient service could be obtained from oil fuel on steam shunting locomotives, large and small, with no more firebox trouble than was normal to steam locomotives as such.

Mr. Macfarlane continued :

Directions in which the fireless steam shunting locomotive can show advantage have been ably put forward by Mr. Hanna and Mr. Thirtle.

Where the working substance for this type of locomotive is supplied from boilers used for this purpose alone, the advantages and economy obtainable from oil-fired boilers, particularly if automatic controls can be employed, should always be kept in mind.

Mr. Stafford has shown that for the conditions at collieries the steam shunter can still offer attractions. Where these are tempered by inability to maintain locomotive power and availability owing to indifferent quality of available coal, use of fuel oil, properly applied, may offer advantage. The advantage would be associated as much with definite ability to cope with as much traffic as the engine can handle as with saving in the fuel it consumes which, as Mr. Stafford has mentioned, is but a small percentage of the tonnage handled. Where technical and economic advantage can be obtained by doing so, there is nothing incongruous in using an oil-fired locomotive at a colliery. Coal firing is used in oil refineries where technical and economic advantage accrues from its use. Maintenance of oil-firing gear suited to a colliery steam shunting locomotive would be well within the capabilities of the average colliery mechanic.

To the users of steam shunting locomotives, fuel oil can offer a contribution towards improved performance and efficiency for their "Fuel and the Future" requirements. Should they decide to make use of it, attention to the points mentioned will be found helpful.

By giving attention to these points an important concern abroad, operating a large quarry and associated industrial plant requiring close adherence to traffic schedules, was able to obtain from steam shunting locomotives which they fired with oil, trouble-free service and performance.

Particulars of the locomotives concerned are :—

Type : 0-4-0 T

Steam : Saturated, working pressure 160 lb./sq. in.

Firebox : Copper.

Grate area : 3 ft. 3 in. long  $\times$  2 ft. 10 in. wide = 8.89 sq. ft.

Heating surface total : 449 sq. ft.

Cylinders : 2 of 11½-in. diameter, 16-in. stroke.

Diameter coupled wheels : 2 ft. 6½ in.

Weight in working order : 19.85 tons.

Wheelbase : 5 ft. 9 in.

Rail gauge : 3 ft.

Loading gauge : 11 ft. high, 8 ft. wide.

Duties : Loads in region of 310 tons at about 5½ m.p.h. up 1 in 200, and at about 18 m.p.h. on level.

Operative and maintenance staff : Asiatic.



## SECTION A. THE GENERATION OF STEAM—*continued*

### SESSION IIIb. The Training of Boilerhouse and Furnace Operators

*Chairman of Session:* PROF. C. H. LANDER, C.B.E.  
PRESIDENT-ELECT OF THE INSTITUTE OF FUEL

This session was devoted to a general discussion on the subject of technical education in fuel to which a number of speakers contributed.

The Chairman referred to the vital importance of the subject. The interest shown by the discussion of this subject before a gathering which was perhaps the largest and most comprehensive ever convened for the purpose, was most encouraging, but the difficulties, both in devising and adopting methods to meet the present needs, must not be overlooked.

One factor which had impressed him was that the standard of technical skill appeared to vary a good deal among different classes of operator and that generally the higher standards were found in those whose occupations offered scope for advancement. It was obvious that encouragement and opportunity to fulfil an ambition and to follow a career should be provided.

He hoped that as a result of the deliberations of the conference the Ministry of Fuel and Power would be encouraged not only to continue but to increase their drive to stimulate all concerned into providing the necessary avenue for the ambitious and skilled worker. He was well aware of the many difficulties to be overcome in ensuring that every operator should be a certificated and qualified expert but he looked forward with optimism to the time when this would be an accepted fact. In his view certificates of competency, increased pay, and other incentives would encourage operators to take a real interest in their work.

Dr. R. J. Sarjant briefly reviewed the work that had been done during the war in the training of personnel, through the work of the Education Sub-Committee of the Ministry of Fuel and Power, of which he was Chairman. Dr. Sarjant said :

Education was from the outset an important feature of the fuel efficiency campaign and steps were taken to provide emergency courses in fuel efficiency for all grades of industrial personnel. At first there were two main types of courses, one for operatives and one for managerial and technical staff, each consisting of some six to twelve lectures, the scheme being operated in collaboration with the Board of Education. At the inception of the scheme lecturers were hard to find, and the idea of the lecture room atmosphere was strange to many. Lecture notes were compiled by the Education Sub-Committee and distributed to all students. The Committee was supported by the Engineering Inspectorate of the Board of Education, the Principals of the Technical Colleges, and the Divisional Coal Officers, who found the students.

From the lecture notes there developed the now well-known textbook "The Efficient Use of Fuel". The Fuel Efficiency Bulletins were invaluable. Later, three films were produced on Boilerhouse Practice, Steam, and Furnaces.

Operatives' courses included as much practical demonstration and as many visits to plants as possible. There have grown also discussion circles, brains trusts and courses of special lectures by well-known experts. The most recent developments have been the holding of refresher courses at the Universities, notably a very successful one at Leeds University, and another of a truly pioneering character, extremely well attended, at Bristol University on steam utilisation. Mr. Oliver Lyle and his Steam Utilisation Panel have opened up a new epoch in fuel education and practice in the work they have done towards the spreading of instruction in this formerly neglected branch of the subject.

Now to the future. Although upwards of 30,000 active workers in industry, of which 15,000 have been operators, have been attracted to these courses, there still remain perhaps ten times that number to be reached. The future calls for the solution of this problem as a matter of urgent and major importance. The lessons of this war-time experience indicate that more systematic technical training must be available. The Joint Education Committees of the Ministry and of the Institute of Fuel are at present engaged on the task of encouraging the institution of suitable courses at as many Technical Colleges as practicable all over the country. My special appeal is to those who have influence with possible students to ensure that every available man is persuaded to join these classes. The manager and the technical man must clamour for the refresher course, the discussion circle and the special lecture. In the operative we must attempt to foster again the old pride in craftsmanship and bring him to realise that instruction is necessary if this purpose is to be achieved.

More attractive and novel methods of instruction must be sought. The lecture room should have the demonstration bench with ingenious and effective experiments to fire the imagination and clarify the understanding. For this purpose facilities in Technical Colleges require to be reinforced. Qualified engineers in industry must be found to help in this work, for until more lecturers are trained there will be a serious dearth of instructors. In remote districts it is hoped that firms will organise their own classes, and appeal to the Technical Colleges and the Joint Education Committees to help them.

For the operative there will be certificates of competency ; for the technical man a ladder of progressive instruction leading to the highest attainments of technical proficiency. Thus may an inherent sovereign pride in skill latent in every one of us be revealed to the benefit of the national welfare.

**Dr. W. Abbott** (Ministry of Education) introducing the subject on "Standard Courses" said he was of the opinion that this question should be viewed as a long-term policy ; he was well aware that for a long time past Fuel Technology had been the "Cinderella" in the field of technical education, but he believed that it was about to come into its own. Close ties already existed between his department and the Ministry of Fuel and Power. A document\* shortly to be issued by the Ministry of Education would recommend that all engineering, chemical and similar courses in England and Wales should cover the subject of fuel technology. Special courses now in being were not on a large enough scale to meet the situation. Fuel technology should be the concern of every Technical College.

Dr. Abbott pointed out that this year approximately 10,000 men would be coming forward for their National Certificate examinations and suggested that they should concern themselves with the conservation of fuel, in view of the

---

\* Now available : "Further Education", H.M.S.O.

fact that the three prime requirements for industrial progress and national recovery—men, materials and power—must each be used with the maximum economy.

He was disappointed to find that the City and Guilds Courses in Boilerhouse Practice attracted only small numbers and suggested that all interested parties should confer, in order to devise measures for counteracting this antipathy. Further incentive was necessary and, in addition to those incentives already recommended, the release of personnel during working hours would bring about a very considerable increase in the number of students.

Finally, he referred to the Institute of Fuel courses as a sound basis for technical qualification, and hoped that these special courses designed to meet the examination requirements of the Institute, would be organised on an ever-increasing scale in the future.

Mr. E. W. Bussey (whose paper was read by Mr. W. C. Stevens, Assistant Secretary, Electrical Trades Union) gave the point of view of the Trades Union Congress on Technical Education. Mr. Bussey wrote :

The Trade Unions have always been advocates of technical training for manual workers. They have, however, taken as a first consideration the human material and the object for which the education is designed. Training for boilerhouse and furnace operators will, on examination, be found to be a very special case.

In the past, the work of boilerhouse and furnace operators was classed as unskilled. The staff was recruited mainly from younger adult male workers, the qualifications for the work being chiefly fitness and strength. The rates of pay were just a fraction over the rates which could be obtained at almost any labouring job, but as the work offered a greater degree of security, there was very little difficulty in recruiting the necessary labour.

Today, things have changed. The furnace and boilerhouse of a supply undertaking are recognised to be, if not the most vital, at least one of the most important sections of the production structure of the undertaking. It is here where fuel can be conserved and working costs reduced. Upon the efficiency of the furnaces and boilers depends much of the efficiency of the power production. It is for this reason that great technical advances have been made in recent years in furnace and boilerhouse plant and apparatus. These technical advances have demanded a greater degree of knowledge on the part of the operator which, *ipso facto*, must enhance his skill as a worker.

It is very encouraging to find that undertakings are beginning to take an interest in the technical education of their manual staffs. It is something which those in the Trade Union movement have advocated for many years, and they will be glad to associate themselves with the good work, for the T.U.C., just as much as the management, want to see the worker technically equipped for the job he has to carry out. Technical education must not be made available only to a selected few, anxious to secure theoretical qualifications and operational efficiency, simply with a view to promotion. Should this happen, the main purpose of the fuel efficiency campaign will not be achieved.

One final point. The Trade Unions are of the opinion that the technical skill of an operative is just as valuable to the industry as the technical efficiency of the plant and apparatus which he is called upon to operate. It is hoped that the industry will recognise this by giving the operative a standard and status in the industry equivalent to his contribution to the industry.

Mr. R. H. Brennan explained the employer's view of technical education. He pointed out that the education of boilerhouse personnel must be considered from several angles, including the size and type of plant, the pressure at which the plant is operated and whether it is fired by hand or mechanically. Mr. Brennan went on to say :

The satisfactory operation of a hand-fired boiler plant demands a certain amount of technical knowledge in addition to plenty of brawn. The work is hard, dirty and often uncomfortable and poorly paid, and as long as a man was strong enough to do the work and keep up the steam pressure, nobody bothered very much how it was done.

The outlook now is different and it is becoming more apparent every day that stokers must be trained in their profession. What degree of training is required largely depends on the type of plant.

If we consider a plant consisting of three or four hand-fired boilers, with a crew of, say, two men, these men would have to be coal runners, firemen and ash wheelers in turn, but they would also require to have some knowledge of the composition of coal, at least an elementary knowledge of the principles of combustion, the ability to understand the readings of any instruments they may have and to vary the firing conditions in accordance with the readings.

Many men will regularly record on the log sheet the readings from the various gauges, meters, CO<sub>2</sub> indicators, etc., but as long as the pressure is maintained, they do not bother whether the CO<sub>2</sub> is 14 per cent. or 8 per cent. or whether the chimney temperature is high or low. I recall an instance that occurred some years ago : I had occasion to point out to a leading stoker (an ex-Naval Petty Officer) that the CO<sub>2</sub> was down. His reply was, "Well, Sir, the CO<sub>2</sub> is there but we can't trap it". That is the sort of ignorance which must be overcome, and this brings us to the questions of what degree of training is required and who is to be trained, and further, should training be compulsory ?

Taking the last query first, I am definitely of the opinion that training should be compulsory, and that nobody should be allowed to have charge of a steam-raising plant until he holds a Government certificate of competency. Possibly many will disagree with me over this, but when we consider the tremendous amount of energy stored in a boiler under pressure and the disastrous results that can follow an explosion, due to inattention or lack of knowledge, and the waste of fuel that can occur, the point becomes clear.

As to the men to be trained, obviously we should consider only the younger men. "You can't teach an old dog new tricks" and you can't break an old stoker of the bad habits he has been practising all his life—I have tried many times but with little success. It is much more satisfactory to take young men who have never seen a boiler before, and train them on the job. They respond to personal interest and attention and take an intelligent interest in their work.

As to what is required in the way of training, this is fully set out in the syllabus issued by the Ministry, but I would say that the first thing to teach a stoker should be the practical work, i.e. methods of firing, the proper use of the various tools he has to use, and the importance of keeping the correct water level. Then and only then, begin to teach him the technical and theoretical part of the work.

Correct firing methods, keeping a level fire bed, cleaning out, followed by the importance of correct air supply, how to use the draught gauge and CO<sub>2</sub> indicator, and the simple physics and principles of combustion are the only

essentials for the man on hand-fired plant. There are of course many plants using mechanical stokers with shell boilers, and others with water-tube boilers, complete with automatic control and other refinements ; for these a higher standard of training is necessary, particularly for the shift foreman, and in those plants where a boilerhouse superintendent is employed, he should hold a Combustion Engineering certificate.

The future, not only of industry but of the country, depends on a more efficient use of fuel. The proper training of boilerhouse personnel will go a long way towards achieving that end, but training alone will not be sufficient : it is well known that it is the hope of reward that sweetens labour, and it will be a waste of time and money to train stokers unless the employer is prepared to pay good wages, make the boilerhouse as clean and comfortable as possible, provide the necessary instruments and finally, when a man has finished his day's work, provide him with facilities for bathing so that he can go home feeling clean and comfortable.

Mr. S. N. Duguid, presenting the subject "Aids for Training" said that in his view, there should be no limits to education for willing and competent persons, and that there should be no reason why the fireman should not finish up in the manager's chair. There was no short cut to knowledge, however, nor was it an easy accomplishment, but he maintained that learning could be made a pleasure rather than a penance if the right methods were employed.

He deplored the widespread belief that operatives as a whole were considerably below average intelligence and were not fitted to sit for examinations. It was only a question of applying the right vision on the part of the authorities and the teacher. If a man could not write good answers it might only be because he was out of practice and the technique could be developed gradually by setting simple home-work questions.

He believed that much could develop from small beginnings and that the first requirement for training was a chemical room fitted with a bench, gas, electricity and water and above all the indispensable black-board and chalk. Simple experiments should be conducted, showing effects of temperature, ignition, explosion, combustion, influence of air, formation of  $\text{CO}_2$ , etc. ; this would not only hold the interest of persons, many of whom had never previously had the chance to see the inside of a science room, but it would enable them to develop their practical and theoretical training side by side. In addition they would learn aspects of their jobs which could not be acquired on the firing floor alone.

The importance of practical demonstrations on suitable plant either in the college or on neighbouring works and visits to different plants was stressed, as was also the use of the instructional films made by the Ministry, film strips, bulletins, the Stokers' Manual, Furnaceman's Manual, and other technical literature. Wall charts and diagrams should be displayed in profusion, because he considered the secret of success was in visual absorption.

Finally, he wished to emphasise that of all the aids to training, the attitude of the lecturer was the most important, and offered the following advice—  
"A good lecturer should never bluff, never talk down to the men, but come down himself to their level, he should be a good psychologist—and not expect verbose discussions or debates, but rather to let discussions develop naturally and informally round the bench. Above all he should possess or develop that saving grace—a sense of humour".

Mr. T. M. Ashford speaking on "The Practical Aspect of Classes for Stokers" referred to the panels of advisory engineers appointed by the Regional Fuel Efficiency Committees and the excellent service they provided. The full benefits of this service, he said, would not be obtained unless operatives were able to understand the principles of combustion, and efficient operation, and so intelligently absorb the advice given. The provision of training courses could, therefore, be considered as complementary to the general advisory work of the Fuel Efficiency Committees and their panels of engineers.

Training courses, he maintained, while primarily intended for the education of personnel were beneficial to plant owners themselves, by assisting as they do in the reduction of fuel costs. It was in the employers' interests, therefore, to encourage and facilitate the attendance of their employees at such courses. The voluntary interest of the men should be stimulated, however, as any form of coercion would be likely to defeat its object.

Mr. Ashford recommended that close attention should be paid to the following points:—Methods of tuition should not savour too much of the school-room atmosphere (to which operatives have long been unaccustomed); the classes should be held in a central spot in the area from which students are drawn; the duration and frequency of the classes should not be too exacting on the time and endurance of the men (the ideal period being  $1\frac{1}{2}$  to 2 hours per week on one evening chosen to interfere as little as possible with the recreational facilities of the district); courses should be duplicated if possible to cater for shift workers and extend possibly to twelve lectures, terminating in an examination which would be partly theoretical, but mainly devoted to practical questions.

The value of diagrams and wall charts was also stressed, as was also the display of working models of stokers and grates, etc.—which might be obtainable on loan from the manufacturers. Mr. Ashford confirmed Mr. Duguid's point that the lecturer must not talk over the heads of the students, and the importance of making a close study of the types of men usually attending such courses. The value of visits to several efficient plants in the locality was confirmed, although the speaker himself did not consider that practical demonstration was desirable or necessary; he rather thought that the stoker resented being shown how to use a shovel, but was amenable to adapting his own stoking under instructions, if the reason for so doing was explained to him.

The scope of the basic syllabus could be extended to cover the field required by the various certificates awarded by the City and Guilds of London Institutes in Boilerhouse Practice, and for this purpose it was desirable that provision should be made for holding a number of refresher courses for those candidates who were preparing to take these examinations.

Mr. W. Bates dealt with standard methods of locomotive firing. He said that trials carried out over a period of years by the L.M.S. Research Department had proved that inefficient methods of firing locomotives could nullify any gain to be expected from change of design. During these trials remarkable variations were discovered in the quantity of water evaporated per lb. of coal and these were found to be due to the presence of varying amounts of the products of incomplete combustion in the flue gases. It was found that these variations were due to the method of firing and it was established that, when the engine was working, the most efficient method was to fire six or seven shovelful of coal at two-minute intervals. This method was now accepted as

the standard method of firing L.M.S. locomotives and formed the basis of the training for all L.M.S. firemen.

Each fireman was supplied with an instruction book explaining this method of firing, also the purpose of the brick arch and the part it played in complete combustion, how the draught was created, how regulated through the dampers and firehole door, how to build up his fire to avoid thick black smoke, and starting with the fire not properly burnt through, how to control it when running to avoid air holes, hollow places and dead patches, to trim the coal to uniform size, to carry the fire not too thick nor too thin, not to over-fire the engine, and at all times to use the system of controlled firing as his guide to the efficient combustion of the fuel.

Many new features had been introduced into locomotives with the purpose of saving fuel and instructors and inspectors saw that men understood these improvements and used them to the best advantage.

In spite of all these improvements, it was still found that the work of the driver and fireman had the greatest influence on coal consumption. Their work was carefully watched by locomotive inspectors and firing instructors who travel on the engines and submit reports on the performance of the engine and the men in regard to fuel consumption.

At all depots, classes were run for the improvement of the men's knowledge. These were given all the encouragement possible by the L.M.S. In addition, educational training lectures were given at main centres. At all these, the question of fuel economy and efficient methods of firing were the subject of frequent lectures. Every depot had its own coal consumption chart showing the rise or fall of coal consumption at that depot.

**Mr. W. Caudle** spoke on the training of boilerhouse operatives from the point of view of a Ministry Stoker-Demonstrator. He pointed out that the necessity for burning fuel of lower grade than was used normally involved greater practical skill and knowledge on the part of the firemen. The speaker gave examples of plants at which the firemen had been totally unable to maintain the steam pressure and supply, however hard they worked, until a skilled stoker-demonstrator had shown them how the job should be done, after which there had been no difficulty. It often happened that the knowledge that could be imparted from the visit of a stoker-demonstrator was sufficient to correct what might appear to be a minor fault of bad practice and in so doing to make all the difference to the operation of the boiler plant. When the practical side was demonstrated the impression made was lasting whereas a talk was often forgotten quickly and could never have the same effect on a boiler fireman as a practical demonstration.

In the Northern region the training of firemen had been gradually evolved from a start made by conducting evening short courses of lectures and demonstrations at various boiler plants. At first no particular interest was observed because very few of those present could see what was being done. It was found that visits by the stoker-demonstrator to individual boilerhouses during the working hours were very useful. Although much good work had been done in this way, considerably keener interest had been shown since the stoker-demonstrator carried round a small projector and with it showed a strip film on boilerhouse practice accompanied by comments. This strip film could often be projected on the walls of the boilerhouse and the demonstration and talk had attracted managers, engineers, and sometimes all the apprentices.

There were many difficulties such as age, shiftwork, reluctance of a man to spend his own time in being trained, and expense.

While visits to works had given useful results, complete training could not be obtained in this way and the speaker had come to the conclusion that there should be an established school in each region conducted by the Ministry engineers and stoker-demonstrators at which works stokers would attend for two weeks and would receive some form of certificate after passing a simple examination on practical lines. It was necessary to maintain contact with the students after this course on their own plants in order to maintain their interest. There was need for stabilisation of teaching technique in place of the improvised courses hitherto held. A fireman who had attended such a course would feel that he knew more about his boiler and about combustion and he would be more inclined to discuss difficulties with his own foreman or engineer, and so open the way to greater efficiency. The technical training of stokers should be placed on a properly organised basis.

**Mr. P. B. Silk** spoke upon "The Duties of Personnel". He pointed out that a clean boilerhouse was an efficient one and for this reason concentrated on the handling of the ash and dust—a problem which had increased considerably in recent years. Higher stoker ratings and increased ash content of fuels had led to heavier clinkering and larger amounts of grit and dust; for high availability boilers must be kept clean internally.

This side of the boilerhouse operations must not be dismissed as being unproductive because the result of so doing was that an unnecessarily large labour force was required and owing to the often appalling conditions of work a turnover of 200 or 300 per cent. per annum of labour in the ash basement had frequently to be faced.

This was not a problem which could be overcome by any training methods and it was essential that reasonable working conditions should be provided. Although it might be argued that the cost would be prohibitive, he thought that a good deal could be done for a reasonable sum and some thought and ingenuity.

He thought it false economy to leave the consideration of the ash and dust plant until all other plant details had been decided—thus leaving the designer the difficult problem of having to instal his plant in the space left over.

**Mr. Silk** illustrated his next point by describing a plant—the very latest in equipment and costing many thousands of pounds—which was operated, as customary, by practically unskilled labour. This had been a trouble job from the start until the management very wisely placed a trained engineer in charge—with spectacular results. This was the opposite to what usually happened. The good type of man was promoted to the firing floor from the ash basement, reducing the average intelligence there and leaving the remaining personnel looking on their job merely as one to get out of at the first opportunity.

In summing up, **Mr. Silk** had two pleas to put forward—first that the ash and dust plant should be adequate and of a type to afford reasonable working conditions, and secondly that having spent good money on the plant it should be operated by reasonably skilled men, with a responsible engineer in charge, or at least taking an interest in it.

**Mr. L. G. Northcroft** referred to the status of the works engineer. A member of the staff who could make a big contribution to fuel efficiency if, like the boiler operative, his status was sufficiently recognised, is the works



engineer. Boiler operatives in the future were likely to be of a higher grade and that must automatically increase the status of the works engineer who was in charge of them. This added to the responsibility of the engineer inasmuch as it became necessary for him thoroughly to understand boiler firing. The boilerhouse, however, was only one part of the works engineer's job. He was responsible for all the different kinds of equipment used in the works, but he had very little official status, very little recognition, a great deal of hard work and very little money.

The need for recognition of works engineers was emphasised by the speaker who also pointed to the difficulty which the works engineer frequently had of being able to convince the management of the soundness of his ideas because of his low professional status. Mr. Northcroft mentioned the need for a live and active Institute of works engineers or plant engineers, and referred to two existing bodies, the Institution of Engineers-in-Charge and the Incorporated Plant Engineers. Very few plant engineers of the ordinary industrial type would ever have the opportunity to study for examinations. They were essentially practical and their practical knowledge needed recognition by some other means than academic qualifications. Mr. Northcroft emphasised that the educational courses of the Ministry in different parts of the country should be followed with keen interest by every plant engineer since they provided one of the first means ever made available to him of improving his status. At the same time the management should give these men every possible encouragement not only to improve their education, but also to put forward their technical views.

#### *Discussion*

**Mr. D. J. Bradbury** wrote : The success or failure of all training schemes for boilermen and furnacemen depends to a very great extent on the amount of co-operation given by the management. If in a factory the management take no interest in their fuel consumption, it is unlikely that the employees will do so. Whilst the Ministry of Fuel and Power is considering ways of training more operatives they should give some consideration to educating the management.

For instance, what is the use of teaching a furnaceman about the importance of waste heat recovery by means of recuperators, waste heat boilers, etc., as is done in the film on Furnace Practice, when probably he will not have the slightest say in the matter of new plant and will spend his days shovelling coal into a contraption which is little better than a box ?

The idea of a certificate of competency for furnacemen and boilermen is very good, but unless there is something concrete behind that certificate the whole scheme will fall to the ground. Few, if any, men will go to the trouble of training for a certificate if, when they have got it, they are going to find that its acquisition fails to bring them promotion or any more pay than the man who has no certificate.

The time and place of classes is also of importance. Classes are of necessity held in the evening when men are most likely to be free ; but many men feel that once their day's work is over they do not want to start again, particularly if they are getting on in years. The presence of many strange faces and a feeling of austerity about the classroom seems to act as a further deterrent. The writer tried running classes in his own works to which men from neighbouring works were invited and the result was quite successful. The classes were

arranged for the time of change of shift in order to catch the greatest number of operatives.

Much of the literature issued by the Ministry of Fuel and Power in the early days of the fuel economy campaign suffered from being too technical. It has got better as time has gone on and "The Stoker's Manual" is clear and well written. "The Furnaceman's Manual", on the other hand, tends to wander off too much into theory. Because a man spends his life operating a boiler or furnace it should not be assumed that he knows all about fuel technology.

**Mr. James Law** wrote : During the past fifteen years in Sheffield, classes for the training of stokers and furnacemen have been in operation and a Furnacemen's and Stokers' Technical Society has been formed. The response, however, has been poor as only about 150 students out of about 4,500 men employed attended. In searching for the causes of this, there are two points that can be emphasised, the first one being that it is the hope of financial reward that induces the men to improve their status, and as no such inducement has been offered, the response has been poor. The second point is that the classes were held at the Applied Science Department of the University, and it is thought that the men found it an ordeal to have to rush home, change, and then make their way to a building which was so imposing. There is a psychological side to this that could be rectified. It was suggested by Dr. Sarjant that if the lectures were made sufficiently interesting the men would attend. It is submitted that there must first of all be some promise of financial reward to induce the attendance and then that the lectures should be held in premises where the men will not feel out of the scheme of things.

**Mr. L. J. Robinson** wrote : I observed with great interest that many speakers acknowledged the need for stimulating the enthusiasm of operatives by providing additional incentives, and I was, therefore, surprised to hear Mr. Brennan (although obviously in wholehearted agreement with the principle of training) imply that an operative's training should terminate at a point where he has acquired just sufficient knowledge to operate the plant in his charge. This is clearly contradictory to Professor Lander's admirable concept that boilerhouse and furnace operation should be but a first step in a career for those with ambition and ability, since there would be little if any scope for advancement in any one firm of the size indicated—unless, of course, one inclined seriously to Mr. Duguid's humorous reference regarding the ascension of the fireman to the manager's chair.

I doubt whether the staffing of the larger gas and electricity undertakings and industrial enterprises can be effected with new recruits alone, in view of their expansion programmes and the yearly wastage. It is probable, therefore, that many operatives will, in the future, have the chance to avail themselves of better positions and opportunities, and no limit should be set to their educational attainments if they are to reach standards which may fit them to occupy these positions—and thus to advance in their careers.

On the question of increased pay incentives, mentioned by many speakers, is it quite true to affirm that on the whole operatives are grossly underpaid ? Whilst this was certainly true in the past, I believe that conditions have undergone a great change. The important point, and one which so far has not been debated, is whether operatives in receipt of fair standard of pay and enjoying good conditions should qualify for increases in pay on the successful completion

of a training course, or whether proper training should be considered *obligatory* on the part of the operative if he is to qualify for such a position.

In the majority of skilled trades the completion of recognised training is a first and necessary qualification for employment as a tradesman enjoying full Trade Union rates of pay, whilst in certain of the larger undertakings other qualifications are often required.

The answer to this problem would, I think, go far to reassuring a somewhat puzzled management, and so increase the prospects of that close co-operation, without which the whole scheme must fail.

THE CHAIRMAN of the Section, **Sir Johnstone Wright**, summed up the major conclusions from the discussions as follows :—

1. *The Availability of Water-Tube Boilers.*—There can be little doubt from the information given in the papers presented that if the recommendations of the Boiler Availability Committee were widely adopted the nation would gain a greatly increased availability from large and small boiler plants, together with a material conservation of fuel. It has also been shown that the knowledge gained with regard to the fundamental causes of the formation of bonded deposits is enabling large boilers to be designed for the highest of pressures and temperatures, which will be able to give continuous service between annual overhauls. A continuation of the work carried out by the Committee will ensure that the best use is made of the capital employed, and the manpower necessary for the manufacture of the boiler plant, and thereby enable increased export work to be undertaken at a very critical period in our history.

2. *Design and Operation of Smaller Boilers.*—The information given on the design and operation of smaller boilers indicates that a material improvement in performance can be achieved by the incorporation of convective heating surface to shell-type boilers, and the addition of mechanically-operated combustion appliances. Attention has also been drawn to the necessity for providing adequate instrumentation, and in many cases automatic or semi-automatic combustion controls. The suggested modifications should enable a material increase in boiler efficiency to be achieved, with a consequent conservation of fuel consumed for industrial purposes.

3. (a) *Shunting Locomotives.*—The information given on the subject of shunting locomotives clearly indicates that a very careful study should be made of the operating conditions in order that a correct choice of type is made. If there is to be a material saving in fuel, it would appear that the use of either electric or Diesel-electric types should be extended.

3. (b) *The Training of Boilerhouse and Furnace Operators.*—The training of boilerhouse and furnace operators is a most important factor of our industrial life if real conservation of our fuel resources is to be obtained.

Sir Clive Baillieu at the opening Session very aptly expressed the ideal of training boilerhouse operators. The necessity for training boilerhouse personnel was emphasised during the discussion at the Sessions and I know the Education Sub-Committee of the Fuel Efficiency Committee has had it very much in mind in their training courses.

The importance of providing operators with adequate instrumentation was also stressed. Many industrial boilers today are only fitted with a pressure gauge and the operator has no quantitative guide. This is fundamentally

wrong. No operator can take an intelligent interest in the plant under his control unless he has visual indication of what is taking place. Several speakers felt that the time had now arrived when all boilers should be supplied complete with instruments as an integral part of the equipment. Surely instrumentation is more important for a boiler than it is for a car and very few cars would be sold today that had not a full complement of instruments on the dashboard. The provision of adequate instrumentation enables a properly trained operator to produce the maximum amount of steam from the minimum amount of fuel, and that is what we are all trying to do.

The electricity supply industry is fully aware of the need for fuel efficiency. Between 1925, the year before the 1926 Act which set up the Board was passed, and 1939 the coal consumption per unit of electricity generated in this country had been reduced from 2·4 to 1·36, a reduction of 43 per cent. Everything possible will be done by the electricity supply industry to help the Minister to gain that further 10 per cent. for which he has asked.

# SECTION B

## STEAM UTILISATION

*General Chairman:* MR. J. G. BENNETT

CHAIRMAN OF THE FUEL EFFICIENCY COMMITTEE'S NEW PLANT SUB-COMMITTEE ;  
DIRECTOR, DELANIUM LTD.

### SESSION I. Where Everything Depends on Steam

*Chairman of Session:* MAJOR EGBERT CADBURY, D.S.C., D.F.C., J.P.,  
CHAIRMAN OF THE SOUTH-WEST REGIONAL FUEL EFFICIENCY COMMITTEE

**T**HE CHAIRMAN: Industries which depend upon steam comprise:—chemicals, paints, films, batteries, food manufacture and food preparation, laundries, woollen textiles, coal, iron and steel, soap, oil, margarine and petrol, cotton and lace textiles, rubber, cables and plastics, paper and cardboard, silk textiles, linen and jute, hosiery, gas, motor cars, the engineering industry, tanneries, tiles and pottery, timber and furniture, breweries, glass manufacture, the making and fabrication of non-ferrous metals, the electrical and radio industry, railways, printing, the aircraft industry—not forgetting Army and Air Force establishments—and last, but not least, the Royal Navy.

Steam is used in all of these industries in greater or lesser degree, but even where steam is used in lesser degree it is an essential service. It is impossible to do more than touch on a few of the many subjects arising out of the use and conservation of this vital form of energy.

We do not want any discussion about leaking valves and joints, or lagging, etc. Any wastage from this cause should have been rectified years ago. Our particular problem is to concentrate on how steam can be used efficiently, and the maximum amount of service and energy obtained from it.

Conservatism, in the sense of refusal to make a change, is particularly strong in trades where for one cause or another competition from abroad is not felt keenly, or where the article manufactured is not suitable for export. But it is important that these industries should be as efficient as modern science and methods can make them as those who have to be efficient to survive, for we cannot afford waste in any shape or form. It would not be difficult to find examples in almost any industry of some process in use which was highly efficient in its time but now could be improved upon if critically surveyed, but is retained because *grandfather* put it in! We as a nation cannot afford to be behind in our methods, and one of the places where there is still plenty of scope for progress is in the efficient use of steam.

The main reason for this lack of progress in the use of steam is because, generally speaking, our attitude and outlook on steam are in the wrong perspective. It is because steam is an essential service that it is too often taken for granted. In how many works is steam regarded simply as something which comes out of a pipe and which is instantly available at the turn of a valve?

The managing director, the works manager, the process manager think only too often of steam in the same terms that they think of water, or of gas or of electricity.

Here is another way to think of steam. When an employee requires a tool for his work—perhaps a blow lamp, or a glue pot, or a hack saw, or a set of dies—it is the general practice for him to go to the appropriate stores and draw it out against a chit. A stores in almost any industry is sacrosanct,—you wouldn't have any process operator just walking into the stores and taking what was necessary for his work without making some account of it. To adopt any other procedure would be to court ultimate bankruptcy. Steam is a tool of industry, a raw material of industry, expensive and in short supply. But yet how many of you ask your process operator or your process manager, or your works engineer for an account of the steam which he has taken from the store? In nine cases out of ten he merely walks into your steam store and by just turning valves takes out of store all the steam he wants.

No food manufacturer would permit his process operator to draw sugar from the store as he required it, and then allow that operator to spill 10 per cent. of the sugar on the floor before it reached his process plant, but in nearly every industry in the country 10 per cent. of the steam which is drawn from the stores is quite regularly and needlessly wasted. It has been said—with very real justification—that for every 10 per cent. economy made in the boilerhouse in steam generation, 20 per cent. can be made in the factory in steam usage.

With this picture of the storekeeping of steam in front of you, it should be easy to see how this waste can occur. In the boilerhouse there is an engineer who is, or should be, trained in steam generation, but in the process plant there is seldom a process manager, or a process operator who is trained in the correct principles of steam usage. The works engineer, who *should* understand the process use of steam, is seldom allowed any hearing in the use of it.

This calls for a fundamental change of attitude on the part of process management towards steam and towards the works engineer. And this is what I trust will be one outcome of the discussion this afternoon.

## 1. "Beer and Coal"

The session first considered the Brewing Panel publication, "Beer and Coal", drawn up by a technical committee of the Brewery Trade under the chairmanship of Mr. Oliver Lyle. This bulletin points out that if brewing processes are linked up as shown in heat flow diagrams printed therein, it should be possible in most breweries to halve the fuel consumption.

The heat flow diagrams have been prepared in an attempt to reduce fuel consumption to a level at which the same degree of cleanliness persists as heretofore, and the quality of beer is maintained. During the preparation of the heat flow diagrams very careful consideration was given to the possible effects on the brewing process of the economies suggested. The following observations embody the technical matters discussed:—

The diagrams refer to three breweries. Brewery "A" represents a brewery where the process demands a maximum amount of heat. There is no wort breakdown and all mashing liquor is raised to 212° F. Breweries "B" and

“ C ” represent breweries where the processes are such that the least amount of heat is required. The liquor is cold sterilised and there is a 50 per cent. cold breakdown. In Brewery “ A ” it is assumed that unlined casks are used and must be steamed. In Breweries “ B ” and “ C ” the casks are assumed to be lined and to require washing only.

The bulletin contains technical details of the brewing processes on which the flow sheets are based and present, technical plans for carrying out these processes with the minimum consumption of fuel.

**Mr. Ralph Worssam** then introduced the bulletin :

Brewing is an art and not an exact science. The article demanded in the East End of London is very different from that in the West End. Birmingham has quite different demands from London, Edinburgh, and so on. Materials vary—not everyone can have the best malt and hops—water varies and so do yeasts. There is also an enormous variation in fuel consumption in different breweries in this country.

In drawing up these proposals, any suggestion which any members of the committee has felt to be impossible of adoption for technical reasons, has been discarded, and every effort has been made to put forward ideas and methods o saving fuel without in any way interfering with the methods generally adopted and considered advisable by practical brewers.

In the past cheap coal has offered little inducement for the employment of the most economical fuel practice. The position is now quite different, and the function of the committee was to help the brewer to use as little fuel as possible. The time may come when the brewer must obtain as much beer as possible with the amount of fuel which may be available for that purpose. It is in the brewers' interest to treat the problem of fuel consumption as one of emergency, and to study the proposals put forward.

The difficulties in obtaining new plant have caused the proposals to be considered from two aspects : “ Short Term ” and “ Long Term ”.

In the bulletin the word “ refrigerator ” has been used where to brewers “ refrigerating machine ” would be the correct term, and the word “ paraflow ” should cover any form of refrigerator.

The main points to which brewers should direct their attention are those of heat recovery and heat wastage.

Whether to heat coppers by steam or by direct fire is a question which has been discussed *ad nauseam*, but there can be no doubt whatever that the fire-heated copper consumes very much more fuel than the steam-heated vessel. The prejudice against the steam-heated vessel has now very largely disappeared, and the survival of the direct fire-heated copper is generally due to a lack of sufficient steam from the boiler plant. It is possible that reduction in steam requirements (which we believe will be achieved by the help of the bulletin and diagrams) may allow many brewers now using fire-heated coppers to change over to steam without any addition to their steam-raising plant. One warning must be given—make sure that the steam heating apparatus which will be installed in the coppers is really suitable for the purpose. Careful thought and study must be given to the design of the heating unit or the results obtained may be disappointing.

There are few coppers in this country today, in which the steam from the wort is not blown away to atmosphere ; this is a direct and considerable loss of heat. The heat loss in evaporating 10-brls. of wort from a brewer's copper would raise about 60-brls. of wort from 55° F. to 212° F. .

I need hardly mention that all steam-heating apparatus should be trapped on the condensate side, and the condensate from it used again. Hot liquor, or even warm liquor, running down the drain may not be usable again from the brewer's point of view, but it contains valuable heat units which can almost certainly be recovered and re-used.

It has not been possible to include in the diagrams every source of heat used and required by the brewer. One of these is primings sterilisation and sugar dissolving. There is some reference to these processes in the bulletin. There are breweries where hot liquor running down the drain in the cask washing yard has been put through a heat exchanger and the heat recovered from it.

All brewers should note what hot or warm liquor is at the present time going down the drain, and see whether it is not possible to use it, or at any rate, the heat units abstracted from it, over again. It may be found that some minor modification in the run of the mains in a brewery may achieve considerable economy in fuel consumption. The brewers should investigate what amount of warm liquor is going down the drain, and what steam and vapour is being discharged into atmosphere, and if the answer is none, and lagging is really efficient everywhere, they would be astonished at the small amount of fuel required. The boilerhouse, which is being dealt with elsewhere, is of very great importance. Whenever a brewery is found to be using three or four times the amount of fuel used by another of comparable capacity, however, the major difference is not in the stoking, but is almost certainly due to heat recovery.

The question of liquor treatment is mentioned in the bulletin, and is of very considerable importance, but is not one upon which I am qualified to comment. The heat required to raise brewing liquor from 180° to 212° F. is very appreciable. Liquor containing high-grade heat is of course, of more importance than that containing low-grade heat, although the latter should not be ignored. I have known cases where warm liquor from attemperators has been re-used, whilst much hotter liquor from the refrigerators has been run down the drain as redundant.

One of the difficulties which sometimes arises in breweries, particularly in the summer, is that well liquor is mixed with company's liquor. In many breweries it is the brewer's opinion that he cannot use the former, and in others the latter, for brewing purposes. When this is so, one of the means of economising in fuel is the use of some form of heat exchanger.

Brewers should carefully examine the diagrams in the bulletin. They are issued with the object of showing what can be done, and it is not suggested that any of these schemes should necessarily be adopted in its entirety. Certain principles and methods, which will fit in with existing plant, some of them for adoption now, and some of them for the future, will suggest themselves by studying the diagram. The average coal consumption in breweries, is far above the figures given in the bulletin and a very considerable reduction in the present consumption is obviously a possibility.

**Mr. Oliver Lyle** discussed the utilisation of low-grade heat. He pointed out that practically the whole of the heat used in industry disappeared as low-grade heat, for example in the flue gases, in condenser water flowing to rivers and cooling ponds, or in process effluents to sewers, etc. A very large proportion of this reject heat was sufficiently hot to be usable a second time. Flue gases at 350° F. could well be cooled to 250° F. by means of a sub-economiser; condenser water at 115° F. might be usable for space heating;



warm effluents could often be used to heat in-going cold water in a counter-current heat exchanger thus recovering two-thirds of their heat ; water vapour at atmospheric pressure could bring cold water to boiling point by direct contact, and water vapour grossly adulterated with air could still raise water to quite a high temperature.

In a brewery there were three major heat losses, namely, from flue gases passing up the stack, from the cooling of hot wort, and vapour arising from the copper. In most breweries the only heat recovered was that derived from cooling the wort.

In a laundry heat was lost also in three major ways, namely, from flue gases passing up the stack, from water discarded down the wash-house drain, and by moisture from the dryers. In most laundries the only attempt made to recover heat was by means of orthodox economisers heating boiler feed water. Very little serious work had been done on recovering the heat in the wash-house drain water.

At first sight the recovery of waste heat from flue gases by means of a sub-economiser would seem the simplest. It was, however, the last source of waste heat that should be tackled. Heat transfer from dry gas to metal heating surface called for a large temperature difference, consequently much less heat was available, in practice, than would appear theoretically.

Heat transfer by counter-current heat exchanger could be extremely efficient and could readily lead to the recovery of two-thirds or more of the total sensible heat in the out-going liquor.

The heat in low-grade water vapour was completely recoverable by direct contact with no appreciable temperature difference.

If heat savings were made from reject vapour and hot effluents, a great saving in waste flue gas accrued automatically. That was why the sub-economiser should be the last piece of heat saving plant to be installed.

**Mr. F. E. B. Moritz:** I have been asked to speak on behalf of the Fuel Committee of the Institute of Brewing and I propose to make some general remarks concerning the brewing process.

The limited time I have at my disposal does not allow for very detailed comment at this stage, and it has already been suggested that such detailed discussions could best be dealt with by meetings of brewery technicians at the sectional gatherings of the Institute of Brewing.

The memorandum that you have before you is an attempt to summarise the main technical brewing matters that were discussed by the panel set up by the Ministry of Fuel and Power. I was a member of that panel, as I felt that it was my duty to the brewing industry to hold a watching brief on their behalf and at the same time to give what assistance I could to the Ministry on this very important subject.

In the letter headed "Brewing" and signed by the Chairman of the Fuel Efficiency Committee you will note the statement that at present the fuel consumption per barrel of beer brewed varies very considerably between different breweries. The magnitude of these differences far transcends anything that can be accounted for by differences in process, product or size of brewery. The main point which I wish to emphasise is that now (and even in the future) it will be extremely difficult, if not quite impossible, to determine what the limit of those differences should be.

Unlike other industries which may come under review by the Ministry, the Brewing Industry has to produce a consumable article which is the direct

outcome of the action of a living organism—a yeast—on a specially prepared fermentable medium, by a process which is complex in all its stages. It will be appreciated that with such a process the highest standard of cleanliness must prevail. To maintain this standard of cleanliness heat is essential, and if there were to be any drastic curtailment of the heat-cleaning process spoilage of beer would be the inevitable result.

The heat used for cleaning purposes in a brewery cannot be assessed accurately pro rata to the barrelage ; this is due to the variation between breweries as regards the type of plant employed, the layout of that plant, and the extreme difficulty at the present time of installing or replacing plant. With the introduction of new plant or the replacement of worn out plant the variation may be reduced, as regards fuel used for cleaning, but in my opinion absolute equality can never be attained.

I now come to the brewing process itself in regard to fuel economy. To some it would appear at first sight that the process is stereotyped, and that therefore the fuel consumption per barrel should be roughly uniform in all breweries. This is not the case, nor, in my opinion ever will be so, if the brewing industry is to meet the demands of the public. It is true that the underlying principles of brewing hold good in all the breweries of this country, but there are essential variations in the process itself which may materially affect the fuel consumption figure. For example, it is idle to suppose that one can produce fine quality ales and stouts, and ales or stouts suitable for export purposes, using exactly the same process, and therefore the same amount of fuel, as for light gravity draught beers intended for strictly local consumption.

Furthermore, it must be realised that it is essential, in order to satisfy local taste, to produce beers of character and flavour suitable for that locality, and that can only be achieved by variations in the brewing process, which in their turn may involve variations in fuel consumption. In the bulletin it is conceded that in all circumstances the quality of the beer must be maintained.

The word "quality" to the technical brewer means a great deal ; to obtain the necessary high standard of quality in the brewing sense the beer must be pure, palatable and bright, and the flavour must be in accordance with popular taste. Every brewer will agree that it has taken years to build up a reputation for his product, and that that reputation is based not only on the quality but also the character and uniformity of his beers.

Heat is an essential factor in maintaining quality, character and uniformity, and any drastic curtailment of heat might have disastrous effects on the production of our national beverage.

In the memorandum we are discussing there are put forward fuel economies which should not in many cases have any effect on the flavour or character of beer, and these, I suggest, are worthy of consideration. There are other suggestions which may call for criticism on the score that they would materially affect the quality and character of beer in certain cases.

With that criticism in view I was in part responsible for the avoidance of any implication in either the Committee's memorandum or letter that all or any of the suggestions for heat conservation are applicable to every brewery.

I have attempted to show why there are variations as regards fuel consumption in different breweries, but I cannot say how far it will be possible to limit them ; I have also attempted to show that variations will persist.

I suggest that it must be left to the individual brewery to effect any further economies that can be made in the future, and I would also suggest that this

is possible only by close co-operation between breweries and the local representatives of the Ministry.

I would add only this : my attendance at meetings of the panel of the Ministry of Fuel and Power have convinced me that the Ministry is at one with the brewing industry in wishing to maintain the output of beer without in any way interfering with local preferences, and is concerned only that the output and quality of beer should be maintained with the minimum consumption of fuel.

**The Hon. John F. Gretton:** Some of the remarks that I have to make may appear critical, but I should like to say that it is with no intention or wish to be unhelpful. I believe that this conference will not only be the means of doing good, but that the bulletin entitled "Beer and Coal" will be of great assistance to all who study the information it contains.

I should now like to refer particularly to the statement that :—

" . . . the fuel consumption per barrel brewed varies very considerably between different breweries. The magnitude of these differences far transcends anything that can be accounted for by differences in process, product, or size of brewery."

Referring first to process and product, may I give one instance where the amount of heat used is closely related to the actual product? It has already been mentioned that the brewing process is a sensitive one, and that large quantities of hot liquor are required for cleansing purposes. Moreover, I submit that the amount depends on the type of plant used. In Burton-on-Trent we have what is known as the Union system, which is used in connection with part of the process of fermentation. This system is absolutely essential to the production of the ales for which the town is famous, both in this country and throughout the world. Considerably larger quantities of hot liquor are required for cleansing purposes with this than with other systems. Here, then, is one clear instance where the type of plant employed may have a great effect on fuel consumption, compared with another brewery using a different process.

What is meant by "size of brewery"? For instance, of two breweries with approximately the same capacity and using the same process, the one may be compact whereas the layout of the other may include a number of extensions which have been added during the course of its development. The fuel consumption of the one will be very different from the other. Again, the bigger the brewery, I think you will find, the greater the number of ancillary services that it will undertake, and these will require fuel to be consumed on the premises. It is on this point that the difficulty arises when it comes to making comparisons between the fuel consumption of one brewery compared with another in terms of lb. of fuel per barrel brewed—and this in turn raises the question—what items should be included or excluded in order to arrive at a basis for comparison?

May I give one or two instances :—

(1) One brewery may pump all its water from its own wells, whereas another brewery may obtain its supplies from the mains.

(2) One brewery may make all its own malt while another may purchase the whole of its requirements.

(3) Some breweries undertake a large proportion of their bottling requirements, whereas the trade of others largely depends on outside bottlers, etc.

I therefore submit that the quantity of fuel consumed per barrel by one brewery compared with another may be most misleading unless a common standard can be devised which will give accurately all the information which may be desired for the purpose of comparison.

I am very glad to see that there is no suggestion that the various types of economies mentioned in the bulletin should in any way interfere with the quality of the product, and that there is no intention to produce a stereotyped beer on the basis of heat units consumed. To do so would lead to the most disastrous results.

I am also very glad that it has been clearly pointed out in the bulletin that the various flow diagrams are not meant to apply to any one brewery, and that each concern will be able to find suggestions which can be adapted to suit its own particular process. There are, however, some suggestions which will need the most careful consideration, and may I say this—it has been found that when changes have to be made, one large-scale experiment is no criterion. The results have to be carefully watched over a considerable period before it can be determined that the experiment has been successful, and that no changes, sometimes of an unexpected nature, will develop.

It is, however, fortunate in respect to long term policy that attention was being given to fuel economy before the war. In 1939 plans were in existence and would have been completed if it had not been for the outbreak of hostilities. The difficulty now is to obtain the necessary licences to put the work in hand. It is here that the Ministry of Fuel and Power can give great assistance.

The brewing industry is not only desirous of making its contribution towards the national need to save fuel, but it is ready to act. May I, however, express the hope that the Ministry of Fuel and Power will not only approach the industry as a whole, but also deal with each firm individually.

## 2. Steam for the Rubber Industry

By FRED. WALKER, M.I.MECH.E.

The rubber manufacturing process calls for the use of very heavy power-driven milling, calendering, and other ancillary plant, on which the rubber is prepared prior to its being shaped and moulded in presses, autoclaves, and other large heating vessels.

In the initial stage of manufacture, electric motive power is used on a considerable scale, to masticate and compound the rubber, whilst in a later stage heat and pressure are applied to complete the vulcanisation process. Steam is the medium generally used to provide the heat at temperatures corresponding to dry saturated steam at pressures ranging from 40 to 200 lb./sq. in. Various supplementary services, such as hydraulic, compressed air, vacuum and refrigeration, have also to be provided, and most of them at several different pressures and temperatures.

The total amount of fuel required to process completely a given weight of finished rubber goods including all services varies somewhat according to the type of goods being produced, and figures ranging from 2 to 4 tons of coal per ton of product have been recorded.

A process such as the one I have briefly described, and which uses fuel to the extent mentioned, is likely to provide endless facilities for the wastage of heat, and, to some extent, of power.

It is, therefore, one of the first duties of the rubber factory engineer to see that all the energy released by the combustion of his fuel, or received from outside sources, is fully accounted for, and also to see that any British Thermal Units found to be leaving the site, in the form of hot flue gas, hot effluent, escaping steam, excess ventilation, wastage of compressed air, or idle power losses, are arrested as quickly as possible.

In order, however, to obtain a proper picture of what is happening in this direction, it is necessary to get down to fine detail, and to make heat and power flow diagrams. Such work is tedious and requires patience, but once accurate data are available, close study will often reveal serious wastages, many of which can be considerably reduced, whilst some can be stopped completely.

For example, let us briefly examine heat losses, and the possibilities of thermal linkage in the rubber industry.

Approximately 85 per cent. of the steam generated is used for vulcanisation, after which it has to be liberated, either to atmosphere or into some form of recovery system. We have found that by introducing exhaust steam heating and vacuum return systems, an appreciable amount of the heat in the process steam can be recovered and used for space heating and also, in certain cases, for further process work, such as the heating of spreading tables, drying drums and calorifiers, etc. ; any balance of heat left over, either as low-pressure steam or condensate, can be put back into the boiler feed water.

It has also been found possible to increase the temperature of the soft make-up boiler feed water by approximately 23° F., by passing it through the water jackets and coolers of air compressors, and at a later stage passing it through heat exchangers, in such a way as to absorb the heat from contaminated hot water coming from mould and other cooling processes. The heat in this effluent is considerable, and is often wasted, either by way of the river or sewer.

Substantial economies have also been made by the replanning of steam mains and in certain cases by segregating the steam pressures ; 95 per cent. of the process steam in rubber factories is required at pressures not exceeding 110 lb./sq. in. By isolating one boiler to work at the highest critical pressure (usually about 200 lb./sq. in.) with a surplus valve into the common process main at about 100 lb./sq. in. it was found that a great easement in boiler working conditions was obtained ; not only was less fuel used, but it also enabled inferior fuels to be handled more easily.

Another fruitful source of fuel economy which has proved well worth while investigating is the production load factor. A careful study of this has in several cases revealed the fact that by a little planning the required output can be obtained in a shorter working week, with consequent savings in both power and heat.

From figures and reports which I have had before me, I estimate that the savings which will accrue from these and similar moves already recommended in the Fuel Efficiency Bulletins will be approximately 15 per cent., and, providing things are not allowed to slide back these savings can be permanent.

Assuming, therefore, that we shall shortly reach the stage when all these items have received attention, what then are the possibilities for future large economies in the use of fuel in the rubber industry ? Shall we see any radical changes in the heat and power requirements ?

New methods of processing are, of course, appearing, but whether or not these will prove to be sound economically still remains to be seen, and the really revolutionary method of manufacturing rubber and at the same time

using considerably less heat and power for such articles as tyres, footwear, conveyor belting and other general rubber goods, has yet to appear.

I mentioned previously that the rubber industry was also a considerable power user, and it may well be asked at this stage why (with a heavy combined heat and power load such as that obtaining in this industry) electricity is still generally purchased from the Grid instead of being generated on the spot by back-pressure turbo-generators.

The short answer is that, owing to the relatively high process-steam pressure required, usually about 100–120 lb./sq. in., and the ratio of the power and heat load, it is not possible, even with very high initial boiler pressures, to generate all the power necessary by means of the back-pressure system. There are, of course, systems of this kind in use in the rubber industry, where the turbo-generators are allowed to run in parallel with the public supply, and there is much in favour of this arrangement from the national fuel economy point of view. Whether such a scheme can be made sufficiently attractive commercially in any particular case is, however, another matter. This, of course, depends on the initial cost of the high-pressure boiler and back-pressure turbo-plant, on the price charged for the balance of power required from outside sources, and on the efficiency of the existing heat and power arrangements. (I mention the latter because, in certain cases, considerable fuel economy is already being obtained from the back-pressure working of steam-driven hydraulic pumps, compressors, and other service plant, the exhaust steam from which is used for space and other low-grade heating.)

In one large rubber factory in this country this problem has been solved very satisfactorily, and considerable advantage taken of the fuel economy resulting from partial back-pressure working, by purchasing all the power and heat required from a power station situated about one-third of a mile away from the factory. Process steam is brought into the factory at two pressures—65 lb. and 110 lb.—the general scheme being as follows:—High-pressure steam and electricity generated at the power station under specialised supervision; electricity and pass-out steam from the turbines delivered to the factory at suitable pressures for process work; steam after use in the process exhausted at low pressure and used for space and other low-grade heating and the condensate returned to the power station, under a penalty, i.e. there is a clause in the agreement by which the suppliers automatically increase or decrease the price of the steam, depending on the percentage and quality of the condensate returned. This scheme has proved reliable in service, and satisfactory to both the supplier and the user.

It is, of course, obvious that owing to their location it is at present impracticable for many rubber factories to purchase both power and heat in the manner described, but, wherever it is possible to employ this method, not necessarily for rubber factories alone, it is well worth while investigating, especially where process and heating steam is generated in low-pressure boilers, and where no form of back-pressure plant exists.

The present system, whereby almost every factory and building has its own heat-generating plant, is to my mind extremely wasteful, and I find it difficult to see how we are going to obtain a further considerable reduction in fuel usage without resorting to some form of centralised combined power and heating plant.

The time has, I think, arrived when serious consideration should be given to setting up back-pressure auxiliary power and heat stations in selected industrial areas.

### 3. The Efficient Utilisation of Steam in the Chemical Industry

By R. BUNTING, B.Sc.

The applications of steam to chemical processes are so varied and numerous that in the time of my disposal I propose only to indicate, as concisely as possible, the principles employed to achieve efficient utilisation on the major steam-consuming unit operations in the chemical industry, namely:— (1) heating, (2) drying, (3) evaporation, and (4) fractional distillation.

When considering the efficiency of application of steam in any process, it is essential to determine exactly where the heat leaves the system. With this knowledge, the potential sources of heat recovery become obvious and the feasibility of re-use can be considered.

Applying this principle to a simple heating process, it is apparent that, unless endothermic reaction heat has been provided, the entire heat input leaves in the effluent from the system. In many cases up to 80 per cent. recovery of this heat can be economically achieved by passing the hot fluid in counter-current flow against the cold feed in a heat exchanger, thereby reducing the steam requirements to one-fifth. Thus, in the recovery of acetone from absorption systems, roughly 90 per cent. of the total heat requirements are attributable to sensible heat in the effluent from the still. By providing heat exchangers on the base of the column to preheat the feed approximately 70 per cent. saving in total heat requirements for the process will accrue. With gases, the heat transfer surface required is necessarily much greater, but 50 per cent. saving can generally be justified. Obviously, heat regeneration can make an appreciable contribution to steam economy and should be given serious consideration.

In drying, heat wastage of up to 30 per cent. of total requirements can arise from losses from the exterior surface of the dryer. In this case, recovery does not arise as the loss can be obviated in large measure by suitable lagging. The major loss, however, is in the exhaust air from the dryer. This exhaust heat should be reduced by giving proper attention to design and operating conditions. A compromise must be made between reduction in exhaust temperature and maintenance of a high rate of output. Apart from temperature, rate of air flow affects rate of drying of the material, and recirculation to ensure velocities of 5–6 ft./sec. should be provided, the additional power costs being relatively insignificant compared with the saving achieved by higher drying rates. Correct distribution is very important as the output of the machine is limited in practice by the condition of the wettest portions of the material and bad distribution can result in very inefficient overall results. The distinction between recirculated and extracted air must be appreciated and humidity control on the exhaust air is strongly advocated. On batch drying the rate of air extraction required will decrease as the moisture content of the charge falls, but the recirculation rate should be maintained throughout.

The prevention of air leakage into and out of the dryer is obviously essential as losses from this cause can ruin performance efficiency.

Even when optimum operating conditions have been achieved, the feasibility of recovery of a part, at least, of the latent heat in the exhaust vapour is worth considering. If these vapours are passed through a spray cooler fed with

water for washing processes, a substantial saving in steam used for the latter process is possible. The equipment is simple and relatively inexpensive and even where contamination is liable to occur it does not normally detract from the usefulness of the water for its particular purpose.

In evaporative concentration, the major heat loss is in the reject vapour and the development of multi-effect evaporators for the recovery of most of this lower-grade heat is too well known to require reiteration. But even here it is often possible to improve the efficiency of heat utilisation. For instance, almost 100 per cent. vapour heat recovery was accomplished in one works by condensing the reject vapour from the final effect of a triple-effect evaporator by exchange with feed water for an adjacent boilerhouse. While this particular application could not be universal, it is surprising how often this linkage of unrelated processes is feasible.

In fractional distillation, the major heat losses are :—

- (a) The sensible heat in the base run-off liquor ;
- (b) The latent heat in the reflux and distillate ; and
- (c) The sensible heat in the distillate.

The magnitude of these various losses will depend on the particular system under consideration. Where the quantity of reflux and distillate is relatively small, the main heat loss will be in the base run-off liquor. This heat is readily recovered by exchange with the column feed, or if this is not practicable, it can often be applied to the heating of washing water, boiler feed-water, space heating, etc. If, however, the amount of distillate is considerable, heat recovery from the reflux and final condensers should be practised. For intermediate cases, both sources of heat loss will be tapped, due consideration being given to the level of the heat to ensure maximum recovery.

While on the question of reflux, it might be useful to make a few observations on reflux-ratio control. In an endeavour to simplify the reflux-ratio control, separate reflux and distillate condensers are frequently used, but there is often little attempt made to ensure accurate control ; the actual ratio used is generally higher than is necessary in order to avoid variations in quality of the head product arising out of fluctuations in feed rate and steam supply to the still. The need for accurate flow measurement is evident and an indication of either direct reflux flow or the temperature rise and rate of flow of water to the reflux condenser is advocated.

Latent heat re-use in evaporation has been mentioned, but owing to the more complex nature of fractionation equipment, it has not been general practice to apply the multi-effect principle to distillation. Under present conditions, however, serious consideration should be given to its feasibility. Usually only two effects are employed, the feed being divided between two columns, one working under high or medium pressure and the other at lower pressure or under vacuum. The latent heat in the reflux and distillate from the high-pressure column provides the necessary fractionation heat for the lower-pressure column, thereby effecting an appreciable reduction in overall heat requirements for the process. This principle is particularly applicable where the temperature difference between the head vapours and the base liquor is small, when the pressure difference required is relatively small. The actual steam saving depends on the operating conditions, but 30–40 per cent. reduction is readily achieved.



A modification of the double-effect process which gives substantial steam savings in some instances is the "Vulcan" Vapor Re-use Process.\* Here, the feed is stripped under pressure with open steam and head vapours condensed in the calandria of a low pressure fractionating column, the condensate from the calandria forming the column feed. The increased feed concentration permits lower reflux ratios to be used with consequent reduction in overall heat requirements. As applied to the recovery of acetone from 1-1.5 per cent. molar solutions, 20-25 per cent. reduction in steam usage is achieved.

Another method of latent heat re-use is by application of the heat-pump principle. The heat in the head vapours is up-graded by means of a compressor and the resultant high-pressure vapours condensed in the calandria. The actual set-up again depends on the particular application. The head vapours may be compressed directly, but where this is impracticable, a heat pump working with a suitable refrigerant, between the condenser and the calandria can be used. The economics of this principle will depend on the temperature range and the relative costs of steam and power, but savings of 20-40 per cent. in distillation costs are quite normal.

## 4. Steam Research and Education

By L. G. NORTHCROFT

Our Chairman, Major Cadbury, has spoken of a new approach on the part of management to steam utilisation in industry. Some indication of the problems and of the savings which are involved in the proper use of steam have been indicated in this Session. We may expect, therefore, that when the Managing Director goes home from this conference, he will be thinking to himself how George, his works engineer, can best help in this problem.

He will ring the bell and say, "George, why have you been wasting 20 per cent. of our steam for the last 10 years? What suggestion have you got for putting our plant to rights?" If he is very quick in the uptake George will immediately produce a plan that he has been wanting to put into force; but if he is really as quick in the uptake as this, it is probable that he would have given up works engineering and would have been a sales engineer many years ago! In fact, it is more than likely that he will know only a fraction of the answer and be able to put forward only a very small part of the scheme which is necessary to put his plant into anything like proper steam efficiency. His management will, I hope, be sympathetic, and I hope they will realise that at no time in his engineering training has George ever had an opportunity for learning the right way in which steam should be used. The plain fact emerges that until very recently there have been no courses at technical colleges, no courses at Universities, and very little written in text books covering the subject of steam utilisation.

Now the problem is just a little bit easier. First of all the works engineer has available a set of magnificent Ministry bulletins dealing with steam utilisation. Perhaps you will take down the numbers of them to make sure

\* D. F. Othmer. Vapor Re-use Process. Ind. & Eng. Chem., 1936, p. 1435.

that you ask for them in the entrance hall. Their numbers are as follows :— 3, 4, 11, 18, 19, 21, 22, 25, 26, 28, 30, 33, 34, and 40. If George reads these and really masters all the information which is in them, he will know much about steam utilisation.

But it is not too easy for a practically minded works engineer to gain information solely from the written word. It would be so much better if these bulletins were backed up by technical courses to which the works engineer could listen. This fact was realised by the Ministry a year ago, and at Bristol a week's course was presented dealing solely with steam for process—not only for works engineers, but also for management. The remarkable response to the course showed how necessary it was. No less than 60 management and engineers were sufficiently interested to leave their work for a week to attend the course, and even then the demand was not satisfied.

Therefore a second steam course was held at Easter this year. This was attended by 89 managing executives and engineers from the South West, 19 lecturers from technical colleges and 20 Ministry of Fuel engineers. Courses of a similar type are even now being arranged in different parts of the country—in London, for example—and everyone is invited to apply to Mr. J. B. M. Mason of the Fuel Efficiency Branch of the Ministry, asking when and where steam courses will be available in your part of the country.

In addition to these Ministry courses, there are now also standard technical college courses, dealing quite largely with steam utilisation, available at Derby Technical College, Gravesend Technical College, and Nottingham University. It is, I believe, a fact that in any part of the country if sufficient engineers can be got together who are interested, the local technical college must do its utmost to meet the demand by laying on a special programme.

This is the short term picture of how the works engineer can almost immediately obtain the necessary information to put to rights the steam utilisation in his works. But there is also the long term programme of fuel efficiency, and in this also the proper use of steam must find its place. With this end in view the Ministry set up an Education Steam Panel to see how the existing syllabuses could be widened, and to see also whether a full subject could be made out of steam utilisation. This panel indicated alterations, enlarging the third year syllabus for the heat engines course, and prepared a number of examples for lecturers. These examples should be of interest not only to lecturers but also to the practising works engineer.

Steam utilisation as a separate subject already figures in the Institute of Fuel examinations. It was suggested by the Education Steam Panel that this might also form a separate subject for consideration by the Institution of Mechanical Engineers and the Institution of Chemical Engineers. To this end a syllabus covering all aspects of steam utilisation was prepared by the panel. Here again it will be, I suggest, of interest and value to the works engineer to have a copy of the syllabus, even if it serves no other purpose than to show him the gaps—if any—in his existing knowledge. This syllabus, also, can be obtained from the Ministry of Fuel and Power.

But when George has read the Ministry's bulletins, and has attended courses, and even when the young George growing up has passed his examination in steam utilisation, he will still be as ignorant as all the rest of us on many aspects of steam. Just because very little research work has been done on the process use of steam at any time in the last 100 years. Steam for power—

yes—that is well known, and well understood, and well documented. But steam for process—no—there still remain great gaps in our knowledge.

Here are two typical examples :—

Now long ago we were in a paper mill. Their papermaking machines are fed with turbine pass-out steam, which is available at either 20 lb./sq. in. with 40° F. superheat or at 30 lb./sq. in. with about 60° F. superheat. It is generally thought that superheated steam does not give up its heat so readily as does saturated steam, and we were asked what was likely to be the effect of, say, 40° of superheat,—would it be worth their while putting in a de-superheater? On the face of it 40° of superheat is very little and one would think it was not worth while putting in a de-superheater. Right! If it was not necessary for 40° of superheat, was it necessary when they were using a higher-pressure pass-out with 60°? At what point would it become worth while to put in a de-superheater? This question is, I suggest, unanswerable at the present state of our knowledge. No experiments and no research has been done on heat transfer from superheated steam when used in process plant of this type.

On the same occasion we were involved in an argument on the merits of increasing the velocity of steam over the heating surface of the paper-drying cylinder. It is well known that increasing the velocity over a heated surface improves the rate of heat transfer. But to increase the velocity of steam into a drying cylinder is extremely difficult because of the great disparity between the area of the steam inlet pipe and the area of the cylinder itself. At what point does an increased steam velocity begin to increase heat transfer? What velocity in fact is necessary to strip the air and condensate films from the inside of the cylinder? Again, nobody knows the answer to this problem. Nevertheless it is one which occurs practically in steam usage in almost every industry.

These are but two examples. It would be possible to go on talking about the effect on heat transfer of non-condensable gases in steam spaces, to talk about dropwise condensation of steam and about nucleate boiling. It would be untrue to say that no work had been done on any such subjects, but in general the work has not been translated into a practical form in which it can be understood by the ordinary steam-using manager or engineer. In many cases it is probable that even the fundamental research work has not been done.

To rectify this situation the Ministry is setting up a Steam Research Panel to gather together all the information which has been gained but which is not available, to translate this information into everyday language and also to determine what research work still remains to be done. It is suspected that in the archives of the research departments of many of our large industries there is information available which would help this panel very considerably in its work. If any such industrial organisation is willing to make the results of such investigations available, the Fuel Efficiency Branch of the Ministry would be very glad indeed of this co-operation.

#### *Discussion*

Upon the utilisation of steam in chemical works, Mr. Wooler suggested that there should be greater recovery of waste heat from the air used in the chemical industry. He advocated the use of heat exchangers in extraction processes.

**Mr. L. G. Groves** drew attention to the high capital cost of chemical plant designed to save fuel.

Attention was also drawn to the inefficient performance of electrically-driven pumps due to the low thermal efficiency of power stations. The judicious use of heat pumps was recommended.

**Mr. W. H. Hilton** wrote : Thanks to the Ministry of Fuel engineers and to voluntary engineers from the rubber industry, most of the rubber manufacturers' boiler plants are now "fuel-efficient" but, as in most industries, there are exceptions to the rule. If fuel becomes short, should not priority be given to those firms having efficient boiler plants ?

Vulcanising pans are one of the causes of peak loads in the rubber industry, and to reduce the peaks as much as possible, curing cycles should be studied and analysed, and production planned, so that as far as possible two or more pans do not go on to the line at the same time. If this is done, advantage can be taken of interlinking the pans, so that as one pan completes its cure, the steam can be exhausted into the next pan going on to cure, to give an initial pre-heat and save the use of live steam for this purpose.

Another source of fuel loss is the sulphuric acid corrosion of cure pans, used in the production of hard rubber products, more commonly known as ebonite. The best cure is, of course, for the pan to be constructed from acid-resisting steel, but capital cost is high. A palliative is the internal painting of the pan, frequently with cement paint, or special bituminous or graphite paints, and the addition to the joint face of the door of a facing of, say,  $\frac{1}{8}$ -in. thick of stainless steel.

The condensate from this type of pan, with its addition of dilute sulphuric acid, given up by materials under cure, is a problem, but the heat can be extracted by the use of a heat exchanger made from acid-resisting metal.

Press platens in the rubber industry are normally steam heated, but as it has been proved that hot water, gas or electricity have higher thermal efficiencies than steam for this duty, consideration can be given to hot-water heating, or in the case of a firm generating its own power, electrical heating.

Radiant heat losses from presses can be reduced by the painting of the presses and edges of platens with special aluminium paint.

**Mr. A. S. Roxburgh** wrote : Mr. Oliver Lyle, dealing with the utilisation of low-grade heat, referred to the heat wastage from a hot-air drying machine. We use hot air with a high moisture content for humidifying a room where fibres are prepared and spun. The hot air, at about  $180^{\circ}$  F., is drawn off by a fan and mixed with air drawn from the atmosphere to give a temperature of  $120^{\circ}$  F. It is then discharged through ducting and the result is improved temperature conditions with material assistance in securing the necessary humidity of the room.

**Mr. B. Wood**, referring to industrial uses of the heat pump, wrote : Mr. Bunting, in his address, referred to the heat pump which has received considerable attention recently in its application as a space-heating machine. Space heating is not, however, the most favourable field of utilisation ; industry may offer much better opportunities. As is generally known, the heat pump can raise heat from a lower grade to higher, by supplying mechanical energy. The ratio of the heat made available to the heat value of the mechanical input is known as the coefficient of performance and is a measure of the efficiency. For pumping up heat from a source temperature of, say,  $40^{\circ}$  to  $140^{\circ}$  F. for

space heating a C.O.P. of about  $3\frac{1}{2}$  is a practical figure which means that about  $3\frac{1}{2}$  times as much heat is made available as the heat value of the energy supplied.

While this may seem to be something for nothing, it must be remembered that if the energy is generated by condensing machines the efficiency of derivation from the original heat in the coal, will be only about 25 per cent., taking an average generating plant and allowing for distribution losses. The net result is that no more than the heat in the fuel is finally made available by the heat pump. Moreover, the load factor of heating load is relatively poor (not higher than 50 per cent.) so that the high capital cost of the heat pump and of the generating station which supplies it, is spread over only half the year. For this reason it is difficult for the heat pump to compete with an efficient stove or central-heating boiler, except under conditions specially favourable to the heat pump.

Turning now to the industrial applications we have a completely different set of circumstances. In many cases the process will operate over the greater part of the year with the result that the incidence of financial charges is reduced. Even more important is that the heat pump can often be driven by a back-pressure steam turbine or by an electric motor receiving power generated in back-pressure turbines. In these cases (since the exhaust heat of the turbine is utilised) the driving energy is produced at a very high efficiency. The heat pump can accordingly really produce something for nothing. It can, for instance, pump up low-grade heat which must otherwise be entirely wasted, such as the heat in the vapours from drying operations or in warm effluents at a temperature too low for recovery by heat exchangers. This heat can be raised to a level suitable for process purposes. A special case is in evaporating processes where the vapour given off (generally water vapour) is recompressed into the heating coil and there condensed at the higher pressure giving up its latent heat to cause a further equal quantity of vapour to be evaporated in the pan. This process is extraordinarily efficient, since the temperature difference through which the heat pump is required to work is only that across the heating coil, say  $10^{\circ}$  or  $20^{\circ}$  F. As is well known, the C.O.P. is ideally proportional to the ratio of the upper temperature (absolute) to the difference of temperature. Coefficients of the order of 10 or 20 are practicable. This means that for a moderate outlay of capital, a pound of coal can be made to do the work of many pounds.

With vapours the volumes are large enough to justify the use of rotary compressors of axial flow design running at high speed with which a very good efficiency can be obtained. When, as is usual in industry, the utilisation factor is high and electrical energy is available at low price, such plant is competitive with multi-effect evaporators. The space occupied is much less, and since there is only one evaporator vessel, its temperature being approximately that of the last evaporator in multi-effect plant, the temperature will be much lower than that of the first effect. Hence there is less danger of burning the product.

Plants of this nature are not new to this country ; there are several installed in chemical works. However, the possibilities in this direction do not seem to have been widely appreciated. They came to the fore in Switzerland during the war owing to the very serious shortage of coal and its high price, in the region of £8 per ton. A considerable number of evaporating plants producing pharmaceutical chemicals, salt, condensed milk, or fruit juices, were changed

over from fuel firing to compressor evaporation. In many cases an improvement of the quality of the product resulted, and the commercial success of the plant will remain assured even when coal becomes plentiful. The method is most advantageously applied to solutions of high boiling point and to those in which the boiling point does not rise much with concentration.

Another interesting example from Switzerland is the use of a heat pump for recovering the heat in the vapours passing from the dryer section of a paper machine at Landquart paper mill.

Lest it should be thought that all these developments are associated only with low price electricity generated from water power, it is worth mentioning that a usual price of electricity in Switzerland, 3·5 centimes per kWh, is higher than the cost of generation in this country in back-pressure steam plant. A rough rule is that compressor evaporation pays on fuel consumption where the cost of electricity per 1,000 kWh is less than that of a ton of coal.

## SECTION B. STEAM UTILISATION—*continued*

### SESSION II. Where Power and Steam Needs Nearly Balance

*Chairman of Session:* MR. CUTHBERT DIXON,  
DEPUTY PRESIDENT OF THE PAPER MAKERS' ASSOCIATION

**T**HE CHAIRMAN: The Paper and Board Making Industry has always been mindful of the saving of coal, as it represents quite an appreciable cost in our conversion of turning pulp into paper or board, in fact, in our industry the "needs" in the title of this Session means "has to".

This Session is considering specially the undertakings whose power and heat requirements are practically in balance, i.e. where there is a case for domestic generation of electricity and the use for process and space heating purposes of the pass-out, or back-pressure steam. It is well known that the overall thermal efficiency of a condensing turbine has now reached a figure of approximately 30 per cent., but if a works' requirements for power and lighting can be generated by an engine, and the exhaust steam be totally and efficiently utilised for works' purposes, then very high overall efficiencies in the region of 70 per cent. can be obtained.

Great economies have been made in the paper, laundry and chemical industries and in hospitals during the last few years, and we shall hear how some of these savings have been made and observations upon the scope for economy which could be made during the next five or seven years. Our main theme is the efficient utilisation of pass-out or back-pressure steam and how a good overall thermal balance for a works can be effected.

#### 1. The Paper and Board Makers' View of Fuel and the Future

By R. G. SANDS, M.I.MECH.E., F.R.S.A., M.INST.F.

We do not need to be reminded of the necessity to examine the future facing our industry in respect of fuel. Indeed, fuel has always been one of our primary concerns, and constitutes a commodity which we must have at our mills before ever one can consider how we are to make paper.

There are unhappy recollections of years ago (and not so long ago either), when we had to pay more for our home-produced fuel than did those of our pulp and papermaking friends abroad, to whom our coal was exported, and we had to exercise our ingenuity to produce a saleable commodity at a bare living price.

It is not surprising, therefore, that we have long been cognisant of the need to extract all we can from this source of energy, and have directed our efforts to this end. Unfortunately, as time goes on the aspect seems to take on a hue more closely resembling that of the fuel itself! This is no exaggeration, and is obvious to anyone when it is known that fuel stocks in some mills recently

have been as low as the equivalent of one week's steaming load, and this, in the so-called summer months, and the mill operating at reduced capacity due to raw material quota restrictions.

Thus it is, our efforts have been redoubled and our Fuel Economy Committee are rendering a great service to the industry in focussing attention on possible sources of further benefits.

It may be useful to view some of these in retrospect, and to consider today how far we have gone, and how much further we might hope to progress in this direction.

Our industry is one where our fuel is converted to both power and heat energy, and often in such cases one hears glib phrases such as "power and heat balance", and recommendations that such a balance should be maintained for maximum economy. It is true that such recommendations are well to the fore in our consideration, but by those outside our industry and our ministerial friends, it should be appreciated that this "balance" target is one which must be qualified by the circumstances.

After all, papermaking embraces not only the manufacture of paper and board, but paper and board conversion, and the manufacture of specialities from this material, such as packaging supplies, cartons and containers. Furthermore, such conversion processes may be carried on in departments or factories adjacent to, or forming part of, a making mill, and the process or heat load in such combined circumstances is vastly different to that pertaining to a straight making mill.

Again, segregating for the moment the making mill from ancillary processing plant, we can have quite appreciably different circumstances attending say a large newsprint mill with high-speed machines, and a small fine mill with narrow slow-running machines running on fine quality or speciality productions.

Rather would one emphasise that we obtain, and shall improve, the overall optimum result within our industry if each undertaking assesses its own so-called "balance", formulating this within the general principles found to be fairly widely applicable to the production of this commodity, correlating the useful work done with the total energy available, and, withal, utilising our existing plant as it is at present installed. This, after all, is our target, and is a measure of overall efficiency rather than any specific balance between two forms of energy.

Let us now briefly review where our attention in this field should be focussed in relation to our productions.

Initially, with our fuel we generate steam because its heat carrying capacity, coupled with the fact that it can be compressed and expanded according to well-known laws, makes it an efficient agent for transmitting energy. In the majority of mills power is generated for the whole organisation taking advantage of the kinetic energy in the steam to drive turbo-generators, turbo-alternators, or steam engines of various types, the prime mover employed depending on the size of the mill and the duty to be performed. Some mills will have "all-electric" drives throughout, both for making machines and auxiliaries, whereas others will have a combination such as a central power house for generation of electricity for certain sections, with compound engines for the machine drives and for driving beaters and other preparatory plant from common line-shafting. Such a combination in some cases shows a higher efficiency than the "all-electric" mill, bearing in mind the type of production, load, and operating cycles.



The question as to whether turbines and engines should run condensing, or should be of the pass-out or extraction type, is, again, a question of the special conditions prevailing with the type of production. For instance, where the power demand is higher in relation to the heating demand, a condensing set would be more applicable. Where the heating demand is relatively higher, pass-out operation is, obviously, more attractive. Again, one set condensing, and one pass-out set, or some such combination would be best. The type of stock processed has a bearing on this consideration, as the beating or preparation of the stock varies quite appreciably—kraft and other quality papers requiring a greater amount of work to be expended on them than on, say, waste paper furnishes.

The economic utilisation of heat and power in paper mills formed the subject of a very valuable paper and discussion before the Technical Section<sup>1</sup> and complementary to this was a similar contribution on the subject of "Electric Driving in the Paper Mill on Heat Economy Lines"<sup>2</sup> both being based on conditions some 25 years ago. Although circumstances have vastly changed, the fundamentals still remain true today, and, whilst we must make correction for present day costs, simultaneously we should make allowance for the increased efficiencies that have been obtained over this period. Reference to these works is made to indicate with what importance this subject has been regarded by us, and to emphasise the lengthy period over which we have been closely studying fuel economy. These studies have resulted in steady improvement throughout the industry brought about by expenditure of capital on new plant and modifications to existing equipment, notwithstanding the handicap of difficult times between the two wars.

As a conveyor of heat energy, steam is used in the paper industry for process work, such as the "cooking" of wood chips, rags, esparto grass, straw, etc., as well as waste paper, to produce the various kinds of pulp. It is also used for drying the paper or board, to heat stock, liquids, chemicals, etc., and to heat and condition the air in the machine rooms and other parts of the mill, as well as adjacent factories and buildings. The employment of this heat energy for these various duties has received just as much attention as the boilerhouse and power generation side, our object in so doing being to extract the maximum heat units available, as well as equalising as far as possible the balance between the two demands.

With the heat conveying system, that is to say, the steam and condenser mains, traps, etc., the obvious economy of lagging these with heat insulating material formed a natural procedure to adopt initially, and closer attention has been given to this, as suggested in the memorandum issued by our industry.<sup>3</sup>

The raw material "cooking" process presented certain problems when supplies of esparto grass were cut off, and we had to turn over largely to straw, and to adapt as far as possible the plant existing for this purpose. The digestion of straw requires more steam per ton of pulp than when "cooking" esparto, and it has to be boiled at a higher pressure and for a longer time. Here is a case where we are faced with an increased heat demand solely to utilise a different raw material, and every effort is being made to limit the additional steam demands. Where pass-out steam is available this is used for the initial heating of the charge, and only when the temperature limit of the low-pressure steam is reached, is the high-pressure steam admitted. In some cases it has been found possible, with well lagged digesters, to shut off the steam entirely when the charge has reached the required temperature, and allow the

“cooking” process to proceed without the addition of further steam. Here again, it is obvious the procedure adopted affects the so-called “heat balance” of the mill. Further suggestions to utilise the heat in the increased steam demand in this process are dealt with fully in the memorandum already mentioned.<sup>3</sup> Similarly, reference is made to possible economies with the evaporating plant.

Coming now to the largest heat demand units, we all know what concentration of thought and effort has been applied to the dryer parts of paper and board-making machines. Coincidental, and indeed intimately related with this, has been the investigation into improved efficiencies on the wet end. Whilst the wet end does not call for any appreciable supply of heat units, its importance is due to the fact that the more water that can be removed from the stock on the wet end the less is there to be evaporated on the dryer part by the application of heat. To the uninitiated this appears to be simply a question of vacuum and additional pressure, but to those of us concerned with the production of paper we are only too well aware of the limits to the removal of water on the wet end by mechanical means, and the vital importance of fibre formation, etc., which can so easily be mutilated by the application of excessive vacuum or pressure with the web in a wet state.

The importance of this aspect, and the result of investigations in this connection, have previously been dealt with<sup>4</sup> and these show that if the moisture content of the web entering the dryer part is increased from 64 per cent. to 70 per cent., the increase in the steam demand for the drying cylinders is of the order of 35 per cent.

W. G. MacNaughton<sup>9</sup> has reported on the results of studies made for the purpose of determining to what extent steam can be saved by better water removal by the press part. The observations recorded apply to actual operating conditions and are most informative on the effectiveness of presses, both plain and suction types, and demonstrate the economics attending the removal of water by mechanical means, as compared with that removed by the application of heat.

With all the improvements we have so far been able to make on the wet end we are still faced with the fact that on the dryer part, by the application of heat, we have to remove approximately 2 lb. of water for every pound of dry paper or board produced. With machines producing up to 12 tons of board per hour it is not surprising that this part of our process and unit of equipment has formed the subject of close and numerous studies. Among these the following considerations have been and can be instrumental in achieving the result we seek.

*Considerations affecting steam pressures to be used in the drying cylinders forming the dryer part.*—T. R. Young<sup>4</sup> has summarised the advantages of designing a dryer part to use as low a steam pressure as possible, and has, at the same time, emphasised other factors which should receive simultaneous consideration. He has also shown that the use of superheated steam is of no advantage to the drying process, and in some respects may be definitely undesirable. The amount of steam supplied to the dryers is no correct measure of the work done by it, unless we consider the amount of condensate and steam leaving the drainage system. In a true sense the proper gauge is the number of heat units actually transferred to the dryers per pound of water evaporated from the web per square foot of dryer surface, and this fact is probably more appreciated today than was perhaps the case some years ago.

*Steam quality.*—The quality of the steam supply to drying cylinders has an important effect on their drying efficiency. The condensate from the cylinders is returned to the boilers for two reasons additional to the thermal consideration, these being that it is pure water and requires no treatment (assuming that it is not contaminated with oil from engines), and when returned hot, it has little entrained non-condensable gases, and it is most important that steam used in the dryers should have as little as possible. T. R. Young<sup>4</sup> deals with this aspect and shows the effect of the presence of air in the steam on the surface temperature of the dryer cylinder, and recommends the practical precautions to be taken to avoid the entrainment of air, at the same time emphasising the difficulties attending the total elimination of such air.

Tatley<sup>5</sup> mentions the amount of air in the steam entering dryers on a certain test to vary between 0·0025 per cent. and 0·005 per cent. by volume. Assuming the latter figure, this would mean a 4 ft. diameter cylinder having a 96 in. face condensing an average of 360 lb. per hour, would contain 10 per cent. air in about 30 hours if no provision were made to eliminate it. (More air would reduce this time.) This amount would reduce the steam temperature in the dryer from about 240° F. to 233° F. and decrease the heat transfer to the cylinder by about 30 per cent.

The satisfactory elimination of air, the employment of flash steam, and the paramount need to raise the dryer part of the papermaking machine to its maximum efficiency, without drastic alteration to the arrangement of the machines, has been instrumental in concentrating attention on cylinder drainage systems, and there is now available a wealth of information on this subject.

At our Fifty-first General Conference the respective merits of the two widest known systems of cylinder drainage were much discussed, and in the report of this conference much practical data has been published. The Ministry of Fuel had earlier been made cognisant of the fact that we are endeavouring to take full advantage of such technical information by putting it to practical use within the limits of the restrictions still imposed upon us in regard to materials and labour, evidence of this being apparent by the reference to a dryer stage heating system in their publication "The Efficient Use of Fuel".<sup>6</sup> This heating system is one of those already referred to, the other being a system employing independent trapping of each cylinder.

The stage heating system, undoubtedly, shows many advantages over the older system, and the principle upon which it works ensures maximum heat economy with lower steam pressures, and this brings us nearer to our target. There are, of course, certain advantages also attending those systems utilising individual steam traps, among these being lower first cost of installation, and wider variation of adjustment on individual cylinders but we must take the long view and weigh carefully every consideration both for and against each system as applied to the different classes of production and machines employed.

An admirable comparison of cylinder drainage systems with a clear exposition of the fundamentals involved has already been made by R. P. Nuki<sup>7</sup> and is available for reference. These systems, of course, are those applicable to multi-cylinder dryer parts, with cylinders arranged either horizontally in 2 or 3 tiers, or in vertical stacks.

Somewhat different circumstances apply to Yankee or M.G. machines where the main drying is performed on one large cylinder of 10 ft., 12 ft., or 15 ft. diameter. Whilst the fundamental principle remains true in so far as

the employment of heat units is concerned, we have a very much larger volume within the cylinder, and this, naturally, reflects on the ease with which air or non-condensing gases can be contained, and, conversely, adds to the difficulty of their removal. Very often, in the past, higher pressure steam had to be supplied to the cylinder in order to compensate for the inefficiency of heat transfer due to the presence of this air, as has already been demonstrated. This has led to the introduction of a new type of construction with the cylinder itself, which enables the steam to be retained in an annular space between the outer and an inner shell, this space being quite small, and of the order of 2 in. or so, thus obviating the large volume within the cylinder hitherto regarded as essential. With the lower steam pressures this construction permits, thinner shell plates can be employed which give a better heat transfer in accordance with Fourier's Law. Flash steam from such machines where there is no other drying stage in which it could be utilised, can be employed in the ventilation plant for the machine house.

Affecting the overall efficiency of the dryer part, consisting of multi-cylinder dryers, as well as M.G. or Yankee cylinders, is the rapid removal of the water as it is evaporated from the web, and this brings us to consideration of vapour extraction and/or vapour absorption equipment, which, to a certain extent, can be regarded as auxiliary to the machine and to the machine house as a whole.

The quantity of water vaporised has been mentioned, and this in itself contains heat, that is, latent heat of vaporisation. This potential source of heat recovery it is possible can be exploited with advantage. The principles underlying such recovery are described in Memorandum No. 2 issued by our Fuel Economy Committee<sup>3</sup> and work already done in this direction formed the subject of notes presented and discussed at our Forty-fourth General Conference in 1942.<sup>8</sup> Since then further investigations have been undertaken and are progressing in an endeavour to increase the efficiency of recovery with smaller equipment and corresponding lower first cost and maintenance charges.

Coincidental with this is the question of ventilation of machine houses and mill buildings. It is felt that if a greater measure of control can be exercised over the conditions prevailing round the drying cylinders of machines, and the water vapour driven off handled more expeditiously and at higher relative humidities, the total ventilation requirements can be reduced, with, again, corresponding economies in heat units, as well as in power required to operate the plant.

With M.G. cylinder machines similar means of controlling the moisture given off on the cylinder, and the application of a close fitting hood or enclosure will not only improve and increase production, but will obtain this at a more economical rate. This is achieved by taking advantage of the heat around the cylinder and within the hood or enclosure, and arranging for hot air to be recirculated to a maximum. The amount of air exhausted for the purpose of removing the moisture, and the corresponding make-up air, can be kept to a minimum by automatic control features applied to operate with any change in the relative humidity prevailing within the enclosure. The proper application of hot air in this way will carry its share of the drying capacity of any M.G. cylinder to the extent of from 15 to 25 per cent.

It is as well to appreciate the beneficial results to be obtained by well designed ventilation systems which can assist the functioning of the machines within

the buildings, maintain good conditions for the operatives, reduce maintenance costs, and retard deterioration of the building structures. In this respect time spent in determining the best type of construction to employ from a thermal aspect will always prove a good investment, and if it is possible so to construct the buildings as to reduce radiation and other losses, the savings effected under operating conditions are continuous. Similarly, careful thought given to the ventilation in terms of air change will be amply repaid, for all air extracted must be replaced, and during the winter months must be heated, so that the smaller one can keep the quantity of air handled, the less heat and power will be needed.

The various types of plant or systems have different advantages to commend them, and these should be compared alongside the specific conditions likely to prevail. It may be that a combination of systems will prove the best, but this can only be determined by comparison and study of the overall thermal performance applicable to both summer and winter periods.

Again, the heating medium employed should be that calculated to give the best overall economy. We have already referred to the availability of low-pressure steam in mills, and, possibly, this is always taken for granted. There are occasions, however, when the mill buildings and converting factories cover a very large area, and each addition must, of necessity, be made further from the boilerhouse and powerhouse, and, due to this, difficulties are experienced in returning all the condensate. Or, again, it may be quite possible practically to return the condensate, but the losses and cost entailed cause it to be uneconomical, even when compared with the alternative of discharging the condensate to waste. In such circumstances it would, undoubtedly, prove satisfactory to install a closed system employing high-pressure hot water as the heating medium.

Existing systems can be converted to the use of such a medium, and the savings effected would be both thermal and financial.

In converting and coating factories there are special drying processes involved, and full advantage should be taken of what might be termed "stage" or "zone" drying, so that maximum recirculation of hot air can be employed. Similarly, with the increase in production speeds now made possible in the mechanical process, straight path or tunnel type dryers embodying heat insulated housings can prove very economical in running, although perhaps their first cost is higher than the older type of festooning gear and drying rooms.

In all these ways we are directing our efforts still further to improve the efficiency of energy utilisation in our industry, and, as already shown, no item is too small for our attention.

#### *References*

- 1 Economic Utilisation of Heat and Power in Paper Mills. W. Adamson. Proc. Tech. Sect., Vol. I, Part 1, March, 1921. Vol. I, Part 2, August, 1921.
- 2 Electric Driving in the Paper Mill on Heat-Economy Lines. A. B. Mallinson. Proc. Tech. Sect., Vol. II, Part 1, December, 1921.
- 3 Memorandum No. 2, Fuel Economy Committee, Paper Makers' Association. June, 1943.
- 4 Notes on Factors affecting the Drying of Machine-made Papers. T. R. Young. Technical Section 51st General Conference, 1946.
- 5 Distribution of Uncondensed Gases in Paper Machine Dryers. L. D. Tatley. Pulp and Paper Magazine of Canada, January, 1927.
- 6 The Efficient Use of Fuel. H.M. Stationery Office. Page 582.
- 7 Individual Steam Traps or Stage Heating System. R. P. Nuki. Technical Supplement, World's Paper Trade Review, 24th May, 1946.
- 8 Heat Interchangers. Fuel Economies resulting from their Use. R. G. Sands. Proc. Tech. Sect., Vol. XXIII, page 60.
- 9 Steam saved by better Water Removal at the Presses. W. G. MacNaughton. T.A.P.P.I. Proceedings, Series 25, No. 1, 1942.

**Mr. T. R. Young:** Mr. Sands has drawn a very clear picture of conditions in Paper and Board Mills, and the rather widely varying steam and power requirements which exist between one mill and another.

Because of the comparatively high ratio of coal required per ton of paper made—from 12 cwt. to two or more tons of coal per ton of paper, according to the quality of paper produced—the papermaking industry has always been very fuel-conscious. Furthermore, competition in the trade has always been keen, and I think I am correct in saying that few, if any, spectacular profits were being made by any paper mills in the years prior to the war.

In view of the high power requirement of paper mills, coupled with a high demand for process steam, it is the universal practice to generate our own power, either by back-pressure reciprocating engines or pass-out turbines. We are then able to operate on an overall thermal efficiency considerably higher than even in the most efficient grid stations, efficiencies of 40 per cent. to 60 per cent. being attained in some mills.

As Mr. Sands rightly points out, however, “it is seldom possible to obtain the ideal of a power and heat balance” owing to the widely varying treatment required for different grades of paper. The nearest approach to balanced conditions would be found in newsprint mills, where the plant has been laid out to obtain the most economic results when making a particular grade of paper. In mixed mills, however, we find that some papers require a large expenditure of power in preparing the stock and comparatively little steam for process and drying, and vice versa.

For this reason, therefore, the pass-out turbine holds the field as the most suitable power unit for paper mills, where of course, the power load is within the economical range of this type of prime mover.

In spite of all that has been done in the past, however, I think we must realise that what might have passed for good efficiency before the war, will not do now with coal at its present price, and that ideas regarding improvements which may have been shelved on account of capital expense may well repay re-investigation.

Looking into the future, I think that generally speaking, for further economies in fuel used per ton of paper produced in the paper and board-making industry, we must look to :

- (a) Higher steam generating pressures.
- (b) More efficient drying or, rather, efficient methods of re-harnessing the heat used for drying on the lines suggested in our Fuel Economy Memorandum No. 2, and discussed by Mr. Sands.
- (c) The utilisation by heat exchange of the heat at present lost up the chimney for, say, machine room conditioning.
- (d) The smoothing-out of peak steam demands which have such a bad effect on the maintenance of efficient steam generation. I have in mind here the possible use of steam accumulators.
- (e) The greatest possible use of flash steam.
- (f) Lastly, but by no means least, improvements in the design of the plant used for preparing the stock with the object of making a saving in the power used per ton of stock treated, and improvements in the design of the papermaking machine itself to enable still higher speeds to be attained without sacrificing running efficiency or quality of production.

In this connection, although I have previously quoted possible overall thermal efficiencies of 65 per cent., this is really no criterion of efficiency of production. It is obviously quite possible to attain high thermal efficiencies, and yet, because of unsuitable or obsolete papermaking plant, the real efficiency, i.e. coal used/ton of paper made, may be poor. It is essential, therefore, that we make use of all devices and improvements which help to increase the rate of production.

It seems that we in industry, however, are being continually urged to improve our combustion efficiency, while there is no apparent corresponding effort on the part of the Ministry to see that we get a class of fuel which can be efficiently used in our respective plants. We know well there are difficulties, but I cannot help feeling that they are at least no greater than the troubles we have had to shoulder in coming to decisions regarding possible improvements to steam-raising plant, while not knowing what type of fuel we may be required to accept from time to time.

**Mr. R. H. Brennan :** Mr. Sands has rightly said in his excellent paper that " we do not need to be reminded of the necessity to examine the future facing our industry in respect of fuel ". To those of us who are responsible for supplying steam to the mills, it is a constant nightmare, but unfortunately there is no prospect of a pleasant awakening to find it was all a dream.

Twenty-five years ago, the late Mr. W. Adamson in a paper read at a Conference held by the Technical Section of the Paper Makers' Association said : " The time has come when it is very necessary that the source of heat and power, which in this country is coal, should be economised to the greatest possible extent. Until recently coal has been so plentiful and so cheap, that the question of its economic use was not very pressing, but in view of the present shortage of supplies, the rising prices, and our ever dwindling national reserves, the question becomes one of the greatest importance ". Those words exactly fit the situation today and I think it is a tribute to the papermaking industry that they were fuel-conscious and were striving for fuel economy for many years before the present crisis arose. Much progress has been made.

In the boilerhouse more efficient methods of burning coal have been introduced and in a number of mills boiler efficiencies are of the order of 80 per cent. In a good many mills pass-out turbines have been installed using high-pressure steam to generate power and passing out the steam at low pressure for process work. The suction couch and the suction press have replaced the old plain ones, and by these means the moisture content of the sheet entering the dryers has been reduced to almost the practical minimum, thus reducing the quantity of steam needed for drying.

Where then shall we look for further economy ? We have been given several answers to this question. One is that we should instal heat recovery plant to extract the heat in the vapour from the dryers. The idea is good ; there are millions of heat units going up in the air but unfortunately it is impracticable for many mills, partly owing to lack of space and partly because of the cost.

Again we are told " Instal a stage heating system, or individual cylinder trapping with air venting ", and here I think is part of the answer to our problem of saving steam. I have no first-hand knowledge of individual trapping but one of the most efficient machines I know is fitted with a stage heating system.

However, before we can carry out any economic reforms, we must first

find out what is wrong and where steam is being wasted, in other words, work out a heat balance. Mr. Oliver Lyle wrote an excellent paper on this subject entitled "The Construction of a Heat Balance without Instruments", and that paper is well worth studying. Mr. Lyle states the three necessary figures as (1) heat input, (2) heat usage, and (3) heat requirements. No. 3 he calls Bogey and is the minimum amount of heat that should be required for the particular unit being investigated. This figure when compared with the heat input and the heat usage will show how much more is being used than is necessary and is a starting point towards economy.

Mr. T. R. Young, in his "Notes on Factors affecting the Drying of Machine-made Papers", has given some valuable information on the effect of air in the steam, but I sometimes wonder if air in the machine cylinders does really accumulate in any quantity. In many boilerhouses de-aerators are installed to remove dissolved gases from the feed water and even though some CO<sub>2</sub> may be formed in the boiler, the amount is small. Further, I am not convinced that when steam is condensed in the drying cylinders all the non-condensable gases remain in the cylinder. Is it not probable that a proportion of them will be re-absorbed by the condensate and pass with it from the cylinder?

Another factor to be considered is the possible wetness of the steam. This cannot be detected by a fall in temperature, as is the case with air, but, unless we know the dryness fraction of the steam, the results of condensate measurement will be misleading. It is the latent heat of steam which is used for heating and drying, and if steam has a dryness fraction of 0.9 then only 90 per cent. of the steam is available.

In preparation for the future, let us first put our existing plant into efficient working order before spending large sums of money on additional plant.

In conclusion I would suggest that in addition to the boilerhouse personnel and engineering staff, the papermakers should be given a course of training in steam utilisation. It is all wrong that the people who use most of the steam should know least about it.

## 2. Immediate and Future Aims of the Laundry Industry

By F. COURTNEY HARWOOD, DIRECTOR OF RESEARCH,  
BRITISH LAUNDERERS' RESEARCH ASSOCIATION

The aggregate consumption of fuel by small steam-raising plants is of considerable magnitude, and in the laundry industry the total annual consumption of solid fuel amounts to approximately 1,000,000 tons. A relatively small percentage saving effected over the whole industry would thus be a real contribution to the national effort: we hope that it will be possible to achieve savings which will be of no mean order. Most of the fuel which is consumed by the laundry industry is used in small or relatively small boiler plant operating at low pressures, i.e. not, in general, exceeding 125 lb./sq. in. The efficiency with which steam is produced is of obvious importance—that problem is common to *all* industries whether steam is produced for use as power or is utilised almost entirely for process work. But since the bulk of the steam-raising plant in the laundry industry is small, there is not the same opportunity of achieving economy by the fitting of large or elaborate accessories to the steam-raising plant; rather is economy to be achieved by paying attention to the



simple details of operation, which are so often easily overlooked. For many years, we have preached the avoidance of waste and the use of the most efficient laundering processes which science can devise: from experiment and from data collected over many plants in all parts of the British Isles, we have established figures which serve as a yardstick to assess the efficiency with which the average plant is being operated.

Apart from soap and other detergents, the two chief "raw materials" of the launderer are water and steam. Economy in the use of water in the laundry obviously leads to a reduction in the fuel and power consumed at the water company's plant. It has been found that a consumption of  $4\frac{1}{2}$  gallons of water per pound of work washed should be adequate for a normal process, and even if the work is abnormally soiled, 5 gallons of water per pound of work washed should suffice. New washing processes based on the results of fundamental research carried out at our Hendon Laboratories were introduced a few years ago and resulted in a 20 per cent. saving in the water normally consumed, about 40 per cent. reduction in the amount of soap required and a considerable reduction in the process time. These factors all materially contributed either directly or indirectly to a saving in fuel and power. There were other developments, amongst which might be mentioned the introduction of a hydro-rinsing device for use with woollen garments which resulted in a saving of approximately 50 per cent. of the total volume of water used for washing and rinsing.

As long ago as 1934 the Research Association investigated the question of water reclamation and issued a special bulletin on the subject dealing with the plant required and the savings in water to be expected if the second and third rinses were reclaimed and returned to the hot water storage tank. Approximately 120 gallons or 32 per cent. of the water used to wash and rinse 100 lb. of white work could thus be saved and the average temperature of such water would be in the region of  $120^{\circ}$  F. Thus if the temperature of the cold water supply were  $60^{\circ}$  F., the amount of heat directly reclaimed would be of the order of 72,000 B.Th.U. for every 100 lb. of laundered white work. I mention these examples to emphasise the point that in every process where steam and water are employed, considerable economies in the amount of fuel consumed nationally can be effected indirectly as well as directly.

The direct economies in fuel which can be achieved by attention to detail in the operation of the boiler plant and in the distribution of steam have been admirably covered in the bulletins issued by the Ministry of Fuel and Power in recent years and apply to all types of industry. But may I just mention that in 1939 the British Launderers' Research Association issued a communication to laundry members pointing out that if more than 6 to 7 lb. of steam per pound of work processed were being used (or slightly more if the work was largely machine-finished) then—

(a) all fittings should be examined for leakage. A hole  $\frac{1}{8}$ -in. in diameter in a pipe line carrying steam at 100 lb./sq. in. would waste 73 lb. of steam an hour or approximately 1 cwt. of coal a day.

(b) all steam and hot water pipes and hot water storage tanks should be adequately lagged. A 1,000-gallon hot-water storage tank measuring 8 ft.  $\times$  5 ft.  $\times$  4 ft., holding water at  $180^{\circ}$  F. (the usual temperature) would, if unlagged, lose 45,000 B.Th.U. an hour, equivalent to some  $9\frac{1}{2}$  tons of coal a working year.

(c) All condensate from finishing machines, drying equipment and the like should be returned to the boiler feed water tank.

These and similar recommendations made over a period of years have resulted in considerable savings in fuel. I would mention that the Research Association has a staff of qualified technical officers whose duty it is to visit all member laundries and to advise on any technical problems which may arise. As may be imagined fuel economy through efficient steam raising and efficient steam utilisation has been well to the fore during the past few years.

The laundry industry affords a good example of the conditions where power and steam needs nearly balance. If the laundry generates its own power, the exhaust steam from the engine is, generally speaking, sufficient to provide for all the laundry's requirements in hot water. All the exhaust heat can be used in the laundry processes.

Having briefly summarised what has been going on in the laundry industry to achieve some measure of fuel economy I come to the question of what is our immediate target?

I have already mentioned that the annual consumption of solid fuel in the laundry industry is about 1,000,000 tons. We have found from experience over a number of years that an average laundry dealing with the normal run of soiled work can process one pound of dry soiled goods for every pound of fuel consumed, provided that the calorific value of such fuel is not low. In other words, 11,000 to 12,000 B.Th.U. are required per lb. of work processed. As the Laundry Panel point out, this is conditional upon the plant being worked to full capacity. Unfortunately, many laundries today, particularly in the London area, are painfully short of labour and this inevitably means that during some period of the week, at least, their plant cannot be worked to full capacity and, in such instances, a good measure of fuel efficiency cannot be expected.

From the Ministry's statistics, it would seem that the ratio of fuel consumed to work processed averages 1.5 : 1 throughout the country. The immediate aim therefore is to achieve an overall reduction to a ratio of 1 : 1, by the application of improvements in the methods of steam-raising and steam utilisation—and particularly in the latter. The potential target therefore is a saving of some 300,000 tons of fuel per annum.

The target for the future is a much more difficult one—no less than a reduction to 0.6 lb. of fuel per lb. of work processed. This will in most cases involve very considerable capital expenditure on reorganisation of plant or the installation of new equipment : and I am sure I need not remind you that licences to undertake structural alterations are not exactly easy to obtain !—nor is new machinery readily available at the present moment.

That the target can be achieved in practice has been proved in one or two instances where the laundry was reorganised just prior to the war, the most up-to-date steam plant installed and particular attention given to the utilisation of steam in process work. A word of caution is necessary, however. In some cases, the amount of expenditure required to achieve this long range target may prove to be quite an uneconomical proposition. We shall, nevertheless, continue to aim at the target. Preliminary suggestions as to how the target may be achieved are given in the Ministry's booklet "Laundering and Coal". Heat and water reclamation are mentioned : I would like to add this—that arrangements have just been made to investigate a system for recovering or

re-using all the warm or hot water used in the laundering process. If this system proves successful, there will be no necessity for heat exchangers : heat units and water will be recovered together !

### 3. "Laundering and Coal"

By W. O. GOLDTHORPE, M.SC.

Mr. Goldthorpe introduced a bulletin on fuel efficiency in the laundry having the above title :

The Laundry Industry uses about one million tons of coal a year and additional quantities of coke. Shortage of labour is causing plant to be worked below capacity with consequent use of more fuel for every pound of work laundered. Until maximum output is obtained from laundry plants the best return from the fuel used cannot be expected.

At the same time, by adopting simple methods as given in this bulletin, an immediate annual saving of 300,000 tons is envisaged. It is intended to show not only how fuel can be saved in the immediate future but also to indicate how, by forward planning, new plant can be made to fit into a plan for fuel economy.

Recommendations are in three sections : the first deals with waste which can be avoided by individuals, including both production management and workers ; the second with economies which can be effected by minor alterations to plant ; and the third section with planning for the future.

In beginning a study of fuel economy in any laundry it is necessary to know the present standard of efficiency. The weight of work processed and the weight of equivalent fuel used should be determined. The ratio between these two weights forms the simplest yardstick. It is indeed difficult to envisage any other standard of measurement. The equivalent weight of fuel consumed weekly divided by the weight of work, both in lb. weight, should be 1 or under when working to full capacity, or to be more explicit, the heat ratio should be 11,000–12,000 B.Th.U. per lb. of work or less. This target, it is emphasised, can be achieved without any deterioration in the quality of the work produced. There are even now a number of laundries with a ratio of 0.75. A few work at 0.6, many operate at 1, but there are far too many working at between 1 and 2. From the statistics available it is evident that the present average fuel consumption is  $1\frac{1}{2}$  lb. per lb. of work processed.

After prolonged discussion of all the factors involved, the panel agreed that if fuel is to be conserved this winter, it would be more rational to place before the industry a target which is capable of achievement by most laundries, and this short range target for the next year was agreed at 1 lb. per lb. and would give a reduction in the consumption of fuel by one-third, i.e., 300,000 tons annually.

To attain this target it is suggested that each department should be studied in turn, the main purpose of this bulletin being to offer suggestions for economy in heat utilisation. Many suggestions for reduction of waste by individual users are given in the bulletin but in particular washhouse waste can be avoided by using a standardised washing process, and by loading machines correctly, since underloading is a waste of heat, water and materials. The waste of hot

water should be checked. In the finishing department each machine should be used to its full capacity and when not required, must be shut down.

The second part of the bulletin deals with putting the plant and processes in a state of efficiency so far as it is possible to do so by minor plant alterations and process changes.

In plans for future development must be included all the points mentioned earlier in the bulletin but by making a serious study the future target that may be achieved is slightly under 0·6 lb. of fuel per lb. of work or 6,500–7,000 B.Th.U. per lb. of work. This target is not yet within the reach of the majority of laundries since it may involve wholesale reorganisation of their plants and for this reason it must be a long-range target. Included in such reorganisation must be the decision regarding power generation. This is a matter of economics and price but if it is decided to rely on generation of power within the laundry then all the heat exhausted from the engine may be usefully used for processing.

It is the intention to set out in much greater detail how this long range target figure can be reached in a future booklet but the various factors involved and the basic data upon which the minimum heat requirements stated have been based are listed below :—

(1) A boiler efficiency of 75 per cent. is envisaged. This entails close control of steam generation, with instrumentation of the boilerhouse.

(2) Standardised washing processes such as those recommended by the B.L.R.A. should be installed.

(3) Attention should be given to reclamation of heat from the liquors passed to drain from the washing machines. Probably the best system will be to have separate drains so that the mixed wash and first rinse liquors are passed into one drain and then through a heat exchanger. The question of dealing with the other rinses is under discussion.

(4) The use of hydro-extractors which reduce the moisture present in the load to 45 per cent.

(5) The installation of finishing machinery involving steam consumption of the order of 2 lb. steam or less per lb. of moisture by drying. Lagging of all plant should be thorough.

(6) To reduce the low pressure both in the washhouse and air-drying machines. This is of particular interest when considering full use of the engine exhaust steam.

(7) All condensate and flash steam should be recovered. The apparatus needed to make these recoveries is little different from normal piping but with regard to the suitable recovery of the heat in the flash steam it may be possible to take the heat out of the condensate by a heat exchanger.

(8) Power consumption ratio equivalent to between 8 and 10 h.p. per 100 lb. of work an hour or less.

(9) The target for this year is 1 lb. of fuel per lb. of work. For the future 0·6 lb. fuel per lb. of work is capable of being achieved provided that it becomes possible to make the necessary alterations in the organisation of the laundry and renewal or replacement of plant.

Mr. Geo. A. Crosland believed that the value of by-product steam might be over-emphasised and industrialists induced to instal engines of unnecessary

power under the delusion that the additional exhaust supplied will be an economy. Actually over-engining merely to obtain this extra exhaust is an expensive business, for the load is still carried by the original steam, the excess merely using the engine as a reducing valve.

One of the laundry industry's most vital requirements for fuel economy is a thermostatic valve fitted to steam supply injected into washing machines which can be relied upon to cut down the steam, quickly and surely, as soon as the bath reaches boiling point.

Attention was drawn to the effect of a supply of low-grade fuel upon a laundry already well designed and well balanced when using graded fuel. The loss in efficiency is cumulative, the drop in steam output affecting every unit in the laundry—calenders not heated properly, hydros not drying sufficiently—with a considerable drop in laundry efficiency.

The best means of obtaining fuel efficiency in laundries would be to ensure that proper fuel was available and sufficient labour to keep the machines working to capacity.

Mr. I. R. Brown pointed to the difficulties which were being experienced in the supply of equipment required for promoting more efficient working. He had just been quoted 28 months for delivery of motors and understood that the reconditioning of his oil burner equipment—out of use during the war, when he was relegated to coke breeze—would take seven months. The advantages of the use of fuel oil far exceed the strict ratio of calorific values. In fact, they would warrant fully 75 per cent. extra cost. The three requirements for full fuel efficiency and upon which the aid of the Ministry was sought are labour, fuel and equipment.

#### 4. Steam and the Hospital Engineer

By J. J. TOMLINSON, A.H.A.

Mr. J. J. Tomlinson pointed out that the necessity for fuel economy in hospitals has long been a consequence of the need for financial economy in those institutions. Among the purposes for which steam is used in hospital work are the following: The generation of electricity; laundries; space heating; the provision of hot water; cooking; sterilising; fumigating. Given suitable plant, there are many opportunities for the multiple use of steam, but unfortunately all hospitals are not equipped with plant designed and arranged to make use of exhaust steam from prime movers for low-grade heating. Electricity should be generated on the site where the conditions of layout and size of hospital make it economical to do so and where the thermal demand is closely related to the electrical demand. A hospital, with its large demand for hot water, would appear to be an ideal site for generating electricity.

A description was then given of the plant at King's College Hospital, London. This hospital used 6,250,000 gallons of hot water during the year 1945; to heat this water through 120° F. with a boiler efficiency of 65 per cent., 465 tons of coal are required. Under these conditions Diesel engines may be useful since the cooling water from the jacket gains 70° F. and thus would allow 250 tons of fuel to be saved.

All condensate from calorifiers and radiators is collected and returned to the hot well. The make-up water for the boilers at this hospital has been

reduced from 11·7 per cent. to 5·1 per cent.—the 5·1 per cent. being irreducible because it is considered inadvisable to connect to the condensate line the wastes from certain large sterilisers and apparatus such as incubators used in the pathological and biochemical laboratories.

Hospital boilerhouses are in general deplorably short of instruments. The fuel used and the water consumed should be measured at least, and it is of great assistance to know the draught over the fires and the  $\text{CO}_2$ ; the boiler staff must be instructed in the use of instruments.

The work of a hospital engineer does not end with the efficient generation of steam. A hospital is very different from an industrial establishment, one difference being that while in industry the same operator may use an apparatus for years, operatives in hospital are continually changing. Nurses operate much of the steam-using plant. Above all, the patient must come first. As a result one finds much careless waste, such as sterilisers kept on steam unnecessarily, vegetable steamers left on after the vegetables have been removed, wards allowed to become too warm and in consequence windows thrown open instead of shutting off the radiators, and so forth. Serious heat loss is caused by maids washing crockery in running water under a hot tap; that source of loss was ended by supplying the water too hot to allow of the wasteful practice (at  $165^\circ\text{F}$ . instead of  $120\text{--}130^\circ\text{F}$ .). In a large hospital hundreds of baths are taken each day and it is quite common to see the overflow running to waste. No little ingenuity is necessary to find means to circumvent these and other wasteful practices.

**Mr. R. G. Rogers** said that the primary engineering requirements of hospitals were heating and ventilation, adequate electrical services for power and lighting (which must never fail), an unlimited water supply, means of cooking and supplying domestic hot water, and where hospitals have their own laundries, high-pressure steam for calenders and presses, etc., and low-pressure steam for washing. The most economical method of providing these services, while depending on the size and locality of the hospital, is, in general, site generation with combined power and heating. The economy of such a plant, however, depends on maintaining a correct heat balance all the year round.

To illustrate how this balance can be obtained the author described the installation under his charge. The hospital contains a total of 1,038 residents and staff. The plant consists of two natural-draught Lancashire boilers, 28 ft.  $\times$  7 ft. 6 in., working at 100-lb. pressure, with a 96-tube Green's economiser. Natural draught is provided by a 90-ft. stack. The generators are steam-driven compound sets totally enclosed, two of 100 kW and one of 30 kW at 200 volts, D.C., working at 8–10 lb. back pressure. An oil separator is fitted, but the engines have gunmetal piston rings and run without cylinder lubrication, taking steam 100 lb./sq. in. The domestic hot water supply is provided by 2  $\times$  300 gallon storage-type calorifiers each capable of raising 3,000 gallons  $100^\circ\text{F}$ . an hour when taking 3,260 lb. of exhaust steam at 5 lb. gauge. The hot water is circulated around the buildings by steam-driven impulse turbines with alternative electrical drive. The latter is more economical than the impulse turbine which is rarely used.

Heating is provided by hot water circulation heated by two exhaust steam non-storage type calorifiers, each capable of 1,500,000 B.Th.U. an hour when taking steam at 5 lb. gauge at 1,550 lb. per hour. The method of

circulation is the same as for the domestic hot-water supply. In addition, one live steam calorifier is installed of the same size and type for boosting purposes, but this has never yet been needed. The condensate from these calorifiers is collected in a receiver and raised by a lifting trap to a high level tank (to which is married a make-up feed tank). From here it gravitates into a Lea recorder tank at floor level, from which it is pumped by one of two Weir pumps through a pair of filters, two exhaust steam pre-heaters in series, which may be by-passed at will, through a Kennedy piston-type meter provided with a by-pass, and through the economiser to the boiler. The instruments in use are a 5-cwt. weighbridge on which all coal is weighed in, and ash and clinker weighed out; a CO<sub>2</sub> indicator and recorder, steam flow indicator, recorder and integrator, 3-point pyrometer, draught indicators on each furnace, and also at the bottom of the stack. Draught control is by means of a swing damper between the economiser and the stack. Recording thermometers are used on the feed water entering and leaving the economiser, and a steam pressure recorder records the boiler pressure. Boiler feed water is measured by a Lea recorder or Kennedy meter, or both, and one can be checked against the other when necessary. All these instruments are absolutely essential for the efficient running of the plant, as they enable one to see at any given moment what is happening and at the same time provide a record of such happenings.

The water supply is taken from an outside source, and is 19–21° of hardness. This is softened by base exchange to 2–3° for boiler feed, laundry and hot water service (elsewhere crude water is used). The biggest demands for electrical power and steam come from the kitchen and laundry. No gas is available, so that all cooking and laundry process work is done by electricity or steam. Here is where one has to be careful in the installation of equipment, because it is here that the balance between heat and power can be made or marred. In the kitchen a balance has been struck between the electrical load and the resultant exhaust steam (no live steam is used here), so that the two loads are practically coincidental. All traps are fitted with sight glasses and all the condensate (except from steam ovens) is returned to the engine-room hotwell.

The laundry deals with about 30,000 pieces weekly. Here live steam at 100 lb. per sq. in. is supplied to two 120-in. calenders (one 24-in. and one 36-in. diameter), three twin rapid presses, one Hoffman press (reduced to 60 lb.), two sets of stocking dryers and a disinfector (reduced to 30 lb.). The continuous dryer, washing machines, soap boiler, starch emulsifier, etc., are all supplied with exhaust steam at 5–10 lb. per sq. in. Here again all traps are fitted with sight glasses and condensate is returned to the hot well. The total condensate returned from the plant as a whole amounts to 70–74 per cent.

The plant is so nearly balanced as between electrical and exhaust steam demands that no live steam has been used in winter to supplement the exhaust system for about ten years, and only in extremely cold weather is the steam turbine circulator used; at all other times the electrical drive is used. In summer there is seldom an excess of exhaust steam, except very occasionally on peak electrical loads, and this can usually be balanced by the use of feed-water heaters and a 3,000-gallon hot-water storage tank. At night, when there is no demand for power or exhaust steam, the generators are shut down from about 11 p.m. to 5 a.m., during which period fires are banked and the electrical load is carried by a 960 amp.-hour battery, and hot water is supplied from the 3,000-gallon storage tank.

The yearly consumption of fuel for all purposes (except for the bread bakery which has coked-fired ovens) is as follows :—

Total residents . . . . .	1,038
Steam coal consumption . . . . .	1,154 tons
House coal consumption . . . . .	648 tons
Total . . . . .	1,802 tons
Tons of coal per head per annum . . . . .	1·77 tons
Total water consumption, including farm, garden, laundry, etc. . . . .	9,789,636 gallons
Total water consumption per head per day . . . . .	25·8 gallons
Electricity generated . . . . .	231,918 units
Electricity generated per head per week . . . . .	4·3 units

These figures include the hospital proper, and staff residences, totalling 32 houses which are supplied with coal, water and electricity from the hospital services. Hot water is supplied in five cases only. The author doubted whether these services could be provided at less cost, or with a lower fuel consumption by any other means than combined power and heating, and looked forward to the time when district power and heating services in this country will be almost as common as other public services, and an end to the practice of warming up the water of our rivers, canals and huge cooling towers by exhaust steam from big power stations.

**Mr. Chynoweth** drew attention to the economy to be obtained by attention to the small items such as leaks, etc. Rooms change their function and so require a different temperature. If the change required is upward it receives attention but not otherwise. Attention should be paid to the lower heat requirements of store rooms and similar places not requiring such high temperatures. It is possible, also, by proper organisation to restrict the use of such rooms to hours of daylight. Radiators in corridors, being in an air stream, have a relatively high heat emission and should be watched carefully. Peak loads must occur in different departments but there is no reason why they should coincide and a little intelligent planning under the engineer armed with executive powers can flatten out these peaks by staggering the loads in the laundry, cookhouse, and other consumers. The provision of automatic air vents on steam heating apparatus such as steam-jacketed pans, ironing machines, etc., was so important and leads to such great economies that he suggested that equipment manufacturers should incorporate such items on all their apparatus. The shape of the appliances should be considered in the design stage so as to facilitate lagging.

## 5. The Use of Back-Pressure Steam

By D. L. COPP, A.M.I.C.E.

I think we all agree that the fuel efficiency campaign has been more successful than its sponsors have claimed ; this is proved by rising industrial output achieved with a steady availability of coal tonnage allocated to industry generally. Nevertheless the fringe of fuel efficiency has scarcely been touched, as is demonstrated by the unchallenged figures presented by Mr. Lyle in his notable paper "Inefficiency".



The term back-pressure steam includes pass-out steam. Chemical production requires simultaneously large amounts of power and of low-pressure steam. The steam is used for distillation, closed and open heating, solutions, dilutions, vapour-pressure control, chemical reactions, space heating, and drying, among varied and interesting applications.

The method of production of process steam is of primary importance. If it were possible, all power should be produced by back-pressure turbines and engines. On back-pressure steam hangs the main hope of reaching high fuel-using efficiency. There should not be a condenser even in the biggest power station; condensers should be used only for the production of distilled water for chemical processes. The thermal efficiency of a good base-load power station is 26 per cent. to 29 per cent., while a very ordinary back-pressure installation has a thermal efficiency of 75 per cent.

The back-pressure generator is far cheaper to buy, far cheaper to instal and far cheaper to maintain. If the back pressure necessary for the process is high, and the power required is under, say, 1,000 h.p., reciprocating engines have the advantage, as will be seen in Table IV of Fuel Efficiency Bulletin No. 33.

As I see fuel efficiency in steam usage, there are a few rules which have to be observed, and which are fundamental, but sometimes idealistic:—Never exhaust to atmosphere (with one exception which I will mention later); never use a condenser; never use an unnecessarily high steam pressure for any purpose; never let heat dissipate uselessly; break down steam pressures in sequence. To explain the meaning of the last item, suppose that the factory processes demand steam at two temperatures, one equivalent to steam pressure of 60 lb./sq. in. gauge and one equivalent to a steam pressure of 10 lb. If the back-pressure steam is supplying the 60 lb. demand, then the 10 lb. steam must be derived from it, and not from steam at boiler pressure.

When one gets conditions approaching balance, it is more than ever necessary to evolve a temperature gradient plan. The way I have done this on big schemes at chemical works is to take a works plan and upon it mark by "balloons" and arrows the minimum steam temperature (or pressure) and the quantity of steam per unit time required by each item of plant. By placing a piece of tracing paper over such a plan it is convenient to outline with coloured pencils possible heat linkages until the best arrangement is arrived at.

The objective should be to make all one's works a huge counterflow cooling plant, utilising sequences of steam temperatures, condensate temperatures, and flash steam, together with all the various devices for vapour recovery, thermal compression, heat pumps, heat recovery from products, moisture extraction by mechanical means rather than thermal drying, vacuum distillation, thermostatic control, and so on. It is necessary to emphasise one great cause of heat losses, namely, the over-dilution of materials prior to processing.

But my subject is the use of back-pressure steam where power and steam needs nearly balance, and perhaps it will be advantageous to consider briefly our attitude first to excess of low-pressure steam, and secondly to excess of available power. It will always be necessary to have in mind the scale of operations of our plant; a 5 per cent. excess on a weekly fuel consumption of 10 tons is a vastly different thing from the same percentage on 1,000 tons of fuel a week.

If there is an excess of low-pressure steam exhausted from a turbine, we do not want to condense it, and we do not want to vent it to atmosphere.

What can we do ? Measures which might be taken are :

(1) Introduce a new process or product requiring heat but little or no power ; or perhaps do additional feed-water heating.

(2) Sell the steam to a neighbour (more will be said of this later).

(3) Increase the boiler pressure and superheat. On a new installation provision could always be made for increased pressure, while an increase in superheat, where permissible, very much reduces the " lb. per b.h.p." required by a prime mover ; e.g. a compound non-condensing engine which when supplied with saturated steam used 28 lb./b.h.p./hr. would be expected to use but 22 lb. if the input steam were superheated 200° F. Generally, if a back-pressure engine is supplied with highly superheated steam, the exhaust is superheated ; it is not usually permissible to use superheated steam for process, so that a de-superheater may be necessary, and it should be installed just prior to the process plant, so that the advantage of distributing superheated steam may be gained.

(4) Buy electricity from the public utility. Clearly this would reduce the load on the generator and would be a proper procedure.

(5) Last, but most important, start a power economy campaign. Run your mill light one Saturday afternoon to determine how much power it requires unloaded—and get an unpleasant surprise. Appoint Fuel Watchers to help you to get the idling machine stopped, the unwanted light switched off, and the half-hidden away electric radiator abolished. (And what about space heating with exhaust steam ?)

There is an exceptional condition in which it is permissible to exhaust steam to atmosphere, but it should then be deliberately done at low back pressure, and not through a safety valve. The circumstance may arise when to supply additional power it may otherwise be necessary to start up an additional prime mover, e.g. if the quantity of steam to be blown off is less than the no-load consumption of the additional prime mover.

Next consider the state of having an excess of power available. The generating conditions which then occur are : the exhaust back pressure being low, it has to be boosted via a reducing valve (a dreadful necessity) because the input steam to the engine or turbine is controlled by the power output ; then the obvious measures to adopt are :—

(1) Introduce a new production requiring power but little heat.

(2) Lower the boiler pressure. In this connection are we not guilty of being mentally static by sticking to some pre-arranged boiler pressure ? Is it not true that because a boiler is insured to generate steam at a certain pressure it is automatically worked just below that figure, so that no one thinks of lowering the pressure when steam conditions favour that course ?

(3) Sell the excess power. By law it would be difficult to effect this to a private consumer, but it ought to be easy (because of national necessity) to sell it to the Grid. But offers of small supplies appear to be unwelcome.

We have now arrived at conclusions of which two are in a sense complementary. Sometimes we want to buy power, sometimes sell power. Clearly, then, the real solution is to " float on the line ". This means that your private generator is in phase with the public supply. Is there any electrical or engineer-

ing difficulty in this? I am unable to believe that the producers of the wonderful, reliable and complicated switchgear and metering equipment which we have in this country cannot provide every device necessary to protect both parties' lines and apparatus. As for generators, the induction generator is beautifully foolproof for floating purposes.

Now I come to a proposal which I would ask you to consider, and if you approve, to talk about it and get it either condemned or agreed as practical.

It is terrifyingly clear that on one hand we have factories, workshops, homes generating heat and buying power, and on the other hand power stations, factories and locomotives generating power at between 30 per cent. and 2 per cent. efficiency, therefore wasting most of the fuel; and gasworks only 70 per cent. efficient when they ought to be 85 per cent. Means have to be found to co-operate, to buy and sell surplus heat and power.

I must say I believe the exponents of district heating by back-pressure steam or hot water from large power stations are off the track; they are trying to sell heat to huge numbers of small part-time seasonal consumers on the ends of long pipes, when the obvious thing to do is to put a brewery or a sweetmeat or chemical fertiliser factory next door; one short steam main, one account to collect, no bad debts, no further public services to "clutter up" already overcrowded carriageways; and moreover it is not easy to prove that district heating to small properties already provided with public services is either efficient or economical.

I would like to see the formation, in our industrial areas, of corporations, the shareholders of which would be the potential buyers and sellers of surplus heat and power. The corporations would be encouraged by, perhaps even formed under the patronage of, the Regional Fuel Committees. They would arrange the buying and selling of power and steam, perhaps own high and low-pressure steam mains, and power cables. The formation of such a body would take place after a regional investigation of the whole heat and power balance of the neighbourhood. New industries would be invited to start in an area which could offer the needed supply. There is no objection either on grounds of efficiency or cost to high-pressure mains up to a mile in length, and low-pressure mains up to half a mile.

The proposed corporation could if necessary be equipped with a low-pressure turbine, so that if there is a reasonable quantity of surplus exhaust steam available, it could be put through that machine and power generated by the heat drop say from 2 or 3 lb./sq. in. gauge pressure to 29-in. Hg vacuum.

#### *Discussion*

**Mr. R. V. Bradshaw** wrote: I was very pleased to hear this morning so much emphasis, particularly in Mr. Copp's paper, on the need for a greater use of back-pressure steam for process work and heating. This has been obvious to most engineers for a long time but in many cases there are two major difficulties, firstly, a variable and sometimes adverse electricity-steam balance in the works, and secondly the need for standby supply or equipment. Both these difficulties can be solved by operation in parallel with a supply company. Unfortunately many such companies frown on this. Various reasons are put forward in support of their attitude, notably that the protective switchgear necessary between the small industrial station and their large one is too complicated. Here I support the speaker who said that our switchgear manufacturers are perfectly capable of solving this particular problem. I

think, too, that the supply companies tend to under-estimate the competence and efficiency of works engineers in dealing with generation.

Supply companies must get more used to the idea of private generation in works where steam has to be produced for process purposes. Both from the national and the industrialists' points of view every pound of coal should be burnt to the maximum advantage. Where the opportunity offers, surely there is no better way of doing this than by generating electricity in back-pressure or pass-out machines and then using the back-pressure steam for other purposes.

The amount of electricity available for "export" from the size of works I have in mind may be small individually but there must be many such and in my own case at least the surplus would be available at the right time, i.e. in winter, and the deficiency, except in case of breakdown, would also occur at the right time from the supply companies' point of view, in summer.

**Mr. J. B. Atherton** wrote : Towards the close of Mr. Copp's interesting Paper on "The Use of Back-Pressure Steam" he states it as his belief that heating engineers are "on the wrong track" in advocating the use of heat from generating stations "on the end of a line" for district heating. He suggests as an alternative that industrial works should be located adjacent to power stations to use the heat rejected, as, in any case, householders have already available a choice of two fuels.

Dealing firstly with the positive aspect, it must be agreed that to erect a factory alongside an electricity generating station, provided full use could be made of the heat facilities offered, would create an excellent combination. The obvious question arises : could the factory utilise to a greater degree the heat available than could a heating service to a district ? Or would not the heat supply and demand be even more out-of-step than in a district heating scheme ? Further, what of the many factors other than heat supply, which must be considered in relation to the siting of a factory, particularly the recruitment of labour ?

Granting that these and other problems could in certain cases be overcome, it still remains to be shown why district heating could not be at least an equally attractive proposition.

Mr. Copp's phrase "on the end of a line" evidently implies that pipe mains present some difficulty. Whatever the inference, there exists no problem which could not be satisfactorily dealt with and which has not been considered by engineers. If Mr. Copp refers to distribution losses there is no incompatibility between his own advice, given earlier in his paper to works engineers, not to look askance at mains up to 30-in. diameter carrying steam at 5 lb./sq. in., and that of running smaller mains at higher temperature, even allowing for increase in transmission coefficient.

That domestic consumers have a choice, presumably of gas or electricity, seems to me irrelevant. Let it be assumed that fuel saving and smoke abatement are the primary reasons for our interest in power-station by-product heat. The heat delivered to the consumer by his electric appliance has an end efficiency of less than 30 per cent. The gas appliance figure may be between 50 per cent. and 60 per cent., neither being very far ahead of the coke fire nor (quite important to the consumer) as cheap. Further, the thermal degradation which accompanies the conversion from raw coal to electric radiation in a room is considered by many to be unwarranted and to be deprecated. Gas and electricity undertakings cannot today cope with additional loads.

A factory generating its own heat (whether or not combined with power) can do so much more efficiently and with less atmospheric pollution than could a large number of smaller units. A given heat production would, therefore, cost less and the products of combustion would be less offensive.

Mr. James F. Smith (supplementing his spoken contribution) wrote that in 1920 the average consumption of coal per unit generated was 3.74 lb., the corresponding figure for 1937 being 1.43 lb. At one of the power stations of his own company, the South Wales Electric Power Company, an operating performance of 1 lb. had been achieved. His experience was that statutory and physical difficulties in the operation of industrial plants in conjunction with power company systems could be overcome with real co-operation.

A proposal by a paper manufacturing concern to establish a new works led to the view being expressed by his own company that whatever might be the balance of steam and electricity required by the mill, the production of both could be carried out more efficiently and economically at the power company's latest generating station; if this could be demonstrated the advantage could be shared between the two companies. The result was that at the present time the paper mill was under construction about 800 yards from the power station and an agreement had been completed whereby up to 30,000 lb./hr. of steam at 25 lb./sq. in. would be delivered by this power station to the paper mill, together with up to 2,000 kW of electricity, some 90 per cent. of the steam supplied being returned as condensate at about 160° F. The paper mill had been saved the capital expenditure on boilers and generating plant and the operating costs of that plant; presumably if operating independently the paper mill would require to be equipped with full standby plant. The power company would reap the advantage of supplying current at normal commercial tariff at a high load factor and over a short transmission system, thereby resulting in an attractive average price to the consumer. Moreover, the steam supplied was at a low pressure from which little further energy could be derived at the power station. The power company was virtually selling latent heat since hot condensate would be returned. It was claimed that coal was conserved by this arrangement since the extra fuel required by the power company would be considerably less than that consumed if the paper mill operated independently. Moreover, the modern pulverised fuel plant at the power station would consume fuel of a lower grade than that needed by a plant at a paper mill.

There were numerous other examples of co-operation between the industry and the power company in South Wales and from time to time arrangements had been made for a power station to run parallel with refuse destructor stations, private colliery power plants, steelworks plants using surplus blast-furnace gas, and with other power stations belonging to industry or to local authorities. Several of these arrangements were operated with a view to mutual assistance to meet peak loads and to provide economic operating conditions for the plant concerned. For some years past the power company's generating station at Upper Boat had been supplying considerable quantities both of steam and electricity to the large Trading Estate at Treforest, condensate being returned to the station. Another example had been given by Mr. Walker in his paper "Steam for the Rubber Industry" where co-operation between a rubber works and a local electricity supply authority had been of mutual benefit.

Mr. Smith emphasised the necessity of providing sufficient instruments for coal-consuming and energy-consuming plants. He had noticed a deplorable

lack of even the most elementary measuring devices for coal, steam, water and temperature. Without such instruments it was impossible for industrial engineers to run their plants efficiently.

**Mr. R. C. McLeod** wrote : The difference between back-pressure and pass-out turbines has a most important bearing on the policy to be adopted by industries using process steam. In order to secure the minimum coal consumption from a national point of view, power which cannot be generated by process steam should be produced by the grid power stations. In the past it has been usual to use a pass-out turbine where insufficient power is available from the process steam, and good efficiencies have been obtained, but the low-pressure end of a pass-out turbine is seldom as efficient as that in the power stations.

There are encouraging signs that the public supply authorities are more willing to have back-pressure sets running in parallel with their generators, and if in time this becomes the accepted method of making use of the power available from process steam, there is the possibility that pass-out turbines will become as rare as mixed-pressure machines. Whether this comes to pass or not may depend on economics or legislation. If steam users are free to do what they consider most profitable to themselves, they can always use a pass-out turbine if the power supply authority charges too much for power. If, however, the power charges are favourable, no steam user will want to be bothered with condensing plant and means for disposal of low-grade heat. In addition to this, a good back-pressure turbine will generate more power per pound of process steam than the average pass-out machine. It is possible, at a price, to make the high-pressure end of a pass-out turbine as efficient as the best back-pressure turbine, but this is an exception rather than the rule.

**Mr. Smith** of the South Wales Power Co. said that if a paper mill took its steam and power from a grid power station, *all* the coal which would have been used in the paper mill would be saved. This is a fallacy. Some of this coal would be saved, but not a very large percentage.

A modern geared high-speed back-pressure turbine of a size suitable for a paper mill is nearly as efficient as the part of a power station turbine in which the paper mill steam would be expanded, and any saving in coal would be due more to the good boilerhouse control than anything else. The arrangement between paper mill and power station is only attractive with base load stations, because if the steam is bled from the turbine its absolute pressure is approximately proportional to the load on the turbine.

If it is not a base load station, it may not be able to supply steam at a constant pressure unless a pass-out turbine is used in the power station and a pass-out turbine running at partial load in the power station would not do so well as a back-pressure turbine running at full load in the paper mill.

**Mr. W. J. Dickie** wrote : I feel that as the balance between steam and power demands has such an effect on the overall thermal efficiency it cannot be dismissed lightly. I submit that the industry should not continue to consider the generation of power with condensing plant as inevitable, but should consider every means of ensuring that all power demands are generated entirely by prime movers exhausting to process only. The continuous use of even a small balancing condenser can lower the overall thermal efficiency by 12 to 15 per cent.

I fully appreciate that the power/steam demand ratio varies with the nature of the process, but would suggest that much could be done in most cases to ensure a more favourable balance. The modern tendency in design is the more extensive installation of electrically-driven units and, after the economies which should be made in steam utilisation have been realised, we are often faced with ever-increasing demands for power and reduced demands for process steam. It does not follow that this additional power demand must be generated with condensing plant. The employment of high primary steam pressures should be considered seriously before that of condensers.

The raising of the stop-valve pressure of the prime mover has the following effect :—

Steam pressure, lb./sq. in. gauge	Steam temperature ° F.	Approx. increase in power generated per cent.
From 340 to 640 . . . . .	738 to 766	16·0
From 340 to 1,405 . . . . .	738 to 824	32·0
From 640 to 1,405 . . . . .	766 to 824	14·0

In each case a back pressure of 30 lb./sq. in. has been assumed. The thermodynamic efficiency of the prime mover has been taken as 80 per cent. for the low-pressure, 75 per cent. for the medium-pressure, and 70 per cent. for the high-pressure set. The power absorbed by boiler feed pumps has been taken into account in each case. The steam temperatures selected are those which give an equal heat content in each case.

The percentage difference in the power generated would increase rapidly as the back pressure rose, especially at the highest steam pressure quoted. Comparison of the power generated at the back pressure of 100 lb./sq. in. with an initial pressure of 1,405 lb./sq. in. g. and that at 340 lb. per sq. in. g. shows an increased generation of the order of 71 per cent. The operation of steam plant at high pressures presents no great difficulty today, and if a closed feed system is employed, incorporating a heat exchanger plant, the control of the boiler feed water is comparatively simple.

All the above figures are those appertaining to turbo-alternators, but it is appreciated that the total power demands of many mills is of the order of 1,000 kW or less, at which outputs the steam turbine is at a disadvantage as compared with a steam engine. In these cases steam engines can be used to advantage up to 1,500 lb./sq. in. g. with a reliability equal to that of turbines.

It is possible that in some installations a limited amount of power only is generated, and the remainder required is purchased. In these cases the use of higher steam pressures would certainly show savings on the power purchased.

It should be appreciated that the raising of the initial steam pressure is a long-term policy, but nevertheless it should be seriously taken into account when considering the needs for the future.

**Mr. R. P. Nuki** wrote : Mr. Sands mentioned in his paper a new type of drying cylinder for M.G. machines. I should like to draw your attention to a design of a drying cylinder which I worked out several years ago. This is shown in Fig. 38.

This cylinder has a narrow annular steam heating space, formed between an outer and an inner cylinder shell. The inner shell is bolted to the outer

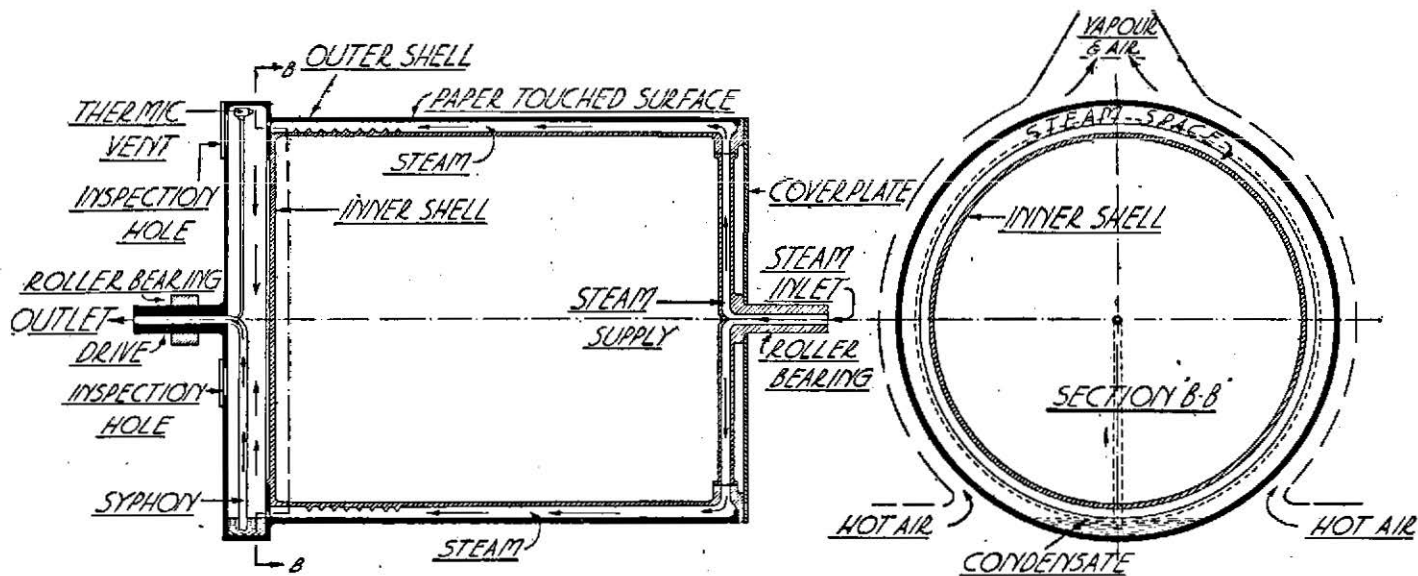


FIG. 38.—Drying Cylinder.



shell and can be made of mild steel. The inner shell can be equipped with small fins, deflectors or undulations in order to cause turbulence in the steam flow. The steam enters through the front journal, passes through a number of hollow arms and flows then through the annular space towards the driving side of the cylinder into a compartment "A". This compartment is larger in diameter than the main body of the cylinder, and therefore the condensate flows soon after it has formed into this compartment A, either by gravity or in very fast runners by centrifugal force.

The actual heating surface of the cylinder is kept practically free from condensate and steam touches the whole heating surface. In cylinders of the orthodox design, a certain area at the bottom of the cylinder is covered with condensate; condensate, being a poor conductor of heat, is detrimental to good heat transfer.

From the compartment A, the condensate can be discharged either by buckets, syphons or by means of thermostatic valves inside the cylinders. The inside of the cylinder and the front plate can be fitted with insulation, the same applies to the end at the driving side.

Due to the better heat transfer which is to be expected through the actual heating surface, and due to the reduction of radiation losses at the sides of the cylinder, it should be possible to work with a lower steam working pressure. What this means is well known: reduced radiation losses, with increased power output in the back-pressure turbine or engine. If the steam working pressure is not reduced, production will be increased and this also means a saving per pound of dried product. Increased production and decreased waste will also be achieved due to shortening of the starting-up time. As the steam space is small, any air contained in it is driven out quicker than from a standard cylinder.

The question now is whether the new construction is practicable as regards the provision of an even surface temperature over the whole width of the cylinder. A disadvantage of the new design is that it certainly will be more expensive than a simple cylinder. It should, however, be well worth while to give the design a try-out for an M.G. or fast-running machine. At least, the diagram should give food for critical thought and serve as a basis for further development from the usual cylinder construction which does not seem to have changed much during the last hundred years.

Mr. Sands mentioned that stage heating systems are applicable to multi-cylinder machines, but less to M.G. machines or Yankees. On M.G. machines the steam used for heating of the large cylinder can be exhausted either into pre-dryers and from there into air heaters, or if there are no pre-dryers at least from the big cylinder into the air heater, thereby improving the steam circulation and heat transfer. Besides, the flash steam is used in stage heating systems for pre-heating cold air in a special air heater coil before the air enters the main air heater. M.G. machines usually work with a higher steam pressure than average paper machines, therefore the flash steam quantities are greater and it is even more important to make use of this flash steam.

**Mr. J. Seddon Brundrit**, commenting on the statement that 30 lb./sq. in. was a satisfactory maximum working steam pressure for laundry washing machines, wrote recounting an experience dating from 1935 in which he arranged for the installation of an exhaust steam recovery system at Virginia Steam Laundry, Liverpool, which included the reduction of pressure to the

washing machines to 7 lb./sq. in. ; this arrangement had been completely successful over the past eleven years. The Ministry's own publication referred to other laundries also using 7 lb./sq. in. steam pressure in their wash-houses.

Mr. Brundrit continued : A point which should be emphasised is the need for the installation of drain traps on compressed air receivers and pipe lines, and the important point that the inlet pipe to the compressor should be so placed that the air taken through should be as dry as possible.

Too often these compressors are sited in a corner of the wash-house or near to the exhaust from suction calender fans or drying machines or tumblers.

I cannot quote figures for laundries in this connection, but at a large refinery in this district the installation of adequate draining to receivers and mains resulted in their being able to meet their load with one 100 h.p. compressor, instead of the two they had had to run prior to adequate drainage.

The use of steam recirculation on calender beds, and pressure heads and beds, can give startling reductions in steam consumption per lb. of work processed, and this field should be fully explored as well.

Further, the installation of thermostatic air vents to calender beds and steam mains gives a still further reduction in the weight of steam used, and all possible advantage should be taken of air venting.

Mr. J. D. Lewis contributed some notes upon the problems of larger hospitals dealing with more than 2,500 patients. These hospitals were usually situated in rural areas, the engineering staff being responsible for all essential services including hot and cold water, gas, power and heating required by the hospital wards, kitchens, laundry, workshops, farms and private dwelling houses situated on the estate. They were ideal for a combined power and heating installation, but while a balance could be obtained in winter, there might be difficulties in summer. A stand-by Diesel set was advocated in preference to electrical storage batteries, especially with a Diesel set equipped with a waste heat boiler and in which the heat abstracted in the engine cooling system was utilised. An alternative would be the installation of a small steam turbine operating on the surplus exhaust steam from the main generating sets after all other low-grade steam or hot water heating requirements had been met. Such a unit could be used during the summer, at nights and week-ends. Some hospitals used exhaust steam at 2 lb./sq. in. from generating sets for space heating, the condensate return main being under vacuum.

Some hospitals had their own wells, others might take a supply directly from trunk mains at points between the gathering grounds and the filter bed ; the water supply might thus be dirty and contaminated and unless provision was made for proper treatment considerable waste of water and fuel would occur. Water from a trunk main might be at high pressure and this could be used to economise in fuel. Fire mains should be kept entirely separate from domestic mains.

Some hospitals operated their own gas works, generally based on horizontal retorts, but the average hospital engineer had not the necessary training to operate these plants economically. The local gas engineer or the builders of the plant should be consulted by the hospital engineer. An instance was quoted of a plant making 7 million cu. ft. of gas a year in which a slight modification reduced the quantity required and secured a higher yield with a 40 per cent. reduction in fuel consumption.

Hospital laundries might be larger than many commercial laundries, but much could be learned from the laundry trade, as coal consumption per lb.

of work processed was often very high. Some hospitals used patients for laundry work, a practice which led to fuel wastage. Plant layout should receive particular attention, and so also should the utilisation of flash steam. At one hospital it was proposed to couple the laundry surplus flash steam to the space-heating main which runs in a subway adjacent to the laundry building.

There might be two miles or more of subways in and about a hospital and each of these usually contained more than one pipe together with the necessary steam traps, expansion joints, anchors, glands, etc. All these must be maintained in good order, and this meant regular routine inspection. More consideration should be given to the design of these subways; neither their dimensions nor temperature were conducive to conscientious inspection. An example was given of a subway constructed recently in which it was necessary to proceed in a crouched position for several hundreds of yards at a temperature of 130° F. The trouble was intensified by pipes which were too large, poor insulation and expansion joints designed for a pressure only half that at which they were working. Other subways were known to the writer which were equally bad.

Oil fuel had many advantages over solid fuel for these large hospitals.

Some of the larger rural hospitals were provided with their own locomotives which might be either steam or Diesel-engined. Steam engines could be of the fireless type where steam was supplied from the main boilers to a receiver on the locomotive. These were economical and gave satisfactory results.

Fuel watchers should be under the control of a competent fuel efficiency officer, who in hospitals should be the chief engineer. The suggestion might well be made also that examinations should be instituted to assess the capabilities of future candidates for engineering posts in hospitals. Certificates of competency issued by the Ministry of Fuel on lines parallel with those issued to marine engineers by the Board of Trade would materially assist in the proper use of fuel.

## SECTION B. STEAM UTILISATION—*continued*

### SESSION III. Where Power Outbalances Process Steam

*Chairman of Session:* MR. ALLAN DRAPER,  
DIRECTOR, MESSRS. RICHARD HAWORTH & CO., LTD.

#### 1. Where Power Outbalances Process Steam

By F. BUCKINGHAM, B.SC., A.C.G.I., M.CON.S.E., A.M.I.C.E., A.M.I.MECH.E.,  
A.M.I.E.E.

This paper is concerned with the large number of factories where the power requirements are greater than can be met by using back-pressure engines supplying steam for process and space heating. In this category are paper and textile mills using a certain amount of steam for process as well as heating, textile mills and general manufacture and engineering works where, apart from power, steam is only required for space heating and a few ancillary operations.

The opportunities for double use of steam may not arise or may be less spectacular than in cases where the demand for process is in excess of the requirement for power, but the present conditions require that wherever there is a use for low-grade heat it should, if practicable, be made to contribute its quota of power.

There is no general solution but in such instances as paper mills and multilateral textile mills where the process requirements are considerable there is the choice of

- (a) using a back-pressure engine working in parallel with the main engine or turbine, or a supply from outside,
- (b) using a pass-out condensing engine or an extraction turbine for both purposes.

In either case where there is a use for hot water, if an engine is used as the prime mover, it should be remembered that the condenser can afford a copious supply at about 120° F. If the raw condenser water is not considered suitable for process there is nothing to prevent the installation of an intermediate heater between the exhaust and condenser through which treated or town water can be circulated and heated to the temperature of the condensate.

Where, as in spinning and manufacturing mills, the process steam is only required for sizing and space heating there is less scope for this kind of economy. The quantity of steam required may not be considered sufficient to justify the use of pass-out engines or extraction turbines and the demand will not necessarily coincide with the demand for power. For this type of mill the requirements of heating and process will not generally be considered in deciding the type of power to be used. Even so where a reciprocating engine is used there is often the opportunity of adapting it for pass out at small expense with good economic results. Any doubts as to whether this is the correct course can be resolved by installing a back-pressure set of a size appropriate to the process load and if the mill is electrically driven an automatic balance of power generated to suit the process can be obtained by driving a generator in parallel with the main supply.

In most textile mills the means of driving, if not still the actual boilers and engines of 50 years ago, are boilers and engines whose design is determined by the practice of that time. It is a fact that shell boilers give little trouble, are not very particular as to the kind of feed, give a ready response to the fluctuating dyehouse load, and the mill engine is amazingly reliable, but considered only as a means of generating power this equipment falls short of modern power station standards. At steam pressures of 180 lb. per sq. in., 150° superheat and a vacuum of 27 in. the usual cross compound Corliss valve mill engine uses steam at the rate of 13 to 15 lb. per b.h.p. hour and coal at the rate of 1.5 to 2 lb. per b.h.p./hour.

With Uniflow engines these figures may be reduced 20 per cent. The same is true of turbines in the larger sizes, but the advantage of turbines is clearly limited by the steam and vacuum conditions and the relatively small units employed, rarely larger than 2,000 h.p.

The vast majority of spinning and manufacturing mills are driven by such engines through rope drives and line shafting and the loss in friction may be anything from 20 to 50 per cent. Most mills have some experience of electricity. A generator driven from the mill engine will often supply lighting, or a convenient supply from outside has enabled many mills to instal additional machinery to meet changing conditions of trade in rooms which would not allow of line-shaft drives, or rooms remote from the main engine, or under conditions where the engine is already fully loaded. The advantages of electric drive and in particular of individual drive where it is practicable in maintaining production and quality of product are such that, financial considerations apart, no other method would be adopted.

Having in mind the large capital cost of installing a small private generating plant of relatively low efficiency, the losses involved in the double conversion and the fact that the existing plant is not necessarily inefficient, there is nothing to be said for private electrification on this basis, but it is often the case that the supply authority, having already a footing in the mill, is able to offer terms sufficiently attractive to warrant a change-over to the outside supply.

Every case must be considered on its merits but it is clear that in cases where engine and boilers are due for replacement this is the obvious choice and the point does not need to be laboured. The mill manager will no longer need to give much of his time to power generation, involving purchase of fuel, repairs to boilers and engines and will be relieved of much anxiety on that account. If he is content to replace the engine by one large motor or a number mounted in the rope race driving existing line shafts the capital expenditure will be a minimum.

For a new mill or a reconstructed mill the same advantages will accrue but additionally there will be the opportunity of installing individual drives with their undoubted advantages. This is more costly but it enables an entirely different type of building to be used. Sheds can be built with greater spans and spacing of columns or indeed without columns at all. It ought not to be necessary for a new mill using little process to be built with its own power unit.

The same considerations which favour the individual drive in textile mills have long operated in general manufacturing and engineering works. The time has gone by when an electric motor is to be regarded as merely the replacement of another driving engine. To make full use of its possibilities the motor is brought closer to and often right into the driven machine, becoming in effect an integral part of it, dispensing with line shafting and fast-and-loose

pulleys, and often clutches and transmission gearing, the required starting and speed variation being obtained from the inherent characteristics of a specially designed motor.

While recognising the inevitability of extensive electrification and the equal certainty that most of the power required will come from the public supply authority, it would be right to recognise that the modern oil engine has a field of its own in power production in which it cannot be touched. Its thermal efficiency within limits is practically independent of its size and is higher than that of the most up-to-date super station. This brings within the reach of the small user wherever he may be, a source of power which compares favourably with the cheapest electrical supply. The consumption of a modern engine is about 0.36 lb. per b.h.p. hour and with fuel at £8 5s. per ton, the cost of fuel for electric generation is under 0.5d. per unit. The heat of exhaust and of jacket water can be usefully employed for space heating and process, the former being at a considerably higher temperature than the waste heat available from a steam engine.

The average coal consumption per unit sold by the electricity undertakings is 1.6 lb. per kWh and of the private plant rarely as low as 2.4 lb per kWh, so it appears that if we are concerned with power production alone the shutting down of all private plants and the transference of their load to the supply authorities would make for a considerable saving of coal. We have observed the tendency in this direction and other advantages, particularly the reduction of smoke and grit from industrial areas, can be visualised as something to be attained in the not distant future. But it is to be noted that this performance is achieved on a very high load factor whereas the power of an average mill or factory working a 48-hour week has a load factor of only about 18 per cent. For the electricity undertakings to maintain this low rate of coal consumption it is necessary for them to develop an additional domestic or other load of approximately equal magnitude, to keep up the load factor and so keep the price per unit at a figure which can compete with the mill engine. This may not be easy to do, although there seems no reluctance on the part of electricity undertakings to make the attempt.

It is noteworthy that the winter peak load on the grid is 1.6 times the summer peak and that 30 per cent. more units are consumed in the winter six months than in the summer six months.

To carry the peak load it is necessary for secondary stations to be run for short periods and their consumption instead of being 1.6 lb. of coal per kWh may be as high as 4 lb.

Clearly here is a case where the private plant generating electricity and passing out steam for heating is not only of financial advantage to the factory in question but makes a much needed contribution to the national problem, and supply authorities should give every encouragement to individual consumers to deal with their lighting and heating loads in this way.

Appended are recent examples of alterations in works power plant, modest in scope but none the less indicative of great cumulative effect if the methods used were generally applied.

#### EXAMPLE A

A multilateral cotton mill engaged in spinning, weaving and dyeing is driven by a 1,000 h.p. triple-expansion condensing engine for the main drive

of the spinning mill, a 250 h.p. compound for the weaving shed and a 60 h.p. engine exhausting to atmosphere for the dyehouse.

Four 30-ft.  $\times$  8-ft. Lancashire boilers could only with difficulty cope with the morning load. The lodge water is unsuitable for dyehouse purposes and town water is used heated from cold.

No major change was possible but it was considered that economics would result and conditions of working be eased by installing a large tank of hot water in the dyehouse, utilising the waste heat of the engines to maintain the temperature. Accordingly a 6,000 gallon tank was installed with a separate 1,000 gallon feed tank in parallel with it. The town supply was introduced through this tank and circulated by motor-driven pump through a tubular heater placed between the main engine and its condenser. The vacuum was improved by about 1 in. and the temperature of 6,000 gallons of water per hour was raised from 54 to 120° F. At this temperature it entered the main storage tank where it was further heated to 160° F. by a coil connected to the exhaust of the dyehouse engine. A live steam coil brings the tank to the required temperature during the night to facilitate an early start in the mornings. Condensate was returned to the hot well from the heating system and drying stoves.

The cost of these alterations was £2,200.

The saving in B.Th.U. per hour is 6,000 gallons raised	
66° F. by main engine heater . . . . .	3,960,000
Raised further 40° F. by dyehouse engine exhaust . . . . .	2,400,000
3,500 lb. of condensate return $\times$ 100° F. . . . .	350,000
	6,710,000

equivalent to 6,000 lb. of steam per hour.

With an evaporation of 7 lb. of steam per lb. of coal, and coal at 45s. a ton, this shows an annual saving of £2,070.

The load which formerly was carried only with difficulty by four boilers is now carried easily by three.

It remains still further to level out the dyehouse load by adapting the displaced boiler as an accumulator working between 180 and 80 lb. per sq. in.

#### EXAMPLE B

A blanket finishing mill is driven by a 250 h.p. gas engine and producer and raises steam in a boiler at 50 lb. per sq. in. for process. The output is increasing with an immediate requirement for 300 h.p. and an ultimate load of 400 h.p. with 4,000 lb. per hour for process.

The early stages of the new development suggested the use of a back-pressure set exhausting for process, in which case the example would not fall within the scope of this paper. The increasing demand for power and the fact that much of the process steam is to be used for heating water suggested a solution on the lines of Example A with the difference that steam is passed out for process.

Accordingly a 400 h.p. engine is installed taking steam at 160 lb. per sq. in. and passing out process steam as required at 20 lb. per sq. in. A 4,000 gallon hot-water storage tank is installed with a 1,000 gallon make-up tank through which the condenser water circulates at 120° F. The large tank is further heated by pass-out or live steam. Water as required for process is drawn from

either tank. When 8,000 lb. of steam per hour is fed to the engine the products are as follows :—

Pass-out Steam, lb. per hour	b.h.p.	Condenser water raised from 60° to 120° F. Gallons per hour
2,000	405	9,920
3,000	375	8,100
4,000	340	6,400
5,000	310	4,650

Under most conditions of working it is expected that up to an engine input of 8,000 lb. per hour full use will be made of all available heat, the only losses being engine friction and radiation from engine cylinders, pipe lines and tanks. The story would not be so satisfactory but for the use of the warm condensing water.

In this instance no outside electricity supply is available, but if it were it is difficult to see what contribution it could make.

#### EXAMPLE C

A large spinning mill finds it necessary to improve its lighting to bring it up to Home Office requirements. The cost of electricity purchased from outside for lighting only is 3 pence per unit and for power is 0·65 pence per unit.

The mill is driven by a 2,000 h.p. engine with 450 h.p. margin of power not used.

The engine is quite efficient and uses only 10·25 lb. of steam per i.h.p. hour.

It was decided to instal a 300 kW alternator driven from the engine to carry the lighting load.

With an engine efficiency of 90 per cent., alternator efficiency of 93 per cent., the coal per kWh is 2·35 lb. and at 40s. per ton the cost for fuel is 0·5 pence per unit.

The cost of the alternator, drives and switchboard was £2,000. An annual charge of 10 per cent. covers interest and sinking fund and on a consumption of 175,000 units per annum adds 0·275 pence to the unit cost.

The annual cost of generation is

therefore . . . . . 175,000 units at 0·775 pence = £565

Purchased from outside the cost is 175,000 units at 3·0 pence = £2,190

As the load on the mill extends, it is the intention to transfer a proportion of the power load to the outside supply, continuing to generate for lighting.

Clearly this is a case in which the reserve capacity of the mill engine is usefully and economically used to keep down the supply undertaking's peak load to the advantage of all parties.

#### EXAMPLE D

A pottery consists of a factory working a 48-hour week and a grinding mill working 134 hours a week.

Factory heating and drying kilns require 4,700 lb. of steam per hour in summer and 7,300 lb. per hour in winter.

The factory is already electrically driven and the decision has been taken to modernise the grinding mill which necessitates individual motor drives for the grinding cylinders.



The power requirements are :—

	Maximum demand kW	Units per annum
Factory	280	610,000
Grinding mill	120	864,000

There is the alternative of buying all electricity under an E.H.T. two-part tariff or dealing with the factory in this way and generating for the mill by a back-pressure engine, exhausting into a vacuum heating and drying system.

The comparative costs are as follows :—

(a) Purchasing all electricity, 1,474,000 units at 0.785 <i>d.</i> . . . . .	£ 4,822
Heating and drying, 2,960 tons of coal at 40 <i>s.</i> . . . . .	5,920
	<u>10,742</u>
(b) Purchasing for factory and generating for mill.	
610,000 units for factory at 0.97 <i>d.</i> . . . . .	2,474
Heating and drying and power generation, 3,235 tons at 40 <i>s.</i> , generating 864,000 units for mill . . . . .	6,470
	<u>8,944</u>

showing an annual saving of £1,798.

The cost of a 125 kW set with switchgear is £2,500.

A third possibility is to instal a larger set capable of taking a proportion of the factory load.

In the winter months we could generate up to 200 kW burning little extra coal. In this way the maximum demand on the outside supply could be kept down and purchased units saved. With care 300,000 units could be saved in this way. The figures become :—

(c) 310,000 units purchased at 0.97 <i>d.</i> . . . . .	£ 1,253
Heating and drying and power generation. 3,300 tons at 40 <i>s.</i> generating 864,000 units for mill, and 300,000 units for factory . . . . .	6,600
	<u>7,853</u>
The saving is now . . . . .	<u>2,883</u>
The cost of a 200 kW set with switchgear is . . . . .	<u>3,500</u>

It is unlikely that this arrangement will work in parallel with the outside supply, but it is worth while pointing out that the set could generate outside factory hours 600,000 units per annum which the supply authority could have for nothing and sell for heating and sky signs when these are again permitted.

#### EXAMPLE E

A works has use for power and process steam at 300 lb. per sq. in. and 150 lb. per sq. in. pressure. Steam is generated at the higher pressure and superheated to 550° F. The bulk of the high-pressure steam not used for process is

already passed through turbines driving pumps, and discharges into the 150 lb. range. The balance of the 150 lb. steam, some 4·5 tons per hour, is obtained from the high-pressure mains through a reducing valve. A large electrical load is carried by the public supply.

It is obvious it would be an economy to extend the principle already employed in the turbines to driving another power unit by 300 lb. steam, exhausting into the 150 lb. mains. The fluctuating character of the demand for 150 lb. steam would make this difficult to arrange but for the fact that the works constantly takes more electrical energy from outside than can be generated from the high-pressure steam passing through the reducing valve. It follows that if this steam is used to generate electricity in a set running in parallel with the outside supply, a saving in units can be made in exact proportion to the existing demand for 150 lb. steam. The power thus made would not be employed to drive any particular machine but would be available for any purpose which already employs an electrical drive, and would produce a corresponding reduction in the electricity bill.

It may be difficult to get a supply undertaking to consent to a small alternator being synchronised with their mains, and such a machine with a fluctuating load is difficult to control. The machine itself is relatively expensive and the cost of suitable synchronising gear disproportionate. In view of the fact that the works is always taking a supply from outside, and the generator will never be called upon to run independently, it becomes possible to use an asynchronous machine which is simply a squirrel-cage induction motor run slightly above synchronous speed. Such a machine is simpler and less expensive than an alternator, has no brush gear, does not have to be synchronised, and can be brought on to line with no more current surge than is caused by starting an ordinary induction motor, which in fact it is. If a condenser is connected to the set so that its output is at about unity power factor, the connection to the line will serve only to fix the voltage and periodicity and to afford a means of putting energy into the mains. From the supply undertaking's point of view the effect is exactly the same as if the total load is reduced by a motor of similar size and similarly fluctuating load.

The 4·5 tons of steam an hour used in a small turbine will give an output of 45 kW but a reciprocating engine gives 94 kW. The choice is clearly a reciprocating engine.

The cost of such a set installed and connected up was £3,000. The gross annual saving working on a load factor of 50 per cent. with electricity at 0·75*d.* per unit is £1,300. The power is not obtained for nothing. With an engine mechanical efficiency of 0·9 and an electrical efficiency of 0·91, each kW requires 4,200 B.Th.U. equivalent to 3·62 lb. of steam. Thirteen tons of steam are obtained per ton of fuel at £4 5*s.* per ton. The cost for fuel of the 412,000 units generated per annum is £220 leaving a balance of £1,080 to cover standing charges and yield a profit.

## 2. Heat Conservation in the Dyeing and Finishing Trades

By E. E. STIMSON, A.M.I.CHEM.E., A.M.I.MECH.E., F.INST.F. and  
R. BUNTING, B.SC.

Fuel is the key factor in this, as in most trades. Apart from the national necessity for achieving maximum efficiency in the utilisation of fuel, there is no

escaping the fact that the present acute fuel shortage represents a definite limitation on production. No reminder is needed that the cost of industrial coal has been approximately trebled during the last ten years. In many cases there is an appreciable lag in the practical application of knowledge.

To achieve our object of using heat to the maximum advantage, it is obviously essential to know where every heat unit we generate, is going. This involves a complete survey of all heat-using units, not forgetting attendant distribution losses. In the dyeing and finishing trades, heat is applied to process almost exclusively in the form of steam, and it is convenient to consider heat utilisation under two main sections: steam generation and steam utilisation.

#### STEAM GENERATION

The Lancashire boiler lends itself admirably to the steam loading peculiar to the dyeing and finishing trades, and is almost universally used in the industry, particularly in the case of smaller works.

The average efficiency of steam generation in the trade is still deplorably low—60 to 65 per cent.—and the saving in processing costs which can be achieved by attention to this factor is appreciable, quite apart from the question of conservation of fuel. Steam accounts for 10 to 20 per cent. of total processing costs, so that the boilerhouse attendant is responsible for a very large item of expenditure.

The importance of control instruments in the boilerhouse is frequently overlooked and certain minimum requirements are necessary, comprising steam meters, draught gauges (over the fire and in side flues), CO<sub>2</sub> indicators and means for determining the amount of fuel used. Instruments will need regular inspection and servicing. It is equally important to ensure that the operators appreciate fully the significance of the readings.

An economiser should be regarded as an integral part of any boiler unit, providing, as it does, additional boiler heating surface at a lower cost than the equivalent surface in the boiler. Not only does the installation of an economiser effect a saving of from 10 per cent. to 15 per cent. in fuel costs, but it also results in an increased output from the boiler of approximately the same magnitude.

The installation of mechanical stokers in place of hand firing is also recommended as an economic proposition. A conservative estimate of 10 per cent. saving in fuel can confidently be expected. Add to this an increase in steam output of 20–30 per cent. and the desirability of the conversion is evident.

#### POWER GENERATION

A demand for process or heating steam at low pressure exists in the trade, and furthermore, steam and power loads are favourable to total generation of power requirements.

The requirements for one particular works will be taken as typical of the trade :—

Steam . . . . .	1·5 million lb./month.
Power and lighting . . . . .	10,000 kWh/month.

Steam was distributed at a maximum pressure of 140 lb. per sq. inch absolute, but more than half the steam was used at a pressure of approximately 40 lb. per sq. inch absolute.

Estimating the saving which would ensue if power generation was applied in this instance, we find :—

Initial steam pressure . . . . .	140 lb./sq. in. absolute.
Total heat . . . . .	1,193 B.Th.U./lb.
Total entropy . . . . .	1·575.
Exhaust pressure . . . . .	40 lb./sq. in. absolute.
Latent heat . . . . .	934 B.Th.U./lb.
Total entropy . . . . .	1·676.
Evaporation entropy . . . . .	1·284.
Entropy change = 1·676 - 1·575 = 0·101.	

Thus the wetness of the exhaust steam =  $\frac{0\cdot101}{1\cdot284} = 0\cdot0786$ , equivalent to a dryness of 91·56 per cent.

$$\begin{aligned} \text{The total heat of the exhaust steam} &= \text{Total heat of 1 lb. water} + \text{latent} \\ &\quad \text{heat of } 0\cdot9214 \text{ lb. steam.} \\ &= 1 \times 236 + 0\cdot9214 \times 934 \\ &= 1,096 \text{ B.Th.U./lb.} \end{aligned}$$

$$\begin{aligned} \text{Thus the adiabatic heat drop from} \\ 140 \text{ lb./sq. in. to } 40 \text{ lb./sq. in.} \\ \text{absolute . . . . .} &= 1,193 - 1,096 \\ &= 97 \text{ B.Th.U./lb.} \end{aligned}$$

Assuming a turbine efficiency of 65 per cent., the actual heat drop would be  $0\cdot65 \times 97 = 63$  B.Th.U./lb.

At 94 per cent. generator efficiency the power generated would be :—  
 $\frac{63 \times 0\cdot94}{3\cdot413} = 0\cdot0174$  kWh/lb.

The steam requirement for the generation of 10,000 kWh/month would thus be  $\frac{10,000}{0\cdot0174} = 575,000$  lb./steam/month.

Therefore, of the total steam generated, approximately one-third would be reduced to 40 lb./sq. in. in generating the total power requirements, giving 530,000 lb./steam/month at this lower pressure.

If only 50 per cent. of the heat in the condensate trapped from the wet steam is recovered by return to the hotwell, the overall heat loss per pound of steam fed to the turbine will be :—

$$63 + 0\cdot0393 \times 236 = 72\cdot3 \text{ B.Th.U.}$$

$$\text{This is equivalent to } \frac{72\cdot3}{1193} = 0\cdot0606 \text{ lb. steam at } 140 \text{ lb./sq. in.}$$

or roughly 30,000 lb./month additional generation.

On the basis of steam at 4s. 6d. per 1,000 lb. distributed and power purchased at 1d. per kWh the annual saving in fuel cost would be :—

*Case 1. Steam generated. Power bought*

Steam 1·5 million lb./month at 4s. 6d./1,000 lb.	£4,056 per annum.
Power 10,000 kWh/month at 1d./unit . . . . .	504 per annum.
Total cost . . . . .	<u>£4,560 per annum.</u>

*Case 2. Steam and power generated*

Steam 1·530 million lb./month at 4s. 6d./1,000 lb. = £4,130 per annum.

Total saving £4,560 - £4,130 = £430, equivalent to a saving of 9·4 per cent.

At present price levels, the turbo-generator would pay for itself in approximately two years, so that even on this small scale, power generation is an economic proposition. For larger installations, the economics of the conversion would be even more favourable.

It would be foolish to deny that difficulties could arise with such power generation. The need for maintenance of a steady steaming pressure would certainly become more acute, yet in some ways it might be advantageous to have attention drawn to the magnitude of peak steam loading in the trade. By the nature of the dyeing process, peak loading is inevitable, but if the seriousness of the effects of this evil on both generation and process were more widely realised, greater attention would, we feel sure, be paid to staggering of boiling-up times. The subject of "peak loading" is adequately treated in Fuel Efficiency Bulletin No. 26.

The magnitude of the sudden demands imposed in the trade is quite beyond the capacity of even a Lancashire boiler. The installation of a steam accumulator to obviate the major fluctuations in distributed steam pressure is strongly advocated. The greater part of the steam used in dyeing is supplied at low pressure and the accumulator principle is thus particularly applicable. Steam accumulators are costly, but any shell boiler not in use can be readily converted into an improvised accumulator. For example, a 30 ft. × 8 ft. 6 in. Lancashire boiler converted to this use will store 7,000 lb. of steam between 150 and 40 lb./sq. in. pressure and can discharge without priming at a rate of 20,000 lb. of steam per hour. With the provision of a steam accumulator and judicious staggering of boiling-up times, it should be possible to obviate in large measure the serious loss of efficiency and processing time resulting from excessive peak steam demands which are otherwise inevitable in the trade.

Except where power generation is practised, superheating of steam should never exceed the minimum requirements for offsetting distributional heat losses. Most of the steam used in the trade is applied at low pressures so that superheating by pressure reduction at the point of application is unavoidable. In dyeing and finishing processes, superheat is generally undesirable, resulting in loss of efficiency of application or reduction in output of equipment, and the installation of de-superheaters has been found justifiable for certain process demands.

**LATENT HEAT UTILISATION**

The higher the steam pressure the lower its latent heat content. It follows that the higher the steam pressure, the greater the amount of steam needed to provide a given quantity of latent heat. It is obviously advantageous to use the steam at as low a pressure as possible. There is, however, a second factor to be considered. The lower the pressure the lower the temperature of the steam. These two factors are in opposition, as the lower the temperature of the steam the less tendency is there for the heat in the steam to be usefully applied.

From the practical viewpoint there should be minimum resistance to the flow of heat from the steam. When designing equipment, the amount of

available heat transfer surface should be made as large as practicable, but with existing equipment this procedure cannot be adopted. There is, however, a course of action open to us.

Before the heat can be applied, it has to pass through the metal, a water film and a film of air. The relative conductivities of the three materials are 1,000, 1·7 and 0·1, assuming the metal wall to be copper. Obviously the major resistance to heat flow will come from the air and water films, so we must endeavour to reduce the thicknesses of these films to a minimum if heat is to flow readily to the outer metal surface.

(The authors then discussed the reduction of the thickness of the water and air films, steam traps, the need for keeping heat transfer surfaces clean, the desirability of individual trapping as contrasted with group trapping, air venting, the use of flash steam and the need for lagging; c.f. "The Efficient Use of Fuel", and bulletins 2, 22 and 28.

Having dealt with the generation and transmission of steam, the authors gave a general resumé of the steam-consuming operations involved in dyeing and finishing, making reference to some practical economy measures.)

#### SCOURING, BLEACHING AND STEEPING

As received by the dyer, textile fabrics and fibres are invariably contaminated, either with natural impurities or with oils or sizes added to facilitate previous processing, and it is generally necessary to remove the adulterants to some extent preparatory to dyeing. The nature of the scouring process obviously depends on the type of impurity, the class and form of fibre and the treatment the material is subsequently to receive, but in general, some application of heat is necessary.

Cotton is usually "bleached" in high or low-pressure kiers.

In this operation, the steam consumption is normally 0·8–1·2 lb. per pound of cotton processed, but far higher figures are frequently met, particularly where excessive liquor ratios are used and insulation of the kier is neglected. Appreciable steam savings can be achieved by utilising the heat in the spent lye by exchange with the first wash water.

Rayon, on account of its comparative purity, requires far less drastic treatment, and hot treatment is only resorted to for certain specialised grades of fabric. Where necessary, steeping is carried out at 80–95° C., either in open baths or continuously. In the open bath treatment, the pieces are steeped in "reel" or "hank" form for 1½–2 hours and reduction of steam requirements is effected by using the standing bath principle, the steeping liquor being changed approximately weekly. Figures for a typical batch will give some indication of the steam saving achieved by this conservation of sensible heat in the liquor. The steam required to blow a 10,000 litres bath up to temperature from cold is approximately 3,000 lb., while the maintaining coil uses roughly 200 lb. steam per hour at a bath temperature of 90° C.

Thus, starting with a cold bath for a 2-hour steep, a 200 lb. batch will use  $3,000 + (2 \times 200) = 3,400$  lb. steam. If the bath is re-used immediately after discharge of a batch, its temperature will be about 65° C. and with a water make-up of 400 lb. the blow-up steam required will be 1,000 lb. The total steam requirements in this case will be  $1,000 + (2 \times 200) = 1,400$  lb.

The saving of 2,000 lb. steam represents a reduction of 60 per cent. in the heat requirements to 7 lb. steam per lb. of fabric.

The steam consumption of the process is the same irrespective of loading so that in all cases the bath should be used to maximum capacity. In this connection, the use of compartmented baths has proved economic where full loading is not always practicable. The figures given are for metal baths encased with 3-in. pitch-pine boards which act as a fair insulator, a point which should not be overlooked in bath construction.

The desirability of covering the baths is obvious, but in our experience this has not proved to be practicable in all cases, since with certain rayon fabrics, the covers interfere with manipulation.

Total covering of the bath has been accomplished by using continuous steeping and the steam requirements for the operation are approximately halved, apart from the attendant reduction in the time and labour factors.

#### DYEING AND PRINTING

The dyeing of yarn in hanks is generally carried out in open rectangular baths, the hanks being suspended on sticks by means of which they can be turned occasionally, or alternatively the hanks are continuously rotated on porcelain arms as in the Sellars machine. Heat losses by evaporation from the liquor and exposed surface of the yarn are inevitably high and considerable economy in steam can be effected by completely enclosing the bath with a solid or fabric structure, e.g., Klauder-Weldon hank dyeing machine.

Three main economy points are worthy of mention in this class of dyeing. Firstly, the use of the minimum possible liquor/yarn ratio. The baths should always be loaded to maximum capacity compatible with handling of the particular class of yarn being dyed. By attention to this factor alone, the steam consumption for dyeing rayon yarn was reduced by 20 per cent. in one works, a ratio of 30 : 1 being found practicable for the finest yarns on the Sellars machines in use, while with the heavier deniers a ratio of 15 : 1 could be achieved.

A second economy measure is the use of the standing bath principle to obviate the steam wastage in blowing up the baths. Baths used for dyeing rayon yarn have been in use for 18 months without dropping with a steam saving of 25 per cent. Incidentally, the foreman in this dyehouse claims superior dyeing using this principle, no levelling assistants being needed once the bath has stabilised.

The third point is the insulation of the baths. There is a tendency to eliminate the wooden framework in dye baths nowadays.

This is a retrograde step from a heat economy point of view, as the wooden casing effectively reduces heat losses from the exterior of the bath.

The two principal machines used for dyeing piece goods are the "Jigger" and the "wince beck", the former being much more economical in steam usage, although limited in application to fabrics where warp tension is permissible.

The difference in steam requirements for dyeing with these two machines arises mainly from the much smaller liquor volume needed with the jigger. Thus, a wince beck for handling a 500-yards batch of fabric requires approximately 2,000 litres of liquor, while an equivalent jigger uses only 200–250 litres.

Reduction in steam consumption of dye jiggers can be accomplished by using a minimum liquor volume and reducing external heat losses to a minimum. The body of the jigger should be shaped to conform to the run of the fabric and if a single immersed roller is used, a liquid volume of half that

of the conventional double roller type can be accomplished. This shaping is illustrated in Fig. 39.

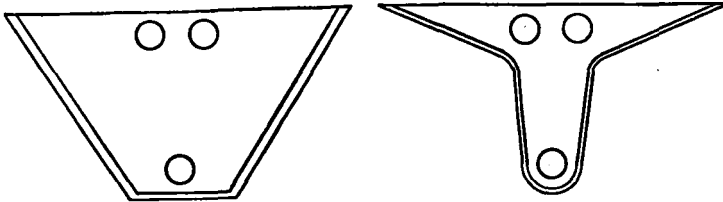


FIG. 39a. Original Type Jigger Body.

FIG. 39b. Modified Type Body.

Heat losses from the jigger arise by evaporation from the fabric and loss from the body of the bath. The evaporation loss has a serious effect on dyeing and it is usual to find live steam jets fitted between the rollers to prevent temperature reduction in the fabric, thereby assisting level dyeing and avoiding listing. These difficulties can be overcome by fitting covers over the jiggers, thus effectively reducing evaporation from the fabric and obviating the need for atmospheric steam supply. The covers may be constructed in wood with "Perspex" doors or may comprise a fabric canopy. In practice, a reduction in steam usage of roughly 25 per cent. results from covering. The heat loss from the body of the jigger is appreciable only in the case of cast iron construction and insulation usually takes three years for repayment. Provision of external insulation should, however, be considered when new jiggers are to be installed.

The steam consumption for wince-beck dyeing is approximately ten times as much as for the jigger so that an appreciable saving in total steam usage in the dyehouse would accrue from economies effected in this process. It is convenient to consider the steam requirements under two main heatings; boiling up and the actual dyeing period.

#### BOILING UP—WINCE BECKS

The boiling up of the beck is accomplished with an almost theoretical efficiency of utilisation of the available heat, provided that there is no direct steam loss due to superheat, so that saving is only possible by reduction in the quantity of water to be heated or the temperature interval through which it has to be raised. The water volume for a beck is only variable between narrow limits; it therefore follows that maximum loading with fabric should always be aimed at. Where batch sizes are necessarily small, the dyeing should be carried out in a smaller beck, but where this is not possible, the liquor level in the beck should be reduced proportionately to the size of the batch within the limits imposed by the beck construction. A factor closely associated with water requirements is leakage from the beck, as the make-up water has to be heated to bath temperature.

Leakages from the drain plug frequently go unnoticed except by the dyer and can constitute a serious steam wastage over the whole dyeing period. Routine inspection and maintenance of plugs is very desirable; we ourselves have experienced cases where defective drain plugs have accounted for 10-15 per cent. increase in steam required for dyeing and no report had been made to the maintenance engineer.

We have advocated the "standing bath" principle for steeping and yarn dyeing, and in wince-beck dyeing this principle can be applied to a limited



degree with attendant economy in steam. Normally, when a batch has been "shaded" the bath is cooled down and then dropped. If the bath is retained for the dyeing of a subsequent batch of similar shade, only half the normal boiling up steam will be needed for the second batch. For example, in dyeing a knitted rayon fabric, the bath is quenched to 45–50° C. and the fabric unloaded. The beck is then reloaded for dyeing and boiling up from 45–65° C. instead of 15–65° C. is required; this represents a 60 per cent. reduction in steam for boiling up and 20–25 per cent. on the whole dyeing process. This principle is not practicable in all cases but where feasible it certainly justifies application.

#### DYEING PERIOD—WINCE BECKS

The major heat loss during dyeing is due to evaporation from the exposed fabric and liquor surface and the rate of evaporation will depend on the humidity and velocity of the air over the beck. The humidity can be increased and the velocity decreased by covering in the beck and in practice a reduction of 25–30 per cent. in steam for maintaining the bath temperature is achieved by this means. Maximum reduction is obtained with a rigid covering with transparent plastic front and back sliding doors but a canopy of oiled fabric on a wooden framework is very effective. The following figures for a 4,000-litre beck with a capacity of 1,600 yards of rayon fabric will illustrate the advantage of covering. Actual dyeing tests were carried out under close supervision, first with the open beck and then after covering. The covering consisted of a wooden framework with fixed oiled fabric top, and sides, front and back curtains. Steam used was measured on a "Kent" shunt-type meter.

Water volume for all tests . . . . . 3,700 litres  
Yardage (Fabric 5 yds./lb.) . . . . . 1,500 yards

Temperature of liquor	65° C.		70° C.		80° C.	
	Steam lb./hr.	Per cent. saving	Steam lb./hr.	Per cent. saving	Steam lb./hr.	Per cent. saving
No covers . . . . .	280	—	310	—	590	—
Top and side covers . . . . .	230	17·8	260	16·1	525	11·0
Fully covered . . . . .	200	28·6	225	27·4	430	27·1

These figures are for "rayon" conditions, but where higher dyeing temperatures are used, the importance of covering is even more striking.

During the course of these trials some very interesting observations were made on the importance of accurate temperature control on the bath. For example, it was demonstrated that with a bath temperature varying by  $\pm 5^\circ \text{C.}$ , the steam usage was approximately 5 per cent. higher than at steady temperature, even though the bath was returned to normal before the end of the operation. Installation of a thermograph on a beck in normal operation by the dyer revealed that variations of this magnitude were quite normal, though it must be pointed out that with the guidance given by the temperature recorder, far closer control was subsequently achieved. Incidentally, the provision of an automatic temperature controller has justified itself in more even dyeing and easier repetition of batches due to more accurate shading, apart from time saving on the final matching process. Insufficient results have so far been obtained to justify any definite claims in this respect.

One observation which has since been applied in practice with a saving of 5-10 per cent. of steam on the dyeing process, was the possibility of dyeing at a falling temperature. The steam was turned off half an hour before the end of the dyeing time and the temperature allowed to fall. No difficulty was found in shading and as stated, this practice is now applied for normal production batches.

#### PRINTING

In the roller printing process, the main steam usage is in the drying and steaming stages. Drying will be considered under the next section, but the steaming and ageing operations can be classified as dyeing processes. The vat steamer and ager are similar in operating principles, differing mainly in the duration of the steaming to which the fabric is submitted, and economy suggestions apply equally to either machine. Physical wastage of steam in processing is high, often much higher than is absolutely necessary, and every endeavour should be made to ensure that only a reasonable safety margin in steam requirements is permitted. The steam exhausted from the chamber is generally contaminated and unfit for direct process application, but the latent heat can be recovered by condensation in exchange with water for washing and dyeing operations. Corrosion troubles are considerable and hot water storage necessary, but the available heat in this exhaust steam is worth some trouble in recovery. Precautions are invariably taken to eliminate condensation on the roof of the chamber, but the sides are often unlagged and appreciable steam wastage occurs here. While it is agreed that this condensation effectively prevents superheating due to the exothermic fixing reactions, the cost in steam may be unjustifiably high. The practicability of lagging of the side walls is proved by the number of successful steamers in use which are effectively insulated on all exterior surfaces.

#### DRYING

Although not actual steam users, mechanical dryers such as the mangle, centrifugal hydro-extractor and successe have an important influence on the steam required for subsequent evaporative processes. Operating conditions for these machines should be set to ensure optimum overall drying efficiency and their performance checked by batch weighing. Mechanical equipment has a habit of falling off in efficiency and the result in this case is abnormal, as the increased load falls on the cans or stenter, and in addition, the processing time becomes greater. Mangles should be checked for evenness in the nip, and hydro-extractors for speed and obstructions in the basket. If the hydro-extractor is belt driven, alignment and belt tension should be tested and lubrication of plain bearings given proper attention.

The commonest form of drying machine is the steam-heated can dryer. The two principal causes of inefficiency with this equipment are air locking in the cans and heat loss from the ends of the cans. Air locking is a very prevalent trouble and results in serious reduction in output with consequent increase in standing losses, due to lower surface temperature of the cans. To some extent this temperature loss can be compensated by increasing the steam pressure, but as indicated earlier, this results in higher steam consumption for the same heat output. The obvious solution to the difficulty is proper air venting. The ideal method of achieving this is the installation of individual traps to each can, preferably the balanced pressure thermostatic type since these are small and do not require air venting, but it is generally impracticable to do this as

the condensate header forms part of the frame of the machine. Under these circumstances, automatic air vents should be fitted at the tops of the headers, and steam traps with automatic air vents installed as close as possible to the bottom of each header. By this means the evils of group trapping incorporated in the design of the machines will be minimised. The heat loss from the ends of the cans means wasted steam and can be effectively reduced by fitting sectional end covers made from insulating board. A further steam wastage with these dryers is manipulative ; steam left on the cans when idle. There is some excuse for the operator when air-locking troubles are present, as heating up is then very slow, but if vented and trapped as advocated, the drying temperature is rapidly attained.

The can dryer has several disadvantages, it does not permit width control, it creates warp tension and it tends to give a harsh finish to the material. Where these deficiencies cannot be tolerated, the convection type of dryer is employed. There are several variations of this latter type of dryer, but in principle they are all similar, hot air being blown over or through the fabric to evaporate the moisture.

The factors influencing efficiency in heat utilisation in hot-air drying machines are :—

- (1) Efficiency of the air heaters.
- (2) Temperature and humidity of the exhaust air from the machine.
- (3) Conduction through the chamber walls.

It will be convenient to consider these factors in their relation to hot-air stentering machines.

#### I. AIR HEATING

Incidental heat losses from a stenter are inevitably considerable so that maximum rate of throughput of fabric must always be aimed at. This obviously involves maximum output from the available heat transfer surface, and for efficient steam utilisation the lowest possible steam pressure should be used. The influence of water and air dilution on heat transfer rates and the effects of steam and air locking of traps have already been mentioned but it is surprising how often the elementary precautions necessary for obviating these troubles are overlooked in practice. With the single-run type of heater, for example, provision of adequate fall to the outlet to permit effective drainage of condensate is often neglected, or a concentric reducer is fitted to the heater outlet, resulting in the bottom of the pipe being full of water and completely ineffective from the point of view of heat transfer. Such heaters should be effectively drained, using eccentric reducers with ample fall to the outlet, and traps should be of the open top or inverted bucket type to withstand the effects of water hammer associated with this class of heater. Air vents of the liquid expansion type should also be fitted on the drains immediately before the traps.

With heater elements fitted in parallel between steam and condensate headers, the same precautions for condensate removal will apply and in addition the possibility of by-passing certain elements must be watched.

In the case of multitubular unit heaters the danger of steam locking is particularly acute, as their location usually involves fitting the steam trap some distance from the condensate outlet. Here a trap fitted with steam-lock release should be installed, air venting, of course, being additionally required.

Heat transfer from the heater tubes to the air will be improved as the air velocity over them is increased, and the installation of baffles often assists in this connection on forced convection units.

In all cases, the condensate discharged should be passed to a flash tank for recovery of a portion of its heat as low-pressure steam. In some instances we have found this condensate being used in a supplementary heater placed on the cold-air intake with consequent further increase in output from the machine.

## 2. AIR TEMPERATURE AND HUMIDITY AT EXHAUST

For maximum theoretical efficiency, the fabric being stentered should leave the machine in a suitably conditioned state at the temperature of the incoming air, while the air exhausted should be completely saturated, the air and fabric travelling counter-current to one another. Such conditions would involve a stenter of infinite length and in practice a compromise has to be made. The rate of evaporation of moisture from the fabric determines the length of run necessary to effect drying, and is in turn governed by the humidity, temperature and velocity of the air over the fabric. The maximum operating temperature is restricted by the nature of the material being processed, but humidity and air velocity can be controlled. Air velocity at the fabric surface can be increased by reducing the free space in the drying chamber and passing the air from side to side across the fabric *via* the heater, thus giving it a longer passage between inlet and exhaust. Alternatively the air may be re-circulated over and under the fabric in stages or direct impingement of the hot air from jets or slots may be applied.

From the point of view of capital cost and stenter dimensions, some degree of air velocity increase should therefore be attempted. Low humidity results in excessive heat loss in the exhaust air and high power cost on the fans, so that the highest practicable humidity in the air leaving the stenter should be aimed at.

Humidity control can be effected by varying the rate of feed of fabric, the chamber temperatures and quantity of air exhausted. Rate of fabric throughput will obviously be as high as practicable, but the two other factors will depend on the material fed. Temperature control is eased by provision of independent sectional heaters and this is strongly recommended. Quantity of exhausted air is, however, the final control and this can be accomplished by provision of a damper in the air outlet on the machine. Indicating or recording hygrometers are available and their installation on the exhaust vent is strongly advocated. The amount of moisture to be evaporated in the machine inevitably varies from batch to batch and for efficient operation, a knowledge of the humidity at any time is essential.

From what we have said, it is evident that all the air used should be taken in at the fabric exit and exhausted at the feed end of the machine. On many stenters, however, there is considerable air leakage along the length of the stenter, which represents a serious heat wastage as maximum humidity conditions can only be attained at the exhaust end of the machine. Every effort should be made to eliminate these leakages. It is quite usual to find the fabric feed passing through an open gap of considerable proportions, sufficient in fact to pass more air than is needed for the drying process. Under these conditions humidity control is impossible and the gap should be reduced to a minimum by means of shutters. The importance of this point was brought home very forcibly to us recently when we were proudly told that an appreciable reduction in steam consumption in the stentering process had been achieved by shutting off the exhaust fan; the saving was no doubt commendable, but we wondered how much greater the potential economy might be.

## CONDUCTION THROUGH THE DRYING CHAMBER WALLS

The external surface area of the drying chamber on a stenter is large and very considerable heat losses will occur unless adequate insulation is provided. Lagging with  $1\frac{1}{2}$  in. of cork slab, hair felt or similar insulator gives approximately 80 per cent. reduction in loss of heat from this cause.

The drying efficiencies of stentering machines vary widely and generally the deviations from good average performance are readily explained after even a casual inspection of the plant. There are far too many stenters still in use which have a matchboard heating chamber and single air-feed fan with full length run gilled heating tubes. With such units it is difficult to maintain a ratio of steam used to moisture evaporated of 6 : 1 whereas a well-designed efficiently lagged stenter will give a ratio of 2 or 2.5 to 1. Complete re-design of the heating chamber and air system is the only satisfactory solution in this case. In one conversion we saw recently, the old chamber and air system had been scrapped and replaced by a panelled sheet-iron cork-insulated structure with sectional heaters and re-circulation fans. The total cost for the job was just over £1,000 which would be recovered on steam saving alone in two years. Actually, the feed rate for fabric was stepped up 50 per cent., and of course, the finished stenter represented a considerable increase in capital value over the original inefficient unit.

In the present circumstances, the performance figures of all equipment should be reviewed and serious consideration given to conversion or replacement of inefficient units. Maximum output must be the objective of all managements, and equipment which does not attain a certain level of heat utilisation efficiency must be regarded as a limitation on this policy. In the long run it may pay to scrap such equipment for the sake of increasing production with existing fuel availability.

Most of the special finishing machines are comparatively small steam users, but in total they represent a fairly considerable steam consumption. In general, the major economy lies in obtaining maximum possible rate of throughput.

Proper steam trapping and air venting are often the key to this problem, and survey of all calenders, embossing machines, presses and similar equipment from this viewpoint may indicate points for additional economies. The possibility of using flash steam on these units is also worth attention and it will often be found practicable to use this low-grade heat when proper attention has been given to steam trapping.

We have endeavoured to give some indications of potential steam saving on individual units in the hope that these examples will encourage the study of efficient steam utilisation in all stages of processing. Too often we have found a surprising lack of information on the steam usage of the various items of equipment involved in dyeing and finishing and we return to our earlier statement that to effect substantial economies it is imperative to know just where the steam is used. On indirectly heated equipment, much useful information can be obtained by condensate measurements, and where this method is not possible we advocate the use of a steam flow meter. Meters of the shunt type are inexpensive and generally justify purchase on the saving they indirectly create. If such a meter is installed for short periods on the main steam-consuming units in turn, a check on operational improvement in unit steam consumption invariably ensues.

We turn now to the question of control instruments. The dyeing and finishing trade generally compares very unfavourably with the chemical and

other industries in the application of instrumentation to their processes. In our opinion, a far more rigid control of operations and a higher degree of efficiency would result from an increased use of modern scientific instruments. Where they have been applied they have proved almost indispensable and an undoubted economic proposition. Temperature, humidity and fabric dryness can all be controlled far more accurately with the aid of instruments than by rule of thumb methods, and once the operator gains confidence in these aids he finds time to give those incidental attentions which mean so much in obtaining a perfect result.

While on the subject of control we should like to mention a control system for the entire process which, as applied to one works, has resulted in a truly astounding reduction in fuel wastage. Each day a "target" steam consumption is prepared for the work in hand. An "ideal" steam consumption for every piece of equipment has been determined and standard factors prepared for range losses, fog dispersal, space heating, etc. From this information it has been possible to determine approximately how much steam should be used for processing any type and finish of fabric. The work for the day is analysed into machine hours and hence steam consumption, and, after addition of the standard factors, gives a target steam consumption which can be compared with the actual usage as measured by the main steam meter at the end of the day's working. Any difference greater than 5 per cent. results in a detailed analysis of machine cards which show the times of processing the various batches. The system works satisfactorily and employs one girl clerk for 3-4 hours/day, but it is only fair to say that a considerable amount of spadework was needed to establish the system and fit it in with an existing bonus scheme. However, the system pays good dividends and we strongly advocate the application of some such scheme to every dyehouse to ensure the maintenance of the highest level of efficiency in steam utilisation. A preliminary survey is essential, but the work thus involved is almost sure to be justified by the consequent elimination of wastage.

In this paper we have endeavoured to emphasise the importance of a complete appreciation of the utilisation of heat in every stage of dyeing and finishing processes and have advocated proper instrumentation as an aid to the maintenance of the highest level of efficiency. The importance of a "target" for every process cannot be over-emphasised. Our experience may have been unfortunate, but nevertheless we have been astounded at the lack of reliable performance data in the various dyeing and finishing works we have visited. In far too many cases we have encountered the attitude of "leave well alone" and, while we appreciate the high standard of shade and finish demanded of the trade, we do feel that the present emergency demands a more venturesome outlook.

### 3. Steam Utilisation in the Dyeing and Finishing Trades

By C. T. WADE

In my experience, if proper attention is paid to the design and layout of a dyeing and finishing plant, it should be possible to generate all the power required without wilfully discarding a single B.Th.U. in the form of cooling water or steam blown to atmosphere.

In support of this statement I begin by examining a few typical steam-consumption figures (Table 1) which, in common with all data in this paper, are based on records taken over a considerable number of years on the various plants with which I am associated. It is obvious that there will be considerable deviations from these figures on other plants but in the very great majority of cases these deviations are not sufficiently serious to affect the issue.

For the sake of convenience these consumptions are expressed in pounds of steam per yard of cloth processed. They are grouped under four main headings:—(1) Steam which can be supplied in the form of hot water, (2) Steam which can be supplied at pressures of 10 lb./sq. in. or under, (3) Steam for generating power (a steam pressure and temperature are assumed which are well within the limits of normal Lancashire boiler practice), and (4) Steam for all other requirements. These will be considered in more detail.

TABLE I  
STEAM REQUIREMENTS FOR WORSTED PIECE DYEING AND FINISHING

	lb. of steam per yard processed
(1) Steam which can be supplied as hot water (120–140° F.)—	
Scouring . . . . .	2·5
Boiler feed water preheating . . . . .	2·0
	4·5
(2) Steam which can be supplied at low pressure (10 lb./sq. in. or under)—	
Dyeing . . . . .	15·0
Space heating, etc. . . . .	2·0
	17·0
(3) Steam for generating power (160 lb./sq. in., 500° F.)—	
(A) Exhaust 25 in. Hg. vacuum . . . . .	4·0
(B) Exhaust 10 lb. per sq. in. back pressure . . . . .	8·0
(4) Steam for all other requirements . . . . .	8·5

(1) *Steam which can be supplied as hot water.*—Under the heading of steam which can be supplied in the form of hot water is, first, steam for scouring. This is usually supplied in the form of steam which, having been brought on to the job in this form, is there mixed with cold water in order to produce hot water for the process. The only point which I wish to make at the moment is that, if it so suits our book, there is no reason why a scouring machine should not be supplied with hot water just like an ordinary domestic bath.

Next under this heading is steam for preheating feed water in order to bring it to a temperature at which it can be safely and economically introduced into the economisers. When embarking on power-conversion schemes for anti-quoted dyeworks it must not be forgotten that the old steam engine which it is often proposed to replace by a public power supply or a pass-out turbine, quite apart from keeping the wheels going round, is generally providing the major part of the heat required for preheating the feed water used for supplying the steam not only for its own modest requirements but also for all other demands, which in practice usually amount to nine or ten times the quantity used in the engine.

(2) *Steam which can be supplied at pressures of 10 lb./sq. in. or less.*—First under this heading is steam for dyeing. I should have liked, if time had permitted, to have said something at this point about the psychology of dyers and the dark superstitions to which they are heirs. For of all these superstitions none is more deep-rooted than the belief that the nominal steam pressure in their dyehouse range has some mystical significance in the dyeing process. It is now 20 years since I first installed a dyehouse steam-range designed to operate at 8 lb. per sq. in. instead of the 80 lb. per sq. in. which had previously always been considered indispensable, but time has not dimmed the memory of that struggle. So, if by any chance there is anyone present who is engaged in a similar struggle today, I should like to bid him good cheer and assure him that the years which have elapsed since that time have abundantly confirmed that 8 lb. to the sq. in. is an admirable steam pressure for dyeing.

Under this heading is also space heating, which is a variable requirement. Of course, if these low pressures are used for space heating, additional heating surface may have to be installed in order to compensate for the lower temperature of condensation of the steam, but that need not worry you unduly, because by the time you have reorganised the steam-distribution system in an old dyeworks and thrown out all the pipes which are serving no useful purpose, you will usually have enough pipework on your hands to wrap round and round your works as often as you want.

(3) *Steam for generating power.*—I have budgeted for two cases—the first that in which power is generated by a condensing engine working at 25-in. vacuum, and the second in which it is generated by a back-pressure set exhausting at 10 lb./sq. in. back pressure.

(4) *Steam for other requirements.*—Lastly we have all the miscellaneous users that for one reason or another require steam at pressures in excess of 10 lb. The steam which they use represents so much boiler feed-water, which has to be preheated under heading (1).

#### BALANCING POWER AND HEAT REQUIREMENTS.

Suppose that we generate power by a back-pressure set exhausting at 10 lb./sq. in. There will be for disposal 8 lb. of low-pressure steam for every yard processed and the market in which we shall have to sell this commodity will be provided by the demands listed under headings (1) and (2), which together total about  $2\frac{1}{2}$  times the quantity we have for sale. The catch, which arises here, is that the process steam demands in a dyeing and finishing plant are subject to the most agonising fluctuations and, while there will be considerable periods of the day when the demands for steam for scouring and dyeing are greatly in excess of those for generating power, there will be other periods when they are considerably less.

My answer to that one is hot water storage. A well-designed hot-water storage tank is just about the most efficient form of heat accumulator which it is possible to have, and, if the demands under heading (1) are properly exploited and served in connection with a hot-water storage system, it will be found possible to chop off the peaks and fill in the troughs in the boilerhouse steam-demand curve in the most pleasing manner.

#### PRACTICAL WORKING DATA.

In order to illustrate these points curves are reproduced in Figs. 40-46 showing the conditions during an actual typical working day selected at random from my records of a plant working on these lines.



The plant in question, or that part of it which concerns us at the moment, consists firstly of a geared back-pressure turbine-driven alternator—a simple single-velocity-stage machine using steam at 150 lb./sq. in., 500° F. at the stop-valve and exhausting at 10 lb./sq. in. As an alternative to this there is a vertical compound high-speed engine-driven alternator. Then there is a turbine-driven feed pump working under the same steam conditions as the main turbine and as an alternative to this a direct-acting steam-driven feed pump. There is also the low-pressure steam distribution system, which is provided with a hydraulically-operated pressure-regulator on the make-up side and, lastly, there is a 50,000 gallon capacity hot-water storage tank insulated on the top and sides with 4-in. of loose granulated cork and having the main vent and overflow water-sealed to prevent circulation of air.

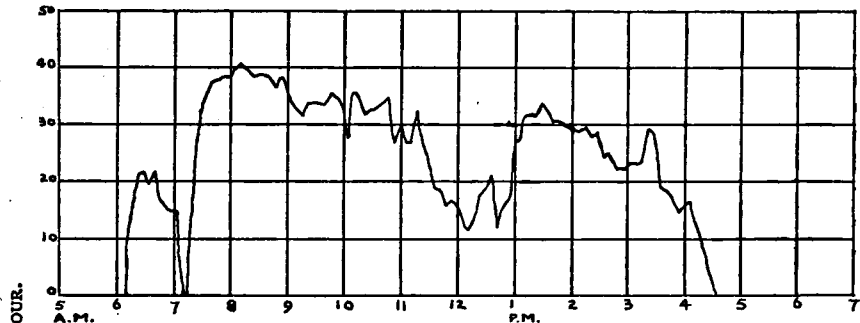


FIG. 40

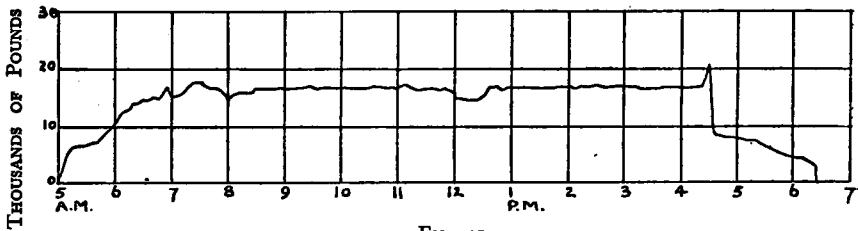


FIG. 41

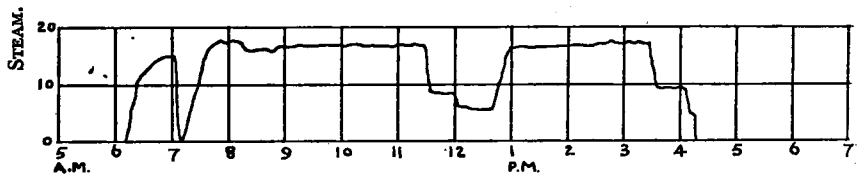


FIG. 42



FIG. 43

Fig. 40 shows the total dyehouse steam demand on the day in question. Fig. 41 shows the total steam supplied to the power units.

Fig. 42 shows the low-pressure steam exhausted from the power units direct into the dyehouse main. It follows that Fig. 42 must fit inside either Fig. 40 or Fig. 41, since it is practically the highest common factor of these two curves. It will also be appreciated that the difference between Fig. 41 and Fig. 42 represents the surplus exhaust steam, which is converted into hot water and used for charging the hot-water storage system.

Fig. 43 shows the steam which would have been used for generating power if the power had been generated under condensing conditions. This curve was actually taken from another set, when an almost identical electrical load was carried on the condensing set.

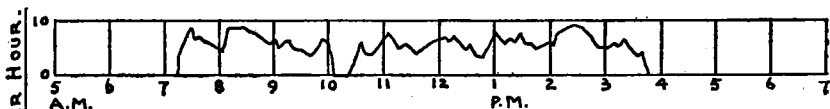


FIG. 44

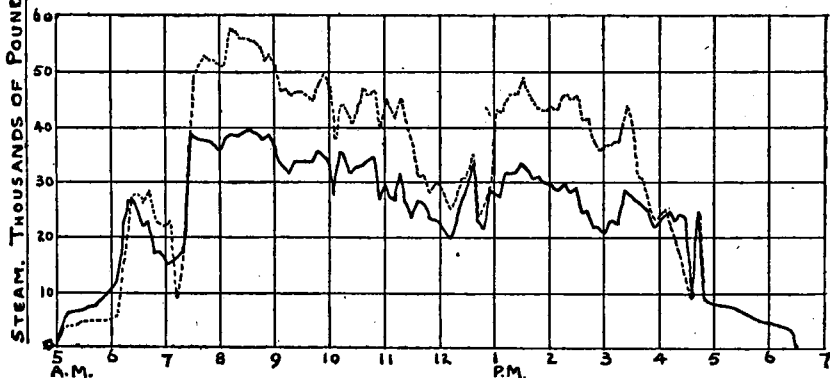


FIG. 45

Fig. 44 shows the steam which would have been used for scouring had steam in fact been used instead of hot water. This record again was taken on another day, when the work passing through the scouring department was approximately the same and when live steam was used for the process.

Fig. 45 compares the net results of these various operations. It shows the total steam used for the four services which have been considered, that is to say power, scouring, dyeing and feedwater-heating. The full-line curve shows the steam actually used for these purposes, while the broken-line curve shows the steam which would have been used had the hypothetical conditions at Figs. 43 and 44 obtained, that is, if power had been generated on a condensing basis and live steam had been used for scouring instead of hot water. The planimeted integrals for the two curves are for the full line 318,400 lb. and for the broken line 378,400—a clear difference of 60,000 lb. of steam for the day's working. But this is only half the story. The full-line curve has a very much better shape considered as a demand on the boiler plant than the broken-line curve; between 7.30 a.m. and 4.0 p.m. the maximum variation in the case of the full line is 19,000 lb. compared with 34,000 lb. for the broken line; and I can assure you, speaking from long experience of this plant, that the final effect of this improvement in shape expressed in terms of coal consumption is no less than that due to the reduction of 60,000 lb. in the total steam-demand.

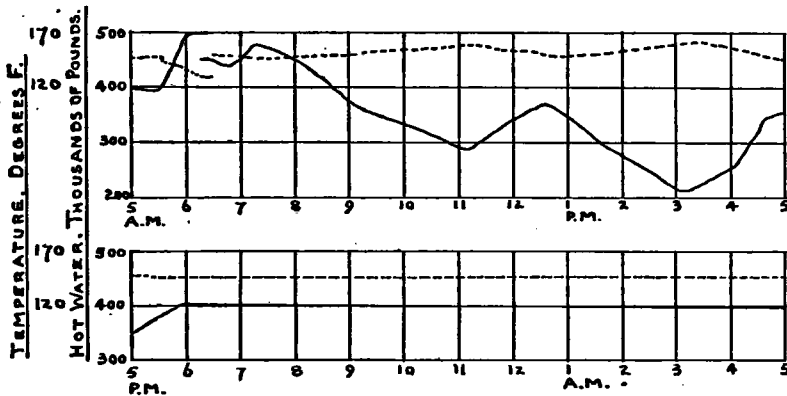


FIG. 46

Fig. 46 provides a sort of commentary on the other curves. It shows the state of affairs inside the hot-water storage tank during the 24 hours. The full line shows the quantity of hot water and the broken line the temperature. If these curves are compared with Fig. 40, it will be found that wherever the dyehouse steam demand is light the hot-water storage system is being charged up and wherever the dyehouse steam demand is heavy the hot-water storage tank is discharging. It will also be noted that the net result of this particular 24 hours' working is a very slight increment in the heat content of the accumulator. The heat-losses during the night are negligible. In point of fact this tank has on occasion stood for as long as ten days full of water at 150–160° F. and the total temperature drop during that period has been of the order of 5–6° F.

#### 4. Heat and Power in the Hosiery Industry

By H. W. PERKINS, A.M.I.E.E., M.INST.F.

The Hosiery Coal Rationing and Fuel Efficiency Committee was formed in 1942 to investigate the generation and utilisation of light, heat and power in the industry and to advise manufacturers in the efficient use of fuel in general.

In 1941, the industry consumed an average of 4,066 tons of solid fuel a week. This figure had fallen to 2,996 tons per week in 1945, a reduction of over 25 per cent. or 50,000 tons per year, with a constant output in terms of clothing. In addition, many unusual and additional tasks were undertaken, some of which had a tendency to increase fuel consumption. During 1945, 54 per cent. of the fuel used in industry was classified as opencast or dry slack.

The industry is made up of many small units, over half of which consume less than 250 tons per annum; no potential saving is too small to receive consideration. Coal will never again be cheap, and there is a tendency for a still further rise over present-day costs which makes it essential to achieve the highest degree of efficiency. The higher the cost of fuel the greater the incentive towards efficient utilisation.

The consumer is largely a victim of circumstances and is not always to blame. The boiler plant and steam equipment manufacturer must be asked to provide more efficient plant. Many large installations are operated at a high

degree of efficiency, but the smaller boiler plant is a different story. Exit flue gas temperatures are usually too high in small plants. All boilers above a certain minimum coal consumption should be equipped with the necessary control instruments.

Makers of steam utilisation equipment, with one or two exceptions, are no better than boiler makers in this matter of efficiency. Machines are built and sold operating at pressures and temperatures far higher than is technically necessary for a particular process usually on the grounds that the process time is supposed to be speeded up or that the machine is cheap in first cost. Such a machine may be cheap in first cost, but is usually expensive in fuel utilisation and running costs. This is the reason why temperatures used in textile drying and conditioning are usually too high. In one instance, temperatures were reduced from 200° F. to 160° F. after machine modification had been made, and this resulted in a steam consumption very near to the theoretical value, reduced the process time very considerably and produced a fabric far superior in "feel" to that produced by the use of higher temperatures.

Hosiery manufacturers from the time of the old hand knitting frames have always welcomed new ideas and inventions that will give worth-while results, which accounts in large measure for the highly complicated and intricate machinery in use today, capable of knitting very delicate fabrics in elaborate design at high speed. When the advantages of thermostatic control were made known and understood, hosiery manufacturers installed it with enthusiasm and with good results. There are today in the hosiery industry, many good examples of space heating control within very fine limits. Certain types of hosiery manufacture demand fine temperature tolerances and not only has this been achieved by properly installed thermostatic control devices, but in many cases conditions have been so improved that wastage has been reduced and the production of first quality goods increased by as much as 8 per cent. In the future, the hosiery industry will study every technical advance in the field of fuel technology not only as items of scientific and academic interest, but as factors of prime importance in the reduction of production costs.

## 5. Power for Cotton Mills

By R. H. HARRAL, M.I.E.E., M.INST.F.

The problem I wish to examine, with particular reference to the cotton textile industry, is the determination of the most efficient and economical method of supplying motive power, light and heat for industries of all kinds.

### PAST AND PRESENT PRACTICE

It has been the practice in the past for cotton mills to provide steam-raising plant, generally Lancashire boilers, and to drive the mills by steam engines of various types. The mills are heated by steam, usually taken from the boiler direct through a reducing valve. When coal was plentiful and cheap, it was possible for the mills to operate at low cost despite the fact that the methods used might have been extremely wasteful. It is perhaps true to state that it is largely due to the fact that coal was cheap in the past that present-day methods are so wasteful.

## THE QUESTION OF MAXIMUM FUEL EFFICIENCY

During the fuel efficiency campaign, attention has been focussed on waste associated with steam-raising plant, but little or no notice has been taken of the uneconomical mechanical transmission methods used in the average textile mills ; yet experience has shown that these losses amount to as much as 20 per cent. to 25 per cent. of the total load. It is useless to introduce fuel saving "gadgets" for fitting on "time expired" boiler plant which cannot be brought up to a reasonable standard of efficiency. Moreover, the cotton manufacturer is concerned with the complete modernisation of his production machinery and the improvement to the mill must be considered as a whole. The only way, therefore, in which all-round economy, resulting in fuel saving to the country and greater production with improved quality at lower cost to the manufacturer, can be effected, is by the adoption of electricity from public supply.

The principal claim made for electrification is that it provides entirely new methods for driving and lighting cotton mills. It is not sufficient to state that electricity is merely a substitute for the steam-driven prime mover, and modernisation must eliminate as far as possible the considerable waste of mechanical energy which occurs in transmitting the motive power from the prime mover to the machine.

## COTTON TEXTILE SURVEY

With a view to finding a solution to the problem of dealing with the cotton power load, and in the hope of making some constructive contribution to the reorganisation of the cotton textile industry, the British Electrical Development Association set up in 1945 a committee in the North-West England and North Wales area to prepare reports and co-operate with all interested parties. As chairman of that committee I would like to report progress during the past year.

There being no accurate record of existing prime movers and methods of driving, or of the extent to which electricity is used in cotton mills, a complete survey was carried out in co-operation with 29 neighbouring electricity undertakings. The survey covered 635 spinning mills, 551 weaving sheds and 205 bleaching, dyeing and finishing works—a total of 1,391 factories.

The existing use made of public supply is indicated by the following table :—

	No. of factories	Percentage of total
Mills using public supply both for power and lighting . . . . .	349	25·1
Mills using public supply for partial power and lighting . . . . .	555	39·9
Mills using public supply for lighting only . . . . .	114	8·2
Mills not yet connected to public supply . . . . .	373	26·8
	1,391	100·0

The total annual consumption of all the mills using public supply is 363 million units of electricity. If all the remaining mills were changed over to electricity they would require an additional consumption of some hundreds of millions of units.

## ADVANTAGES OF COMPLETE ELECTRIFICATION

The advantages of complete electrification of the cotton industry can be briefly summarised. The steadier drive of the electric motor inevitably tends to increase the output and improve the quality of the goods. Where the change to electric driving has taken place, production has increased 3 per cent. in spinning and up to 10 per cent. in weaving operations.

Electrically-driven mills are notably cleaner, better lighted and in all respects healthier for the workpeople. The improvement of amenities in textile factories will help in solving the serious problem of labour shortage in the cotton industry. Advantages to the nation and the general public would be cheaper electricity, reduction in atmospheric pollution and the replacement of the high-grade coal now used in factory boilers.

## COTTON WORKING PARTY'S MEMORANDUM

A memorandum was also sent to the Cotton Working Party, and their Machinery Sub-Committee agree that "the desirability of electric driving appears to be generally conceded".

The Sub-Committee also agreed :—

(a) That, should a steam engine need replacement, it would be best to change to electricity.

(b) That in the case of a new mill, individual electric drives should be installed.

## ECONOMICS OF FUEL USAGE

In the Table 14 (page 34) of the Cotton Working Party report, it is stated the three sections of the industry consumed in 1937 a total of 4,619,100 tons of coal and 500,860,000 units of electricity. To produce the purchased electricity about 336,000 tons of coal would be used at a power station, bringing the total equivalent consumption of coal to 4,955,100 tons. Investigations show that by converting all existing steam drives to electricity, the saving in coal would be at least 750,000 tons a year, i.e. over 15 per cent. of the total tonnage, which at £2 10s. *od.* a ton costs the industry £1,875,000.

## PROGRAMME OF REQUIREMENTS

To carry through a scheme for converting the cotton textile industry to electric drive would involve a number of problems requiring for their solution the full co-operation of Government departments, and the electrical industry. Taking the range of motors between  $\frac{1}{4}$  horse-power and 30 horse-power, the total of motors and starters which will be required will not be far short of 500,000. This number, which ignores entirely the extensive motor equipment which may be needed for air conditioning, dust extraction, etc., is considerably in excess of the present productive capacity of the electrical manufacturing industry. Unless, therefore, this capacity can be very appreciably increased there will be a serious delay in re-equipping the textile industry on the lines of the Cotton Working Party's recommendations. The Government departments and the electrical manufacturers and the suppliers of electricity should co-operate to programme the requirements of the textile industry as a whole.

My committee desire to point out that the installation of new factory drives is being delayed for another reason, namely, the shortage of labour and material for the installation of both electrical and mechanical equipment.

## PROGRESS AND FUEL ECONOMY

Substantial progress is being made in cotton mill conversions as the figures given below clearly show. The progress made in electrification during the

year ending September, 1946, is perhaps one of the best contributions which any industry has made towards fuel saving.

From a further investigation made by the committee, it is found that, in the year ended September 30th, 1946, the following progress has been made in electrification of the industry :—

	Wholly changed over to electricity		Partially changed over		Under modification	
	No. of mills	kW	No. of mills	kW	No. of mills	kW
Spinning .	9	3,782	17	6,260	51	26,106
Weaving .	8	2,015	31	3,610	46	7,368
Dyeing and finishing.	2	850	1	100	3	1,350
<b>Total .</b>	<b>19</b>	<b>6,647</b>	<b>49</b>	<b>9,970</b>	<b>100</b>	<b>34,824</b>

*Summary :—*

Total mills converted . . . . .	168
Amount of electric power involved . . . . .	51,441 kW
Equivalent saving in fuel when completed . . . . .	90,090 tons a year

## 6. Public Electricity Supply in the Woollen Industry and Ancillary Trades

By T. H. CARR, M.I.C.E., M.I.MECH.E., M.I.E.E., M.INST.F.  
CHAIRMAN, E.D.A., WOOLLEN INDUSTRY SUB-COMMITTEE

In June last the Mid-East England Area Committee of the British Electrical Development Association submitted a Report to the Board of Trade Wool Working Party in which the case was made for the adoption of a public electricity supply in the woollen industry and ancillary trades.

A general survey of this area was made through electricity supply authorities to ascertain the amount of private power plants still in use in this industry and its allied trades. The types and outputs of these private plants are as follows :—

	<i>h.p.</i>
Steam engines . . . . .	200,000
Steam turbines (direct drive) . . . . .	4,000
Steam turbo-electric sets . . . . .	23,000
Oil engines . . . . .	3,500

By far the greatest saving would be made by the change-over of the steam-engine plants, and it is estimated that some 360,000 tons of coal a year would be saved, representing a saving approaching 60 per cent. Making reasonable assumptions, it is calculated that this steam-engine load would be equivalent to about 340 million units a year.

The survey returns show that the annual consumption of electricity for the industry approached 120 million units for the year ended 31st March, 1946.

To take a specific case, the highest annual consumption of electricity for the industry in Bradford was 37 million units in 1940, whereas it is estimated that by changing over existing steam engine plants (56,000 h.p. approx.) to public supply some further 120 million units would be required. The saving in coal would approach 80,000 tons per annum.

Over a long period of years there has been an increasing tendency for the industry and its allied trades to turn to public electricity supply, e.g. in Bradford the annual consumption was less than 5 million units in 1920 but reached 37 million units in 1940. Due to war-time restrictions it fell to 27 million units in 1945. Change-over from steam-engine plants to public electricity supply in the Bradford area at the present time approaches 6,000 h.p.

#### ADVANTAGES OF ELECTRIC DRIVE

##### (A) STEADINESS OF DRIVE

It is generally acknowledged by the woollen industry that a steady drive, free from cyclical variation, ensures the best possible production of material. In spinning, it is apparently important to have a constant drive in order to produce the finest yarn. In weaving, constancy of drive appears to be equally important as any variation of speed may cause unevenness in the material woven; moreover, indifferent operation of the looms is also possible due to the shuttle receiving impulses of varying strength.

With the reciprocating engine, cyclical variations are inevitable, and these may assume considerable proportions. Cyclical variation is entirely absent in an electric motor driven from a public electricity supply owing to the absence of any reciprocating motion in the prime mover.

##### (B) HIGHER RUNNING SPEED

In the woollen industry there appears to be a maximum speed at which material can be satisfactorily processed and to obtain maximum production the plant should run as near as possible to this speed.

With electric drive, free from cyclical speed variation, the high speed desired can be obtained, whereas with the reciprocating engine, because of the cyclic irregularity, a margin below the most efficient speed is inevitable.

##### (C) INDIVIDUAL DRIVE

It is only by using electricity that individual driving can be adopted. This method of drive provides greater control of operation, more efficient production, and easier control of costing. It also eliminates overhead shafting and belting, and thereby not only ensures considerable reductions in the cost of engineering and maintenance, but increases the amenities of the factories, thus providing improved working conditions for the operatives.

It is only by the adoption of the individual electric drive that the modern automatic loom can be used.

##### (D) FLEXIBILITY OF OPERATION

It is often desirable to drive part of the plant only, and with an individual or small group electric drive this operation can easily be achieved and economical running conditions maintained.

It is understood that an attempt is being made to recruit part-time labour for evening work only, and where this is possible it would be uneconomical to run a large engine on a light load.

##### (E) SAVING OF SPACE

The space taken by an engine with its usually large transmission system is much greater than that required for the equivalent electrical equipment.



**(F) LAYOUT OF PLANT**

Plant layout in the woollen industry generally has been greatly influenced by the position and availability of line shafting and this practice has often impaired efficient production. Where electrical individual drives or small group drives are used, the segregation of the various processes can be more easily achieved and the fullest use of the available factory space and site can be made, resulting in the most efficient production flow.

**(G) ECONOMY IN MAINTENANCE AND STAFF**

Where private plant is used, considerable skilled engineering labour has to be employed to maintain the engine and transmission equipment. The modern electric motor ensures trouble-free operation with comparatively small maintenance.

**(H) IMPROVED ENGINEERING TECHNIQUE**

In an engine-driven plant considerable power is absorbed in transmission losses—that is, in driving long lines of shafting, bevel gears and the like—before the power is actually applied to the machine. These transmission losses usually vary between 20 and 30 per cent., but sometimes are as high as 40 per cent., even when the machine is operating on full load. In addition, defects in machinery tending to increase power input often pass unnoticed owing to the difficulty in measuring the power taken by individual machines when driven from the line shafting.

Electricity, on the other hand, can be easily and accurately measured with consequent opportunities for locating and remedying any defects tending to increase power input.

**(I) WELFARE OF EMPLOYEES**

Improved lighting, decorations and working conditions would follow the general adoption of electricity in the woollen industry.

**(J) AVOIDANCE OF DAMAGE**

Damage to materials liable to be caused by oil and dirt from overhead shafting, is obviated by the use of individual electric drive.

**ADVANTAGES OF PURCHASED ELECTRIC POWER**

[The author then discussed certain advantages of using electric power that did not intimately concern the efficient use of fuel. Replying to the contention that, when steam is required for process or heating, power can be produced more cheaply in back-pressure steam engines or turbines, the following views were advanced. (1) It is better for the experts of the electric supply industry to handle the power side of the woollen industry, leaving the executives of that industry to concentrate upon textile production. (2) Private plant is more susceptible to breakdown than public supply. (3) With a public supply the demand for power can be increased or decreased with ease as trade conditions necessitate. (4) Capital is better employed in purchasing textile machinery than boiler and power plants. (5) Private turbo-generators need skilled attention and a stand-by unit should be provided. In certain cases pass-out and back-pressure turbine installations are more economical from a fuel-saving point of view and merit careful consideration.]

The costs of generating power in a factory are frequently under-estimated and items which should properly be included are overlooked ; for instance, full allowance is seldom made for the supervision of the various stages of production from purchasing the coal to delivering the power to the machinery, adequate percentages are not always charged for interest and depreciation on

the whole equipment, nor is a fair allowance made for rent, rates, taxes, water, fuel, oil and other supplies, as well as boiler-firing and ash disposal, and in particular for the time and thought given by the management to power problems and difficulties. The staff, space and investment concerned with the power plant could undoubtedly be more profitably occupied with the primary business of textile manufacture.

The potential loss resulting from a breakdown of private power plant is also a factor which should be taken into consideration when comparative costs are being prepared.

When these costs are included in the expenses incurred in the operation of private plant there is clear indication that substantial savings are effected by change over to the public electricity supply, as shown below :—

**TYPICAL EXAMPLES OF COAL SAVING FOLLOWING CONVERSION  
FROM STEAM TO ELECTRICITY**

Case index	Steam		Electricity			Estimated coal saving per cent.
	i.h.p.	Annual coal consumption tons	Maximum demand KVA	Annual consumption of electricity units	Coal for heating, etc., tons	
A	450	1,260	409	792,000	565	13
B	1,192	3,500	1,060	2,080,000	390	49
C	325	938	300	450,000	320	34
D	2,800	4,800	2,000	3,950,000	200	41
E	640	2,900	560	980,000	1,400	29
F	1,500	3,276	—	1,723,600	624	46
G	500	1,392	340	670,000	250	50
H	250	820	220	385,000	150	50

A cost per loom under steam engine and electric motor drive is given to indicate the financial saving effected.

<i>Steam Engine</i>		<i>Electric Motor</i>	
<i>(Cost per loom per annum)</i>		<i>(Cost per loom per annum)</i>	
	<i>Shillings</i>		<i>Shillings</i>
Coal per ton 30s. od.	128	Coal per ton 45s. od.	110
„ „ „ 24s. od.	78	„ „ „ 40s. od.	100
		„ „ „ 34s. od.	75

**CONSERVATION OF COAL**

Three principal factors affecting the economic use of coal are :—

(i) *Quality.*

Generally speaking, the coal supplied to “ Selected ” power stations is of much lower quality and somewhat cheaper than that supplied to industrial plants.

(ii) *Most effective use.*

In “ Selected ” power stations modern boiler plants not only use low grade coal but do so with reasonably high efficiency.

(iii) *Quantities used.*

A considerable saving in coal is effected following conversion from private steam plant to public supply, and complete electrification of the woollen industry and ancillary trades would result in saving thousands of tons of raw coal annually.

## 7. Power Saving in Textile Mills

By T. W. EVANS, B.SC., M.INST.F.

### INTRODUCTORY REMARKS

In textile mills, due to the highly mechanised nature of the operations, it is not usually practicable to effect major savings in power consumption, unless in unusually inefficient undertakings, and the scope for fuel economy by this means is slight compared with that which can be achieved by direct savings in the heat-using processes, particularly in space heating. Nevertheless, small economies in power can be and have been made, and in the aggregate form a useful contribution to the whole.

### POWER PRODUCTION

Where part or all the power is generated by the factory itself, there may be a possibility of utilising exhaust steam for space and process heating, but this aspect of the problem is outside the range of the present review and, in any case, cannot affect about 25 per cent. of the mills which purchase electric power from outside. The present remarks will therefore be confined to what is feasible in the way of reducing actual power consumption.

### SHORT-TERM PROGRAMME

Some savings can be made with existing equipment and others can only be achieved either by considerable alteration or by the purchase of new machinery.

Under the former, or "*short-term means*" the following are the most important which have actually been carried out in the group of large mills in Scotland with which I am connected. These may perhaps serve as a guide to others :—

(a) Where machines are group driven, they should be concentrated on as few motors as possible in order to keep the motors up to their rated loadings and therefore maximum efficiency and power factors. This is most important and is frequently overlooked.

(b) Any shafting which is unused—even if only temporarily so—should be disconnected from the drive, either by removing a belt or splitting a coupling or by similar means. (As a result of the concentration just mentioned, shafting may become redundant.)

(c) Group-driven machinery temporarily out of commission should have the belts removed and not be allowed to run for any length of time on the loose pulley.

(d) In any well-run mill line shafting will be checked for alignment but shafting losses are not great and are generally less than is commonly supposed, being only from 2 per cent. to 5 per cent. of the whole power. *Avoidable* losses are, of course, only a percentage of this.

(e) Where spinning machinery is individually driven and fast and loose pulleys are incorporated, for instance in speed frames, the motors should be stopped whilst doffing, instead of being allowed to run on the loose pulleys during this time, which may well be 10 to 15 minutes.

(f) In doubling frames it has been found if half a size smaller traveller can be used, a saving of  $\frac{3}{4}$  h.p. per frame can be achieved, i.e. about 7 per cent.

—In my group of mills, the power saving achieved by the simple steps outlined above is about 7 per cent. which, on a yearly consumption of 42 million kWh, amounts to the respectable total of nearly 3 million kWh.

## LIGHTING

A further fruitful source of short-term savings is in the lighting installations, especially if recent recommendations asking for an average overall illumination of 6-ft. candles are not taken too literally. Amongst others, the following may well be given attention :—

(g) Reduce wattage of lamps in passages, etc. In some cases this has been cut down by 35 per cent., resulting in one mill in a saving of  $\frac{1}{2}$  per cent. of the total lighting load. It is not recommended, of course, to reduce any lighting where work is being carried out.

(h) Propaganda and supervision by foremen and fuel watchers to ensure that all unnecessary lights are switched off—a saving of 2.25 per cent. of the lighting load by this means has been registered.

(i) Cut out lights over machinery temporarily out of use—saving 5 per cent.

(j) Reduce or entirely remove lamps in store-rooms and outbuildings and arrange to work in those places during daylight hours.

(k) Alter switching arrangements where necessary to give more economical control of lighting.

An all-round saving of lighting, amounting to 12 to 15 per cent. or almost 1 per cent. of the total electricity consumed, has been achieved by these means. In some departments an economy in lighting consumption of as much as 45 per cent. to 50 per cent. has been registered.

## LONG-TERM POLICY

Under a long-term programme, steps may be taken to scrap, or at any rate improve, machinery which consumes more power than necessary. It is most important to know *how much* power each and every machine is, in fact, taking. One of the advantages of individual motor drives is that it is relatively easy to do this and, where possible, frequent use should be made of the ammeter. Any machine showing an undue rise in power consumption should receive attention.

Assuming individual motor drives are installed, there is a considerable field for saving in the adoption of high efficiency motors having an efficiency of say 91 per cent. (for motors of the order of 10 h.p.) as against the more usually marketed units having an efficiency of less than 87 per cent. Where large motors driving groups of machines are installed, correspondingly higher efficiencies will be obtained, but the principle remains the same. If power economy is the aim, the highest obtainable efficiency should be specified.

Motors with a flat efficiency characteristic, having practically the same efficiency from say 20 per cent. overload to 75 per cent. load or even less, and high starting torque (say  $2\frac{1}{2}$  times full load torque) are desirable and motors of the type described have for years been installed in the group of mills both at home and abroad with which I am connected, and the increase in cost is undoubtedly well worth while, especially in times like the present.

Even with flat efficiency characteristic motors it is desirable they should not be underloaded and therefore attention should be paid to their rating. There is, in general, a tendency among machinery makers to overstate the b.h.p. required since they naturally prefer to err on the side of safety.

Coming to machines, in spinning and doubling frames roller-bearing spindles are now coming to the fore. Makers claim a power saving of from 12 per cent. to 30 per cent. but our (admittedly somewhat limited), experience

has been that the power saving on doubling and ring spinning frames, is somewhat less than this. Any gain depends, of course, on how good or how bad the original plain bearing spindles were. At about 25s. a spindle the change-over of even a relatively small mill is costly.

In textile mills air conditioning is receiving attention and where large installations, running to maybe hundreds of horse-power, are involved, very considerable savings can be made by the use of high efficiency fans of aerofoil design. Pump efficiencies can also vary considerably and good characteristics should be specified.

#### GROUP 7. INDIVIDUAL DRIVING

This is a somewhat controversial matter but it is hardly open to question that it is not financially economical to change over from group driving at its best to individual motor drives, i.e. when the shafting is either driven by efficient large-size motors or engines, when the motors are generally fully loaded and when the production is not subject to frequent fluctuations.

Unfortunately, all these conditions are not usually met with and under such circumstances individual drives will show an economy in power and, in extreme cases, even a financial gain notwithstanding the capital charges of the change-over.

When considering new installations, individual motors are definitely recommended since,

(a) the arrangement is more flexible, i.e. the running motive power is always commensurate with the load ;

(b) there is no wastage of power when machines are stopped ;

(c) a motor breakdown only involves one machine and if sufficient spares are carried, the stoppage time is reduced, i.e. there is less production lost by replacing five 10 h.p. motors than one 50 h.p. motor ;

(d) cost of spare motors is less, though neither this nor the cost of belt maintenance and renewals affects power costs ;

(e) when high-efficiency individual motors are in use, the overall driving efficiency is higher than when the drive is subject to line shaft losses, notwithstanding the slightly higher efficiency of the larger electric units ;

(f) it is easier to re-locate machinery for more efficient grouping, as it is generally less difficult to run wiring than to erect shafting ;

(g) the speed of the machine is more constant, i.e. there is no cyclic variation of shafting due to mutual interference of machines and other, causes consequently machines can be allowed to run faster.

There are, of course, other incidental advantages of individual driving which do not affect power economy such as :—

(a) Disappearance of overhead belting which interferes with lighting and other services such as air trunks.

(b) Cleanliness and less moving about of dust.

(c) Freedom from bearing-oil drips.

(d) Ease of guarding.

(e) Greater degree of safety.

#### SUMMARY

We have found that the greatest power savings are achieved by :—

(a) Arranging for individual drives.

(b) Installing high efficiency motors.

- (c) Frequent testing to ensure that machines are running efficiently.
- (d) Cutting out unnecessary shafting.
- (e) Cutting out unnecessary lighting.
- (f) Constant supervision.

## 8. Power for Pumping

By H. R. LUPTON

The total mean pumping load of all the Metropolitan Water Board stations is approximately 19,000 h.p. and is nearly constant. There has been a continuous improvement in the thermal efficiency of the Board's pumping machinery during the past quarter of a century.

Some doubt has existed as to the relative merits, for large stations, of steam-driven pumping sets against the purchase of electrical energy from the public supply. The present tendency is to instal units to 50 h.p. and upwards driven by purchased electric power. Standby Diesel-driven sets may be used to assist the public supply in times of peak demand.

This is an example of that closer co-operation between the public services which is so desirable in present circumstances. For success it is essential that the tariffs offered should be those best adapted to secure true economy.

The steady load on the Board's pumping stations render them specially suitable for drive from the public supply. It is estimated that as the result of such changeovers from steam-driven sets to public electric supply, some 9,000 tons of coal have been saved annually. Every care is taken to co-operate with manufacturers in the purchase of equipment having the maximum true efficiency, and comprehensive records are systematically kept on all plant, thereby enabling a close check to be maintained on efficiency of operation.

The ratio :  $\frac{\text{effective water h.p. hours}}{\text{coal burned}}$  has been reduced in the proportion of 17 : 10 during recent years. Moreover, ever since 1918, the Board's coal has been bought on a calorific value basis, though lately the uniformity essential to ensure the best economy has been notably lacking.

## 9. Mechanical Power Transmission in Engineering Works

By W. R. M. BELCHER

There is a striking difference in appearance between the modern workshop with its cleanliness and neatness and the old-fashioned shop with its multitude of belts, shaftings, pulleys and striker gears. It is with the assessment of the relative methods and with the means by which economies of fuel can be effected that the present paper is concerned.

### TYPES OF POWER TRANSMISSION

Power transmission in engineering shops can be divided into three groups : (1) the main drive, where all the power is provided by one prime mover and transmitted from it by shafting and rope or belt drives to the different machines

often spread over a number of different shops and different floor levels ; (2) the group drive, where the factory is split up into a number of units each with its own motor driving the machines through belts and shafting, and finally (3) the individual drive, where each machine is fitted with its own motor.

#### THE INDIVIDUAL DRIVE

The individual drive is undoubtedly the most efficient and economical to run but, particularly from the point of view of the small machine shop, suffers from the disadvantage of high first cost. The majority of machine tools today are sold equipped with their own motor which, in modern shops with plenty of available capital, makes it easy to instal individual drives on all machines. The smaller shops, however, may be said to exist on machines which are not modern and which were designed for driving from line shafting. These machines can be driven economically from shafting and to convert them to individual drive would probably not repay the capital cost.

The efficiency of the individual drive is high, transmission losses are a minimum, machines can be moved from one position to another with no more work than is entailed in actually moving the machine and re-wiring, and machines are unaffected by power losses in line shafting or by speed variations. The means of coupling the motor to the machine can be adjusted by the manufacturer to give the necessary resilience in working ; where, for instance, a direct gear-driven drive would be too harsh, a flexible coupling or rope or belt drive can be inserted. No power is lost when the machine is not running, and this in the normal jobbing engineering shop with its low factor of usage is a very important item.

The only disadvantages of individual drives are the prime cost, particularly if a clutch for slow starting is required, the difficulty of converting old machines built for line shaft driving, and the necessity of installing motors of h.p. considerably in excess of the normal power requirements of the machine that is driven by the motor ; each motor must deal with its own peak load instead of having one motor which will deal with a number of peaks which are unlikely to coincide.

#### GROUP DRIVING

Group driving has much to recommend it for the usual factory layout. Shafting is only of comparatively short length and thus does not require heavy supporting brackets. One motor can be installed which can be of a size sufficient to deal with the normal running load of the group of machines. Peak loads at starting on each machine will only give a small variation from the mean of a number of machines. Fast and loose pulleys can be used instead of expensive clutch mechanisms. The short lengths of shafting make it possible to instal unorthodox types of shafting such as shafting running along the floor or even in ducts beneath the floor, thus eliminating the need for a specially rigid roof to carry the live loads of the shafting.

#### THE MAIN DRIVE

The type of drive which has almost nothing to recommend it and which has the lowest efficiency is undoubtedly the main drive, and it is against this form of power transmission that our energies should be directed if we wish to obtain appreciable economy in power consumption.

The disadvantages of the main drive may be summarised as follows :—

- (1) High transmission losses, which may amount to 60 per cent. or 70 per cent. of the total power where the shafting system is of considerable

length or complexity. In one instance a complete conversion from main to individual drive resulted in an average saving of 60 per cent. of power. The reason for these high losses lies in the low factor of usage of the machines which gives a high ratio of the power waste to the actual power used. In the textile industry with its high factor of usage, the loss of efficiency is of the order of 20–40 per cent.

(2) Difficulty of maintaining shafting due to movements in buildings. In old buildings, particularly with heavily loaded shafting, these movements may result in considerable misalignment even in so short a time as a year. This misalignment is, of course, reflected in increased power losses.

(3) The need to keep perhaps several hundred belts, shafts, pulleys, etc., in motion because a few machines are working overtime.

(4) A failure on the main motor will close the shop down.

#### RECOMMENDATIONS TO SECURE ECONOMY IN POWER CONSUMPTION

Recommendations which are reasonable, possible, and should not entail expenditure which is not repaid in a short period of time are as follows :—

(a) Place wattmeters on all prime movers and obtain an accurate measure of the power consumed by the motor, by the motor and shafting running light, and finally the average shop consumption. The results of such a test will probably give much food for thought. Data could be collected by the Ministry of Fuel and Power.

(b) Have a thorough check-up of all bearings, shafts and plummer blocks. This is best done by stopping the shafts and testing the bearing alignment. It is particularly important on long shafts in old buildings. All bearings should also be examined and tests taken to determine whether shafting does not deflect unduly under load. It should be noted in this connection that the extra loss due to loaded, as distinct from unloaded, shafts has been assessed at anything from 30 to 100 per cent.

A re-check on the prime mover will give a good indication of the economy effected.

(c) Carry out a survey of the shop to see whether the layout recommends itself to splitting up into group driving. This should preferably be done in such a manner that banks of similar machines run together, or machines which do not normally run simultaneously are coupled together, thus reducing the required h.p. of motor, or that the units are so split that one common size of motor is used throughout.

(d) If it is possible to split the main drive without too much capital outlay, this should be done, using where possible the existing shafting striking gear, etc.

The purist may claim that these are very moderate proposals and, in fact, so tame that they do not concern the majority of users. This is perfectly true, but while we live in an imperfect world the greatest improvement can usually be obtained not by degrees of super-efficiency, but by stopping downright waste. Long lengths of shafting, misalignment of bearings, running a 100 h.p. motor to drive a 3 h.p. machine, are all waste. The greatest effect can be obtained in the least time by stopping this type of waste.

#### *Discussion*

Mr. T. H. Carr, referring to Mr. Buckingham's paper, asked the author if he had any mill plants operating in parallel with public supply networks,



and if so, what were the capacities of such plants. He said that his findings indicated an average coal consumption figure of 2·6 lb./h.p. hour for a steam engine plant, which is a little higher than that given by the author. He confirmed the author's friction loss figures of 20–50 per cent. and the advantages of individual drive.

The most important statement in the paper was considered to be the saving of coal that would result from transferring from existing private generating plant to public supply when no process steam was required. He considered that there was much to be said in favour of the author's suggestion for the retention of combined power and process plants where these were economically justifiable.

**Mr. J. R. Thomson** said that example *E* given in Mr. Buckingham's paper referred to a plant in operation at the works of Manchester Oil Refinery, Ltd. Here the power saving was directly proportional to the increased load and, as the steam and power loads coincided, the electrical peak at this works had been reduced by 14 per cent. In view of statements made at this session of the conference he wished to make it clear that the operation of putting this generator on the line in no way differed from the procedure used in starting an induction motor. He considered it surprising that this simple "hook-up" had not been more widely adopted, for in the opinion of Manchester Oil Refinery there was nothing to prevent the adoption of the arrangement described as standard practice where power savings are made possible by excess process steam demand.

**Mr. Swale** welcomed the statement that public supply authorities would agree to parallel running by asynchronous machines. He queried the speed control of sets, however.

**Mr. Buckingham** in reply stated that accurate synchronism was not necessary. A common American practice was to run one alternator in parallel with 4, 5, or 6 asynchronous generators. The alternator determined and fixed the frequency.

**Mr. Spear** asked what precautions were taken against possibility of damage.

**Mr. Buckingham** replied that none was necessary.

**Mr. W. R. M. Belcher** asked Mr. Lupton if special guarantees were demanded by the Metropolitan Water Board when purchasing pipework.

**Mr. H. R. Lupton** replied that while rigid guarantees were required for plant and machinery, pipework was not so tightly specified.

THE CHAIRMAN OF THE SECTION, **Mr. J. G. Bennett**, summed up the major conclusions from the discussion as follows: There was general agreement in the Steam Utilisation Section that further large savings of fuel and power are possible. More than one speaker, in fact, expressed the opinion that the saving of 10 million tons of coal a year could eventually be obtained by increased efficiency in steam utilisation alone, but if this is to be done, there are certain conditions which have to be fulfilled. Steam utilisation, more almost than any other aspect of fuel and power, is inextricably bound up with industrial processes. Its control is to a great extent outside the hands of the fuel engineer. Apart from the combating of obvious waste, which has already been actively pressed as the result of previous campaigns, the really important savings of fuel

in the future will come from the re-planning of the works. We have had examples where economies up to 20 per cent., or even 30 per cent., can be effected, but there are possible repercussions on the process which involve serious decisions by the management. It is, therefore, supremely important, so far as our section is concerned, to secure the personal interest of the Boards of Directors of industrial companies and to persuade them to consult with their engineering staffs as to the schemes to be adopted. We have also been very much impressed by the demand for more research and educational work in steam utilisation. We were told that there are only two or three technical colleges in the country where, as a result of work by the Ministry, steam utilisation courses have been arranged. We want courses in this subject to be available in all the technical colleges in every great industrial centre.

Then there is the question of the delivery of plant. Cases were cited during our sessions in which plant which would save a great deal of fuel will not be available for eighteen months or two years, and we very much hope that the Government will secure better priorities for the fuel efficiency equipment which is urgently needed. This applies particularly where a rearrangement of steam utilisation plant is involved.

Finally, the most efficient use of steam very often involves an agreed balance between the use of the steam for generating power and the use of the steam for process work. Sometimes this can be achieved by the use of back-pressure steam, which was strongly advocated at our sessions, and sometimes by close co-operation with the public supply company. We were very pleased to learn of the increasing number of cases in which new factories are being installed adjacent to power stations which are supplying them with some considerable financial benefit, both to the power company and the factory, and with a big annual saving of coal to the nation. One particular example was a paper mill which is being erected in South Wales within a few hundred yards of a power station, which will supply it with the whole of its steam requirements. We feel that this kind of development should receive every encouragement.

To sum up, both from the short-term and the long-term viewpoints, the utilisation of steam is one of the most fruitful fields for increased efficiency in the use of fuel and power. The key to success is collaboration : firstly, collaboration within the works between the management and the engineers ; secondly, the Government stepping in to secure priorities, educational facilities and research and, thirdly, collaboration between industry and the electric power companies. If we have that collaboration we shall save the coal.

# SECTION C

## HEAT FOR DRYING

*Chairman :* MR. W. L. BOON, O.B.E.

CHAIRMAN OF THE TECHNICAL SUB-COMMITTEE OF THE FUEL EFFICIENCY  
COMMITTEE OF THE MINISTRY OF FUEL AND POWER

### SESSION I. Drying, Conditioning and Storing

*Chairman of Session :* MR. W. L. BOON, O.B.E.

**T**HE CHAIRMAN : The importance of drying is perhaps not fully appreciated, nor is it generally realised what large quantities of fuel are used for the purpose. The fuel used for drying at a factory is part of the total fuel consumption of the factory, and rarely segregated, so that the actual amount used for drying is not evident. The importance of obtaining separate consumption figures cannot be too strongly emphasized, as this will enable fuel consumption per unit of product to be obtained, and comparisons made.

The papers to be given indicate new developments in design, and it is hoped that the session will bring out the trend of these developments. While modern drying plant is generally efficient, many old and obsolete plants are in use, often operating with very low thermal efficiencies, and as a short-term policy for the saving of fuel, special attention should be paid to these inefficient plants.

#### 1. The Electric Infra-Red Process

By J. C. LOWSON, B.E. (MECH. & ELEC.), A.M.I.E.E.

B.T.H. RESEARCH LABORATORY

##### BASIC PRINCIPLES

There are several ways of generating infra-red radiation by electricity ; but for a number of reasons which are mentioned later, the incandescent lamp is particularly suitable for this purpose and has inherent characteristics which lend themselves to fuel economy. The lamp system is referred to throughout this paper.

In a typical form of lamp equipment the articles to be heated are hung from a steadily-moving conveyor which passes down a tunnel with rows of incandescent lamps along its walls. The filaments of these lamps emit radiant

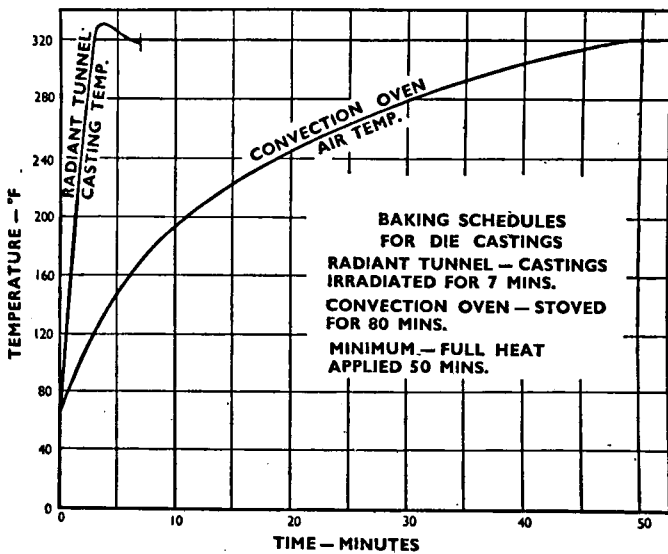
energy and each lamp is fitted with a reflector which collects and directs energy on to the work in a roughly parallel beam.

This radiation is not heat and does not become sensible heat until it has been absorbed in the material. The intervening air does not absorb the radiation to an appreciable extent and is, therefore, not directly heated.

The transfer of energy from the incandescent filament to the work takes place instantaneously and the work can, therefore, be heated up very much more rapidly than by ordinary convection methods. This may be illustrated by a simple practical example :—

Fig. 47 shows the temperature/time curve of a box oven baking a die-cast switch cover coated with an enamel which bakes rapidly at temperatures of about 300° F. The baking schedule of these covers is quoted as “300° F. for 50 minutes”, but in actual fact the curve shows that even the air temperature of the oven does not reach 300° F. for 35 to 40 minutes and the metal temperature is, of course, below this.

The infra-red tunnel, on the other hand, brings the metal temperature up to 320° F. in about three minutes and holds it there for another four. A perfectly baked article is thus obtained in seven minutes as compared with the box oven's 45 to 50 minutes.



(Reproduced by permission of the Illuminating Engineering Society.)  
FIG. 47.—Comparison of temperature cycles in radiant and convection equipment.

#### APPLICATION OF THE PROCESS

The previous example shows how the short baking times characteristic of the process are achieved by raising the work rapidly to the desired temperature. It is clear that infra-red may be most usefully applied to processes in which the speed of action increases rapidly with temperature. The polymerisation of certain types of paint exhibits this characteristic in a marked degree and it is in applications of this nature that the most startling results have been achieved.

These rapid heating characteristics are particularly valuable when compact, continuously operating equipments are required.

The application of the process is extremely wide, but it must not be regarded as of universal applicability. It is obvious that the surfaces of the articles to be baked must be exposed to the radiation or must be so placed that conduction through the work will be an adequate substitute, as in the case of enamel coats on the interior and exterior surfaces of a petrol can which are baked simultaneously by irradiating the outside surface of the can.

If exposure of the surfaces of the article to radiation necessitates a very great loss of space factor, the convection oven may be more suitable. For example, large sheets of metal must be put through an infra-red tunnel edge-to-edge in line ahead; in a convection oven they can be placed parallel and close together, and the greatly improved space factor may compensate for the slow rate of heat transfer and result in a more compact equipment.

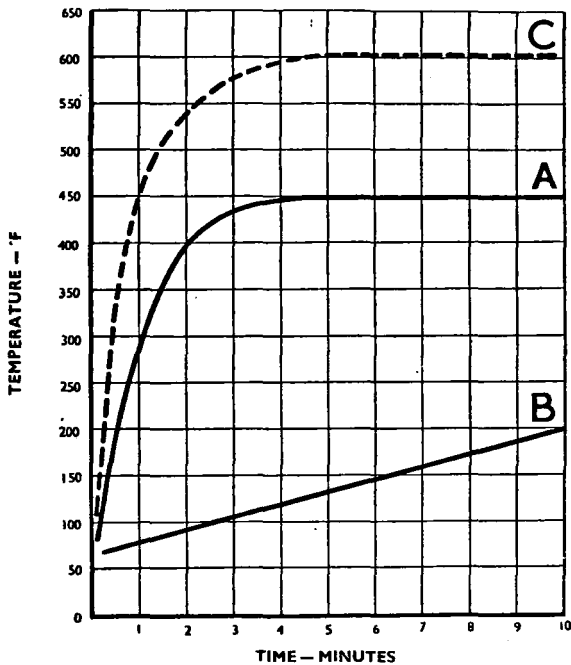


FIG. 48.—Temperatures generated in the work by infra-red radiation.

Lamp infra-red is a medium temperature process. The rate of rise and maximum temperature attainable in any given case will depend on the circumstances, but Fig. 48 gives some general information on the subject. Experience has shown that the family of temperature/time cycles bounded by curves A and B include those most likely to be met with in practice; curve C represents the maximum curve likely to be attainable with standard equipment at the present time. For the purposes of this diagram a time limit of ten minutes has been assumed. While longer times are occasionally used in practice, ten minutes is usually sufficient, and times of five minutes or less are frequently achieved.

It will be noted that curve B differs very little from the convection oven curve of Fig. 47, but such temperature/time cycles are normally associated with very massive articles such as engine castings having a large thermal capacity per unit surface area ; if heated by convection these would have an even slower temperature rise.

It is clear from the foregoing considerations that every prospective infra-red application must be carefully examined to determine its suitability for the process, but it is surprising what a very large variety of articles can be dealt with by infra-red with a consequent gain in speed and convenience. In the field of enamel baking alone these range from small instrument parts to entire aircraft and from light sheet-metal containers to heavy engine castings.

#### CHARACTERISTICS OF THE LAMP RADIATOR

The general mechanical construction of the standard 250 watt infra-red drying lamp is very similar to that of the standard incandescent lamp used for lighting purposes, and it can be mass produced on standard lamp machinery.

The principal difference lies in the filament which runs at a temperature of about 2,200° C., somewhat lower than that of an ordinary lighting lamp.

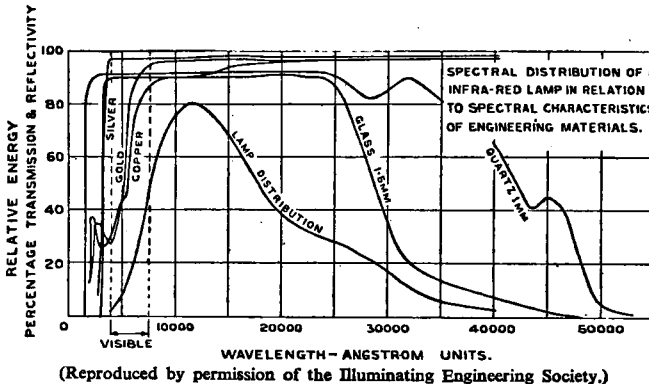


Fig. 49.—Spectral distribution of infra-red lamp in relation to spectral characteristics of engineering materials.

The employment of such a high temperature source has two important advantages ; one is that the source itself can be very compact thus facilitating the collection and accurate re-direction of the energy by a reflector of convenient size ; the other is that the bulk of the radiation produced by the filament is transmitted by glass, so that the incandescent source can be enclosed in a glass envelope which increases its radiation efficiency to a large degree by reducing the convection losses.

With open wire elements of the bowl fire type, a high percentage of the power input is dissipated by convection and only some 40–50 per cent. may be converted into radiant energy, as compared with 80–90 per cent. for the infra-red lamp.

Fig.49 shows the spectral distribution of the lamp and illustrates the fortunate manner in which this distribution fits the characteristics of the materials available for its control. The bulk of the radiation lies between the limits set by the reflecting surfaces at the shorter wavelengths and the protective cover glasses at the longer. Shorter wavelengths are less efficiently

reflected by the available engineering materials ; wavelengths beyond about 30,000 Å are largely cut off by the glass envelope.

Incidentally, the diagram shows why it is impracticable to attempt the reduction of convection losses from a bare wire element by means of a protective glass envelope. The lower the temperature of a radiating source, the longer will be the wavelengths emitted. Even a bare wire element operating at about 1,000° C. will emit a large proportion of its radiant output at wavelengths greater than 30,000 Å. Hence it is only with radiators of the incandescent filament type that convection losses can be effectively reduced. Moreover, the particular band of wavelengths produced by such radiators is readily absorbed by the majority of substances likely to be processed and does not give rise to undesirable photochemical effects.

The foregoing considerations show that the incandescent lamp is an efficient source of pure radiant energy, eminently suitable for industrial applications. It is not suggested that this infra-red system has exclusive rights in the radiant heating principle. Most forms of oven heat their contents by a combination of conduction, convection and radiation. The domestic oven, for example, relies on radiation to a considerable extent and it is well known that a cake will bake more quickly in a blackened tin than in a shiny new one. Even a low temperature steam-heated oven will heat the work to some extent by radiation from the lagged walls.

Such sources of radiant energy have a large thermal capacity and thus a great deal of energy must be expended in bringing them up to temperature ; this process may take a considerable time. In the lamp infra-red oven, on the other hand, the radiant source, i.e. the lamp filament, is small and of negligible thermal capacity. It therefore heats up instantly.

#### FUEL ECONOMY

The flexibility of the lamp system enables fuel wastage to be reduced to a minimum. In the following sections we shall consider various expedients for achieving this end.

The lamp radiates with full efficiency immediately after switching on, thus eliminating the " heating-up " period associated with the other types of oven. This is very important from the fuel economy point of view. In large convection ovens it is often necessary to expend a considerable amount of fuel in bringing the oven up to temperature before work can be commenced. Moreover, once production has started, the fuel consumption will be much the same whether the oven is running full, half full, or empty.

As the infra-red radiation can be switched off and on as readily as electric light, no fuel need be expended in preparing the oven for work. Also there is no need to waste fuel during breaks in production. It is quite a common practice to interlock the conveyor with the lamp switch so that when the conveyor is not moving the lamps are switched off. In America this has even been carried a stage further ; in some very large tunnels used for baking car bodies, a photo-electric system has been installed which ensures that only that part of the long tunnel which actually encloses a car body is switched on, so that the body proceeds down the tunnel surrounded by a moving aura of radiant energy !

Such extreme methods are hardly necessary for ordinary applications but careful attention to the elimination of stand-by losses is well worth while ; it is surprising what a large amount of fuel can be expended in keeping an

oven going during lunch breaks, tea breaks, and small accidental interruptions to the steady production flow. In the incandescent lamp infra-red system such losses can be reduced to a minimum.

#### REDUCED PRODUCTION RATES

So far we have considered tunnels operating at full production capacity. In practice it may be necessary to slow down production temporarily. Such conditions can be catered for by simple switching arrangements and a variable speed conveyor. An elementary example will illustrate this point.

Consider a tunnel 20 ft. long made up of four consecutive sections consuming 6 kW per section. To make our example simple let us suppose that the conveyor is moving at 4 ft. per minute through the tunnel and that the articles are placed at one foot pitch on the conveyor. This means that the maximum production will be 240 articles per hour and the baking time in the tunnel will be 5 minutes. The consumption per article will be  $\frac{24}{240}$ , i.e. 0.1 kWh.

Now suppose that the last two sections of the tunnel have been switched out, reducing its effective length to 10 ft., and the conveyor has been slowed down to 2 ft. per minute. The production is now 120 articles per hour; the baking time is still 5 minutes and the consumption per article is unchanged. In similar fashion three-quarters or one-quarter full production can be handled by switching off one or three sections respectively. In every case the articles receive exactly the same heat treatment, i.e., 5 minutes radiation, and the consumption per article remains unchanged.

We have seen how fuel consumption may be reduced by taking advantage of the flexibility of the system. There are other fuel-saving expedients which may be employed when designing multipurpose tunnels, but in order to appreciate these it may be helpful if we first examine the profiles of one or two typical infra-red equipments to see the general principles upon which they are designed.

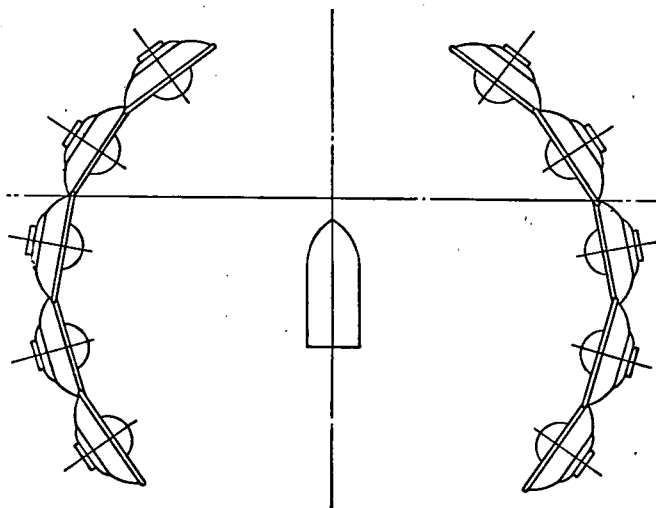


FIG. 50.—Cross-section of tunnel baking paint on solid steel shot.

#### TYPICAL PROFILES

Fig. 50 illustrates a tunnel designed to heat a solid steel shot with very large mass per unit surface area. This sketch shows a cross-section of the tunnel,



and the reflectors represent rows running down the length of the tunnel. It is clear that the beams of radiation from the lamps and reflectors meet at the centre, producing a concentrated field of radiation enclosing this shot. Fig. 51 shows the cross-section of a tunnel designed to bake the Jerrican. Here the radiation is spread over the surface of the can, but the curved portion on the handle and heavier parts. It may be mentioned in passing that this particular application is one in which all parts of the article had to be brought up to temperature with approximately equal speed in order to avoid paint difficulties ; it is in applications such as these that the accurate placing of radiation by means of the lamp and individual reflector becomes particularly important if the most efficient result is to be obtained.

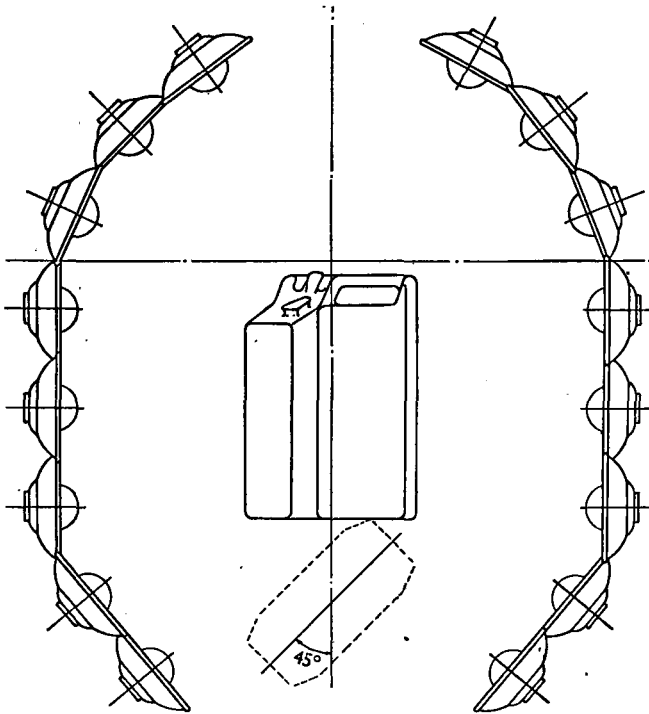


FIG. 51.—Cross-section of tunnel baking paint on petrol cans.

#### MULTI-PURPOSE TUNNELS

So far we have considered equipment designed for a single type of article ; this is theoretically the ideal arrangement, for it permits the accurate tailoring of the infra-red tunnel to the requirements of the work. If a large production of widely varying articles must be handled, it is usually best to divide these into two or three classes, and to deal with them in separate, short tunnels rather than a single long one. The former arrangement will require less equipment since the single tunnel would have to be long enough to handle the total production and big enough to accommodate the largest article.

However, it is sometimes necessary to provide a single tunnel capable of dealing with a range of articles, and in these cases the accurate placing of the radiation is of great assistance in keeping the fuel consumption down to a minimum. We have already seen how the effective length of a tunnel may be reduced by switching off sections of lamps; in a similar fashion the effective shape of the tunnel may be altered by switching off rows along its length. In some cases the rows may be mounted on light swinging frameworks so that the shape of the tunnel can be altered. Fig. 52 illustrates this point by showing the profile of a very large tunnel designed to dry paint on a wide variety of ammunition boxes. When dealing with the largest size of box all the rows were switched on and the tunnel was then in the form shown in

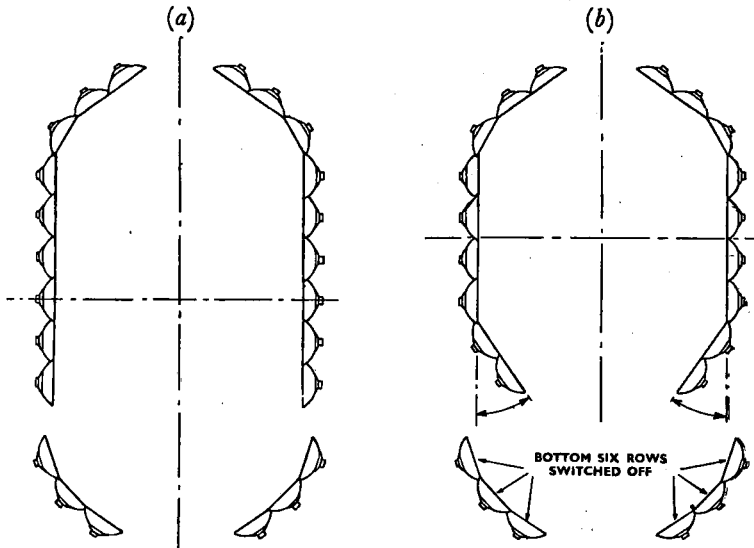


FIG. 52.—Cross-section of adjustable tunnel baking paint on a range of steel boxes.

Fig. 52 (a); but when dealing with smaller boxes the lower six rows were switched off and two rows swung in on each side, as shown in Fig. 52 (b), thus reducing the size of the tunnel and avoiding the wastage which would have been inevitable if the full equipment had been left switched on all the time.

#### FUEL CONSUMPTION CALCULATIONS

The calculation of fuel cost and consumption per article produced is comparatively simple in lamp infra-red plant if the above-mentioned economy measures have been carried out, for the consumption per article will remain a constant and easily calculable figure.

With other types of plant the true fuel cost and consumption per article is more difficult to estimate. There are many variable factors and the true consumption can only be obtained by measuring the total consumption over a representative period, which may be as long as a week or a month, and then dividing this total by the number of articles produced during that period.

It is quite misleading to divide the consumption per hour under steady running conditions by the production in the same hour, for this takes no account of stand-by losses.

For similar reasons it is extremely difficult to make comparisons between various types of heating system even when the application is superficially the same. The average fuel inputs of two different heating processes can only be directly compared if the two plants are producing similar quantities of an identical product under comparable working conditions.

Exact parallels of this nature are hard to find and one must always be cautious about basing generalities upon particular examples for so much depends on the local conditions in each case. If, for example, large quantities of process steam are available this will probably be the cheapest and most economical medium; but in general our experience indicates that, when properly applied, the infra-red process is as economical as any other method and can frequently show a substantial saving.

For example, consider the process illustrated in Fig. 47. The convection oven in question is a factory box-oven of considerable size. In normal production this oven holds 350 switch covers at a time. The average B.Th.U. consumed per cover is approximately 12,500 and the cost of fuel is about 0.5*d.* per cover. The infra-red tunnel on the other hand consumes 775 B.Th.U. per cover at a cost of about 0.18*d.* each. This includes the replacement cost of the lamps.

#### OTHER APPLICATIONS

There are, of course, many applications for the infra-red process besides those mentioned in this paper. Infra-red has been successfully applied to the baking and drying of paint on all manner of articles; the softening of plastic materials before forming; the accelerated drying of cores and moulds, fabrics, metal parts, and even large electrical machinery; the accelerated hardening of synthetic glues; the preheating of pistons, and many other applications. The general principles of fuel economy outlined in this paper can be applied to all these applications and to the many new ones which the demands of peacetime production are bringing.

## 2. Town Gas for Drying by Radiant Heat

By R. F. HAYMAN, B.SC., F.R.I.C., A.M.I.CHEM.E., M.INST.GAS E.

#### PRINCIPLES OF RADIANT HEATING BY GAS

Radiant heating by gas is effected in two ways :—

- (a) By medium-temperature black emitter panels.
- (b) By high-temperature incandescent sources.

The medium-temperature range is from 450° F. to 650° F. although in certain designs of equipment the latter figure rises to 900° F. The high-temperature range is between 600° C. and 1,000° C., i.e. about 1,100° F. to 1,800° F. The temperature gap between the two systems is not at the moment of great

importance since temperatures up to 650° F. are quite adequate for almost all normal drying and particularly metal finishing processes.

The high-temperature range is chiefly of use in ceramic firing and annealing, and has as yet had only a very limited use in drying processes. This paper therefore will deal largely with black emitter systems.

In the medium-temperature range, radiation of about  $5\mu$  or 50,000 Å wavelength\* at peak intensity is produced, the major part of the energy being radiated between 20,000 and 150,000 Å. In a tunnel with panel temperatures of 650° F. the intensity of radiation, or the flux density as it is termed, falling on the stock being treated is about 4,000 B.Th.U./sq. ft./hour.

Heat transfer increases very rapidly with increasing temperature, and with incandescent sources such as high-temperature radiant heating tunnels, flux densities of 50,000 B.Th.U./sq. ft./hour are possible  $\approx$  approx. 100 W/sq. in. (1 W/sq. in. = 491 B.Th.U./sq. ft.).

Medium-temperature equipment is available in the form of tunnels, and flat panels.

#### BLACK EMITTER TUNNELS

The gas-heated black emitter tunnel, originally developed by The Gas Light & Coke Company, consists of a row of non-bunsen-type jets firing into a chamber bounded on the one side by insulation and on the other by a mild-steel black panel. An inner sheet or baffle plate is attached to the lower half of the radiating panel to protect the panel and to provide even heat distribution. The units are normally constructed in semi-cylindrical sections 3 ft. and 4 ft. long which are joined together to form any length desired. The standard diameters are 2 ft., 3 ft., and 4 ft. Provision can be made for a conveyor to travel through the top or the bottom of the tunnel between the two halves.

#### BLACK EMITTER FLAT PANELS

Demands for a flat source of radiation led to the same system of heating as used in the tunnel, being utilised in box shape and single flat panels, horizontal or vertical. In a typical industrial unit, the principles are the same as for the tunnel in that hot gases flow between a black radiating panel and an insulated back.

#### EXPERIMENTAL DEVELOPMENT

In the manufacture of large heating equipment close attention must be paid to heat losses and to minimising running costs. Lack of attention in construction and fitting of panels may mean contacts between hot and cold surfaces resulting in an unnecessarily high gas rate to maintain a desired panel temperature. Much work has been done to ensure satisfactory design of equipment and details of recent development in radiant heating equipment are published in a paper by the author<sup>1</sup>.

Tunnel equipment for continuous production may be any length to suit the process. With open ends appreciable radiation losses are possible and, in general, doors are fitted which can be closed to allow just sufficient space for the work to go through.

---

\*  $1\mu = 1$  micron =  $1/1000$  mm. or  $10^{-4}$  cm.  
1 Å or Angström unit =  $10^{-8}$  cm.

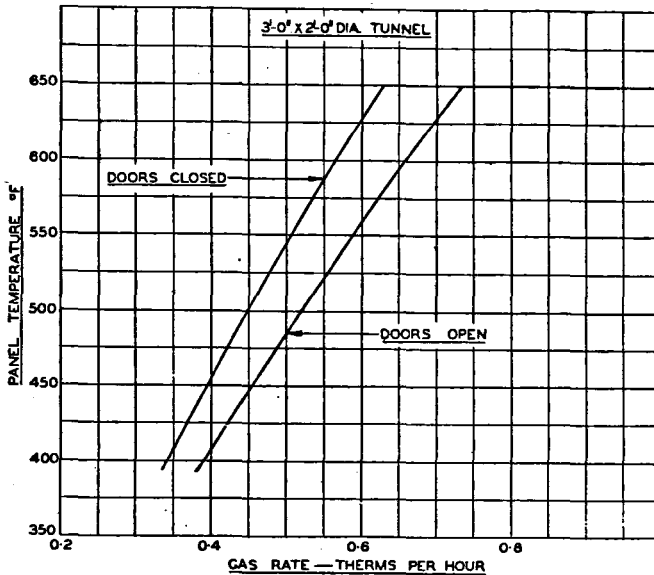


FIG. 53

The importance of doors in saving fuel is shown in Fig. 53 which gives the heat input to maintain a panel temperature of  $650^{\circ}\text{F}$ . in a 3 ft.  $\times$  2 ft. diameter tunnel, empty, with and without doors. With doors a saving of 14 per cent. is effected. The heat loss from the ends will increase with diameter of tunnel; the loss will be proportionately less with additional length of tunnel. Normally, and particularly in the larger sizes, more than one standard unit is fitted, but information on the proportionate saving of fuel with increasing length of tunnel is not at present available.

#### TEMPERATURE MEASUREMENT AND CONTROL

Modern production requirements demand control of quality of output. In radiant heating systems in which the great majority of processes are carried out on a rising temperature, the measurement and control of temperature provide the best method of ensuring a consistent standard of output.

All gas-fired black emitter tunnels have provision for temperature measurement by means of thermocouples suitably attached to the hot panels. The thermocouple junction has a washer brazed to it. It is important to ensure good thermal contact between the couple and the panel because a thermocouple junction which is proud of the panel may well give a temperature reading  $100^{\circ}\text{F}$ . low. The thermocouple leads are insulated in their passage through the flue way to ensure that the higher temperature prevailing at this point is not conducted back to the thermocouple junction, thus producing a high reading.

#### PRACTICAL UTILISATION

##### (1) MEDIUM-TEMPERATURE TUNNELS AND PANELS

(a) *Metal finishing and paint curing.*—By far the greatest volume of work carried out in radiant heating tunnels is metal finishing. This is an excellent subject for radiant heating since metal is a good conductor of heat and full advantage can be taken of the high rates of heat release possible with gas-fired equipment. The successful application of radiant heating to metal finishing has been greatly helped by the study of the types of paint most suitable, and early failures were due to the lack of realisation of the fact that special paints

were required. The paint manufacturers have devoted considerable time and effort to producing finishes which can be cured very rapidly under suitable heating conditions.

One great advantage of black emitter tunnels as a source of heating is that the peak wavelength of the radiation produced is about  $5\mu$ ; this wavelength is not selectively absorbed by paints of different colour, and it is possible to dry all colours from black to white in what is for all practical purposes the same time. This applies, of course, strictly to processing the same objects with the same type of finish but it does mean that in planning continuous production, a process for which black emitter tunnels are very suitable, no serious delays or difficulties due to colour are encountered.

The radiant emission of the black emitter tunnel is practically identical with that given by a black body radiating at  $650^{\circ}\text{F.}$ , or in other words the emissivity of the surface is 1. This means that the surface emits radiation at the maximum possible rate for any given wavelength and temperature.

A great deal of information is now available on metal finishing, and the bibliography prepared by Lewis<sup>2</sup> includes a substantial proportion of recently published work. Appendix I gives a random selection of metal finishing applications (chiefly drying and curing paints) which have been carried out successfully. This list illustrates the wide field of industries covered. Details of time-temperature cycles have not been given as these will vary with thickness of metal, throughput, type of paint used or finish required, and size of tunnel. All tests, however, show substantial saving of time over other methods of heating. To obtain the best results from radiant heating systems it is necessary to have all the surfaces of an object exposed to the radiating surfaces. It is not necessary, however, to limit production to a single type of object as a pre-determined time-temperature cycle combined with a suitable layout of plant will allow of considerable flexibility in operation.

(b) *Ceramics*.—Although painted objects are said to be “dried”, more often than not the process is a physico-chemical one involving polymerisation or oxidation of a resin. The term “curing” is less confusing to use for those operations.

Drying, the removal of water, is a very important unit operation in industry and is frequently a bottleneck. In the pottery industry, for instance, heavy and complicated shapes have to be dried slowly necessitating large drying rooms and spaces. Because of this difficulty the more rapid drying of clay shapes has been regarded with considerable interest. A range from railway and industrial insulators, drainpipes and building materials, to bath-tubs and crockery, has been covered by various workers in surveying the possibilities of radiant heating in speeding up the drying operations. Drying involves the removal of water by evaporation and sufficient heat must be received by the material to convert liquid moisture into vapour.

Work at Watson House on drying a variety of clay shapes by radiant heat has shown that the mechanism of drying is normal and is the same whether the drying agent is radiant heat or convected heat (hot air circulation being the most common system to date). Stout, Caplan and Baird<sup>3</sup> confirm that the mechanism of drying by radiant heat is similar to accepted theory for convection drying. They make the interesting point, however, that in radiant heat processing, increasing air velocity decreases the rate of drying because, while the energy input is free from gas film resistance, an increase in air velocity increases the convection heat transfer coefficient and, therefore, increases heat loss by convection.

Practical results of drying clay shapes are not entirely satisfactory. Small objects, however, such as insulators, teacups, plates and thin sections can be dried without warping or cracking in a fraction of the time previously required. One example of tests at Watson House showed that small insulating rings previously taking anything from one to three days in drying rooms could be dried in 10–15 minutes in a tunnel with a panel temperature of 400–450° F. “Drying”, it must be emphasised, means drying the wet clay to a state suitable for glazing and/or firing. This usually means lowering the water content of the clay from about 22 per cent. to 8 per cent. Ratcliffe and Webb<sup>4</sup> have described in detail with comparative costs the use of radiant heat for the drying of crockery and similar ware. Work is also going on at Leeds University on the subject as described by Roberts.<sup>5</sup>

The importance of the great saving of time and space and consequent increase in production may be judged from the statement by Gould, Evans and Flannigan<sup>6</sup> that drying rooms in which refractory and clay shapes are air dried, occupy three times the space taken up by the casting area, and the substitution of radiant heating will double production for a given casting area. The saving of drying time has the additional advantage of decreasing warping otherwise caused by the weight of unsupported sections of the ware.

Units consisting of non-bunsen-type burners firing on to a radiating panel of insulating refractory material which is heated up to 550° C.<sup>7</sup> are now being used with success for skin drying sand moulds, and for drying pottery. Results show that the cost of drying with these high temperature radiant heaters is cheaper than by other methods in normal use.

The drying of large shapes by radiant heat has so far met with failure since in all cases involving solid blocks of material, cracking has taken place. The only way in which this problem can be avoided is by drastic reduction in panel temperature. This is demonstrated by tests on a 20 lb. block of clay which in a 2 ft. diameter tunnel with a panel temperature of 300° F. dried in about 10 hours without any signs of cracking.

In heat emission above 600° F. the radiation component rapidly assumes large proportions, but below 400° F. radiant heat has no appreciable advantage over convected heat where rate of heat transfer and saving of time is concerned. Thus at the low temperatures demanded for safe handling of large clay shapes, hot air or a combination of convected and radiated heat would be more suitable.

It is concluded from limited experiments to date that 1 in.—1¼ in. is the maximum total thickness of any clay shape which can be dried economically and without cracking by radiant heat. This does not mean that large shapes, for instance bath tubs, cannot be dried by radiant heat. The limiting factor is wall thickness.

There is therefore considerable scope for the use of radiant heating in drying ceramics, and the principle is being applied to a steadily increasing degree in industry.

(c) *Plastics and Textiles.*—As with other processes there is an urgent need to increase production of all classes of furnishing materials, and there are two main fields of development for radiant heating in curing synthetic products covered by the general name “plastics” and in the drying of fabric.

(i) *Plastics.*—Polyvinyl chloride (P.V.C.) is a substance which for many uses is taking the place of rubber, particularly in the present shortage of the natural product. Fabric rolled or spread with this material has only to be heated under a hot panel at a temperature of 600–650° F. for a minute or two for the necessary quantity of volatile matter to be evaporated, leaving a glazed surface which on cooling is the

finished "cured" product. The material is waterproof and creaseless, and can be used for groundsheets, curtains, bags of all types, chair and furniture coverings. All colours can be made and any thickness, from sheets similar in appearance and use to oiled silk, to thick covers more suitable for tarpaulins.

Black emitter panels have the advantage, as has already been stated, of producing radiation of a wavelength which is non-selective to colours and in consequence checked or multicoloured materials can be cured. Here is another example of process well adapted for continuous production, the material in the form of sheet being passed continuously under the hot panel.

(ii) Textiles.—Attention is being paid to the prospects of stepping up production by increasing the speed of drying of treated textiles. Large increase in production is required with the minimum increase in plant on account of both the time and space factor.

Experiments now in hand indicate that gas-fired radiant heating units, acting as either intermediate "boosters" or carrying out the complete operation, will be able to contribute substantially to this field.

Descriptions of plant for the drying of textiles and cloth printing have been given in the papers to which reference is made under 8, 9, 10, 11 on page 262.

(d) *Other Processes*.—Problems other than metal finishing may involve difficulties due to two main reasons :—

(i) Most solids other than transparent bodies are opaque to the infra-red radiation which constitutes the bulk of the heating agent more commonly described as radiant heat.

(ii) In drying processes involving the elimination of water there is a limit, for chemical and physical reasons, to the speed with which that water can be removed.

Wooden painted articles, for example, are poor conductors of heat and the increased time taken to dry the painted or treated surface, compared with metal finishing, in many cases results in the article warping. Thin sections, however, dry satisfactorily, and radiant heating has been successfully applied to a number of drying problems involving non-metallic materials. Appendix II lists a selection of such applications.

#### FUTURE DEVELOPMENTS AND PROSPECTS

Radiant heating by gas has already taken a regular place in the production line. From the point of view of drying processes the main developments will probably be :—

(a) The extension of existing loads.

(b) The increasing use of combined hot air and radiation systems.

#### THE SIGNIFICANCE OF AIR TEMPERATURE

Although in radiant heating systems energy is transmitted from source to receiver without appreciably heating the intervening air, in all equipment where hot surfaces are involved, heat is transferred by convection to the surrounding air both by the source and the heated object.

This additional heat which is manifested in temperature rise of the air can be put to significant use. For an object in equilibrium in a tunnel the gain of heat by absorption of radiation is balanced by the heat loss by convection.

Carne<sup>12</sup> shows that the convection loss is greater for convex, i.e. sharply curved surfaces, than for flat surfaces. On the other hand radiation absorbed per unit area is independent of the curvature of a surface. Thus a thin rod will never reach the same temperature as a flat sheet when both are subjected to the same intensity of radiation. Increasing the air temperature reduces the



discrepancy in heating up between flat and curved objects since, initially, an object receives heat from the surroundings both by radiation and convection, but as the object exceeds the oven air temperature it receives heat only by radiation and loses heat by convection.

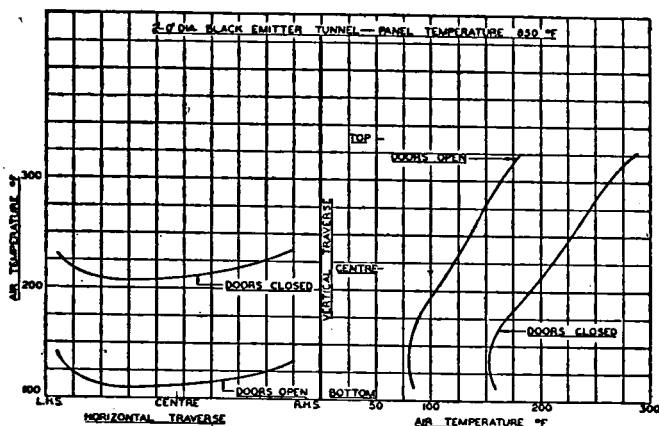


FIG. 54

Fig. 54 shows that the air temperature of a gas-fired black emitter tunnel is appreciable. This is due to the relatively large surface area of hot panel.

The ideal design of radiant heater would be one in which the ambient air temperature equalled the equilibrium temperature achieved by the object being heated. This is impracticable and a compromise must be made. The principle of increasing ambient air temperatures in radiant heating units should lead to saving not only of time but also of length of tunnel required, an important factor where increased production has to be combined with little spare space

#### ADVANTAGES OF RADIANT HEATING

The ability to raise the temperature of an object by direct radiation results in a great saving of time. Sheets requiring 30 minutes in a convector oven can be heated to the same temperature in one minute in a black emitter tunnel.

This advantage is dependent on the object being in full view of the radiating surfaces. The system is, therefore, much more effective when it is possible to convey large numbers of the same objects in line through a tunnel so that each one is not screened by its neighbour. The availability of plant for use in a short time from lighting up, together with the saving of process time and increased output over other systems, means a lower consumption of fuel.

Other advantages, namely, flexibility of control ; a high rate of heat release ; low cost of maintenance, operation and initial purchase ; small size of plant required ; sound design and construction, combine to make radiant heating an attractive proposition where fuel economy and increased production are concerned.

Accurate comparative figures are not as yet easy to obtain since there are relatively few cases where a particular production programme has been carried out using a variety of heating systems, but Table I lists some details of processes now in operation in the area of The Gas Light & Coke Company.

Progress as outlined above will be accompanied by a steady increase in mechanisation of controls and improvement in design and appearance.

ACKNOWLEDGMENT.—Thanks are due to the Governor and Directors of the Gas Light and Coke Company for permission to prepare and publish the information contained in this paper.

TABLE I

PERFORMANCE OF BLACK EMITTER RADIANT HEATING TUNNELS

No.	Material or Process	Type of tunnel  Ft. diam.	Approx. panel temp. ° F.	Conveyor		Process time mins.	Production No. per hour	Approx. consumption therms/hr.	Cost per object at 10d. a therm  Pence
				Spacing	Speed ft. per min.				
1	Painting oil drums 0.024 in. × 17 in. × 11 in.	9 × 2	550	—	—	1.5	120	1.8	0.15
2	Painting mild steel petrol tanks 7 ft. × 1.6 ft. diam., 50 lb. weight.	15 × 3	550-450 graduated	8 ft.	1.5	10.0	6	2.75	4.6
3	Painting sheet metal pressings 22 s.w.g. × 9 in. × 7 in.	9 × 3	500	12 ½ in. in pairs	3.0	3.0	400	2.0	0.05
4	Painting dustpans (domestic)	9 × 2	500	12 in.	3.0	3.0	153	1.5	0.10
5	Painting 20 s.w.g. sheet iron stands prefab. house plumbing equipment, 3 ft. 10 in. × 12 in. × 7 in.	6 × 4	550	2 ft.	2.0	3.0	60	4.0	0.66
6	Painting mild steel tubing 20 s.w.g. × ½ in. diam.	6 × 3	500	4 in.	0.5	12.0	525	1.25	0.02
7	Painting miscellaneous articles including metal tops 6 ft. × 2 ft. and cabinets 3 ft. × 1.6 in. × 1.6 in.	9 × 4 3 ft. extension each end unheated	500	variable	3.0	3.0	60-75	5.5	0.8
8	Painting folding metal chairs ½ in. × ½ in. bar and seat 22 s.w.g. × 1 ft. 3 in. × 1 ft. 3 in.	9 × 3	420	—	—	6.0	90	1.6	0.18
9	Painted chairs as 8 mixed with reflectors for strip lighting.	9 × 3	380	—	—	6.0-7.0	40 chairs 32 reflectors	1.5	0.21

## APPENDIX I

## APPLICATIONS OF PAINT CURING AND METAL FINISHING BY RADIANT HEAT

Pressings of every size and shape	Lamp standards
Electric fire bodies	Shoe horns
Heavy and light iron castings	Folding chairs
Fan casings	Tubular furniture
Aluminium pressings	Shell components
Water heater bodies	Cans and drums
Zinc base alloy fittings	Office furniture
Petrol pump parts	Toothpaste tubes
Shop front sections	Tank parts
Magnesium castings	Instrument covers
Ammunition boxes	Lawn mowers (complete)
Cycle frames, lamps and fittings	Bathroom cabinets
Name plates	Plate racks
Air filter cases	Vacuum flask containers
Radio chassis and components	Sten gun parts
Dynamo cases	Pram components
Shock absorbers	Steel toys
Prefabricated house fittings	Torch cases
Fire extinguishers	Hospital trolleys
Small filing cabinets	Telephone components
Studio and street lamps	

## APPENDIX II

## APPLICATIONS OF DRYING, OTHER THAN METAL FINISHING, BY RADIANT HEAT

Loudspeaker cones	Varnish impregnated transformers
Sand moulds	Filter board
Paint on synthetic resin	Latex
Paint on laminated paper	Shellac bonded mica insulation
Printing ink on fabrics	Granules and powders
P.V.C. on fabric	Frit
Paper board	Phenolic resins
Small and thin clay shapes	Latex covered cartridge paper

## References

- 1 Hayman, R. F., "Recent Developments in Radiant Heating for Industrial Processes," *Gas. Jan. 1947, 1, No. 5.* 356-374.
- 2 Lewis, H., "Bibliography of Published Information on Infra-Red Heating." 1945, Ministry of Aircraft Production.
- 3 Stout, L. E., Caplan, K. J., Baird, W. G., "Mechanism and Rate of Drying by Near Infra-Red Radiation." *Trans. Am. Inst. Chem. Eng.*, 1945, 41, No. 3, 283.
- 4 Ratcliffe, S. W. and Webb, H. W., "The Use of Infra-Red Drying in Pottery Manufacture." *Trans. Brit. Cer. Soc.*, 1945, 44, 119-133.
- 5 Roberts, A. L., "The Application of Infra-Red Radiation to the Drying of Refractories." *Refractories Journal*, 1945, 21, No. 8, 301-313.
- 6 Gould, R. E., Evans, B. B., Flannigan, A. M., "The Use of Infra-Red in Drying Pottery." *Bulletin Am. Cer. Soc.*, 1945, 28, 62-65.
- 7 Communication from Jennings, A. C. The Derby Gas Light & Coke Co.
- 8 "Drying Textiles with Infra-Red." *Rayon Textile Monthly*, 1945, 26, No. 5, 239.
- 9 "Finishing Plant Uses Infra-Red on Rayon." *Textile World*, 1946, 96, 117.
- 10 "Cloth Printing (speeded by Infra-Red Drying Aids)." *Textile World*, 1946, 96, 125.
- 11 Rabold, C. N., "Recent Developments in the Drying of Textile Materials." *Amhr. Dyestuffs Reporter*, 1945, 34, No. 6, 108-117.
- 12 Carne, J. B. "The Influence of Natural Convection on the effectiveness of Radiant. ('Infra-Red') Heating." *Gas Times*, 1945, 44, No. 573, 55.

## Other references

- Andrew, L. W. and Chamberlain, E. A. C., "Radiant Heating for Industrial Processes." *J. Inst. Fuel War Time Bulletin*, 1944, 17, 41-54.
- Coblentz, W. A., "Infra-Red Spectra." I-VII Carnegie Institute, Washington D.C., 1905-1908.
- Roberts, A. L., "First Report on Radiant Heating." Gas Research Board Communication No. 15, 1945.
- Fishenden, M. and Saunders, O.A., "The Calculation of Heat Transmission." (H.M.S.O.)
- McAdams, W. H., "Heat Transmission." (McGraw-Hill.)
- Mackadam, A. C. F. and Janser, A. M. J., "Specific Effects of Infra-Red." *Air Treatment Engineer*, 1945, 8, No. 8, 172.
- Tiller, F. M. and Garber, H. J., "Infra-Red Radiant Heating." *Ind. and Eng. Chem.*, 1942, 34, No. 7, 773-781.
- Ernst, R. C. and Schumacher, E. F., "Infra-Red Radiant Heat Baking of Enamels." *Ind. and Eng. Chem.*, 1944, 36, 1132-7.
- Friedman, S. J., Unit Operations Review—Drying. *Ind. and Eng. Chem.*, 1946, 38, No. 1, 22.
- Maxted, R., "Infra-Red Radiation and Equipment—their Application to Industrial Heat Processes." *Trans. Inst. Illum. Eng. Soc.*, 1942, 7, No. 1, 1.

### 3. Efficiency of Conveyor Drying and Enamelling Plants

By A. M. LEHMANN

This general paper concentrates on air-circulated direct-fired conveyor convection-type ovens, which will be referred to as *conveyor ovens*, a type which may be heated by any fuel, although the use of gas predominates for this plant in this country, and has been found to be the most economical in use. |

I confine this discussion to this channel deliberately. It is considered that the conveyor oven will still prove to be the most efficient oven for general purposes, and will continue to be the type generally demanded. This opinion is substantiated by reactions of many manufacturers who have investigated the drying of their products by means of radiant heat and, alternatively, by a convection conveyor oven in our research department, and in each instance it has been proved to their entire satisfaction that the conveyor oven is by far the better proposition after taking into consideration all factors, such as uniformity and control of temperature, cost of installation, floor space occupied, minimum of attention and service, minimum overall running and capital costs, and, at the present time of paramount importance, the tremendous economy in fuel consumption.

Our extensive experience of *radiant heat ovens* during the war and recent years indicates, however, that this type of oven has advantages over the conveyor oven for certain operations, such as the satisfactory stoving by radiant heat of heavy steel shells, success in the main depending upon each article being identical in shape and weight. The radiant heat oven is not suitable for what we term general purpose enamelling—for example, typewriters, saddles, armatures, cycle frames and components, etc. It is to be borne in mind that we are not comparing radiant ovens with small static ovens, with or without forced air circulation, but we are confining our discussion to conveyorised convection ovens handling reasonably large quantities of work. I would, however, draw attention to the modern trend of using a very small conveyor oven in place of static ovens. It is very easy to load, flexible, has a low capital cost and is exceedingly economical in fuel consumption.

#### DRYING TIMES

Bearing in mind that we are discussing general purpose ovens—it has been determined that if speed of drying is considered of major importance, stoving can be completed in a conveyor oven just as quickly as in a radiant heat oven, and at the same time produce equal, if not better results, providing the same type of paint is used in each instance. For many years paint manufacturers have supplied, for general industrial use, colour stoving paints embodying an oil base, and it has been generally agreed that the drying time required for this type of paint was anything up to one hour at a temperature of 250° to 300° F. in a conveyor oven. During recent years great developments have taken place in paint manufacture, and, briefly, I would refer to two paints now generally known to industry as urea formaldehyde and medium alkyd resins, both of which can be subjected to higher and greater variations of temperature, and can be stoved in quicker time than oil base materials. It is in conjunction with radiant ovens. Therefore, a most important point to remember is, that it is the paint that is the prime factor in quicker drying time, and it is *not* the type of oven alone which determines this more rapid form of drying. In consequence, providing one of the new types of paint is used, the

drying time in the conveyor oven can be reduced to the time in the radiant heat oven.

Consideration should be given to the difference in cost between the oil base, urea formaldehyde and alkyd resins, because the oil base paint is cheaper and requires lower stoving temperatures, a condition which would, of course, materially reduce the fuel consumption. The convection oven is so flexible that it will satisfactorily stove any type of paint without difficulty, the only adjustment required being that of the thermostat for controlling the temperature, which can be made in a matter of seconds. As stoving equipment, the conveyor oven has a range of temperature and control, combined with extreme flexibility, that is second to none.

#### COMPARISON OF GAS CONSUMPTIONS

The comparison here made is based upon equal drying time and similar paint, and is given in Tables I and II.

TABLE I

##### *Radiant Heat Ovens.*

Published rate of the gas consumption for a 3 ft. diameter section 3 ft. long is an average of . . . . .	150 cu. ft. per hour.
Cubic capacity of a 3 ft. diameter section $\times$ 3 ft. long = . . . . .	21.2 cu. ft.
Cubic capacity of a radiant oven, 7 sections long, i.e. 21 ft. 0 in. long $\times$ 3 ft. 0 in. diameter . . . . .	= 148.4 cu. ft.
Gas consumption of the seven sections (150 cu. ft. each section) . . . . .	= 1,050 cu. ft. per hour.

##### *Convection Oven.*

Effective cubic capacity, i.e. the same as the radiant heat oven . . . . .	148.4 cu. ft.
Actual cubic capacity of stove, including heat seals . . . . .	168 cu. ft.
Gas consumption . . . . .	285/300 cu. ft. per hour.

That is 300 cu. ft. per hour as against 1,050 cu. ft. per hour.

This amounts to a difference of gas consumption of 750 cu. ft. per hour or an *annual difference of 1,650,000 cu. ft.* for one small installation. It should be stressed that these figures only refer to small outputs, and that for larger installations the increase is at least pro rata.

In addition, the convection oven will handle considerably more work per hour than the radiant heat oven.

TABLE II

#### FUEL COMPARISON DATA

##### RADIANT HEAT OVEN

*Emitter Temp. 600°/650° F.*

Basis of calculation is 8 to 9 cu. ft. of gas C.V. 450 B.Th.U. per sq. ft. of radiating panel surface. (By courtesy of City of Birmingham Gas Dept. Industrial Research Dept.)

Size of tunnel	Cubic content of tunnel, cu. ft.	Gas consumption per hour, cu. ft.	Gas consumption per cu. ft. of tunnel space, cu. ft.
3 ft. long $\times$ 3 ft. dia. . . . .	21.2	226/254	11.3
3 ft. long $\times$ 4 ft. dia. . . . .	37.6	300/338	8.5
3 ft. long $\times$ 5 ft. dia. . . . .	58.8	376/423	6.8

## CONVEYOR OVEN

Based on Production Runs—Normal Loads—Gas C.V. 450 B.Th.U.

Class of work	Actual oven temp., ° F.	Cubic content of oven, cu. ft.	Gas consumption per hour, cu. ft.	Gas consumption per cu. ft. of oven space, cu. ft.
Wringers and washing machines . . . . .	275	2,070	452	0·22
Stoves, etc. . . . .	425	1,760	1,220	0·69
Gas fires, etc. . . . .	425	1,700	1,050	0·62
Sheet metal furniture, 3½ tons per hour	275	4,550	2,100	0·46
Metal cabinets, 1·93 tons per hour	300	1,500	1,000	0·66

## FUEL ECONOMY

The conveyor oven is shown by Tables I and II to be the most economical in fuel consumption of any type of stoving equipment. It is fitted with fully automatic controls and thermostats. All equipment must be properly designed and used intelligently ; for example, if the manufacturing concern is working on short time, the finishing shop should also be on short time, the oven being efficiently and fully loaded, and if necessary run on half-days or alternate days. The conveyor oven need not be emptied during lunch breaks or at night ; it is only necessary to turn off the fuel supply and stop the conveyor. After the break the plant is re-lighted, when the working temperature is recovered in five or six minutes, and the conveyor is then re-started. This practice is in no way detrimental to the work.

## RADIANT AND CONVECTION HEATING

(a) *Radiant Heat Ovens*.—There are four main types of emitters :—

- (i) Electrical, high intensity, consisting of electrically heated refractories.
- (ii) Electrical, low intensity, consisting of carbon-filament electric bulbs.
- (iii) Gas, high intensity, consisting of gas-heated refractories, usually porous.
- (iv) Gas, low intensity or dull, a fairly general type consisting of a gas-heated mild steel cylinder.

The emitter should completely surround the work being processed, though the ends of the tunnel must, of course, be kept clear for the conveyor. There is difficulty in fitting doors to conserve the heat.

The longer the article stands in front of the emitter, the more nearly will its temperature approach that of the emission surface. Similarly, the closer the article is placed to the emitting surface, the more rapidly will it heat up. Articles subjected to low or high intensity radiation will, therefore, have vastly different stoving times. As soon as an article reaches its stoving temperature it must be removed from the presence of the emitter if it is not to be over-baked and burned. The determination of the correct stoving time for articles of different sizes and shapes stoved in the same batch is thus a major problem in radiant heat oven practice. Diversity of shape, gauge of metal, colour of paint, distance from the emitter and the possibility of portions of the article being shadowed from the radiation all play an important part in this problem.

Shadowed sections must clearly take longer than sections upon which direct radiation falls.

(b) *Air-Circulated Convection Conveyor Ovens.*—In this type of oven, an independent heater is used to pre-heat air to a pre-determined temperature, which is thermostatically controlled, at the oven inlet. No part of the work can thus be heated above this temperature and be over-baked. Any shape, size or weight of articles can be stoved satisfactorily at the same time.

The conveyor oven is a complete drying unit, incorporating a spraying and dipping section, including paint circulation and filtration system, a draining section followed by pre-heat with secondary drain, a stoving section, which latter is sealed at each end with natural heat seals, and a cooling section. The efficiency of this system, comprising adequate thermal insulation, is such that it can be claimed (Tables I and II) that a conveyor oven of the camel-back type uses not more than half the fuel used by any other type of oven for equal quantities of work and utilising equal paint and giving equal results.

The conveyor oven is distinguished for the total absence of hot spots, and short peak temperatures in any part of the oven. By the application of dampers, the heat curve through the stoving section can be adjusted to abnormal stoving conditions, should production requirements necessitate unorthodox settings. The fume extraction system in use on these ovens is a highly important feature, for unless fumes arising from solvent evaporation are removed, the work will be dulled, frosted, or otherwise spoiled. The temperature is controlled, in spite of the fume extraction, within 5° F. over a normal working range of 200–600° F.

Other claims made for the convection oven include economy of paint due to the dipping equipment, reduced floor space in consequence of the conveyor oven being more heavily loaded than the radiant heat oven, and low maintenance cost.

#### STOVING PRINTED OR VARNISHED TIN SHEETS

Convection drying is particularly advantageous for treating tin-plate sheets. The sheets can be stacked vertically in wire frames at approximately 1-in. pitch on a travelling conveyor. With a radiant heat oven the sheets must pass through the heated zone in a horizontal position on a table travelling conveyor.

The comparison between the two types of oven for this purpose is given in Table III.

TABLE III

	Radiant oven, including cooling	Convection oven, including cooling
Length . . . . .	884 ft.	99 ft.
Width . . . . .	{ 4 ft. internal 5 ft. external }	5 ft. 6 in. external
Floor space occupied . . . . .	4,420 sq. ft.	550 sq. ft.
Cubic capacity of stoving section . . . . .	2,550 cu. ft.	735 cu. ft.
Output . . . . .	2,750 sheets per hour	2,750 sheets per hour
Drying time . . . . .	1½ min.	20 min.
Cooling time . . . . .	5 min.	5 min.

## 4. The Drying of Foodstuffs and Waste Products

By A. W. SCOTT, PH.D., B.S.C., M.I.MECH.E.

### I. INTRODUCTION

This discussion is limited to the drying of heat-sensitive products with a high initial moisture content—over 80 per cent.—and a final moisture content after drying of about 5 per cent. Vegetable dehydration is a typical example of this group but the principles and methods apply to a wide range of products. The most common methods of drying such materials are by forced circulation of heated air in conveyor dryers or in tray and tunnel dryers.

In the design of a dryer for a given product there are two distinct aspects to be considered. The first, which may be termed the scientific aspect, deals with such factors as (a) the experimental determination of the rate at which the product will give up moisture under varying conditions, and (b) the air circuit, or cycle, to be used. The second, or practical aspect, deals with the mechanical arrangement of the dryer to ensure economic construction and ease of operation and control. Both the scientific and practical aspects have an important bearing on the thermal efficiency of the dryer.

This paper deals largely with the theoretical aspects of the various air circuits which can be used, as an appreciation of these factors is essential for the achievement of high thermal efficiency. The basic requirements for the air circuit can be appreciated from the drying characteristics of the material under review. In the initial stages of drying, down to about 60 per cent. moisture content, the moisture evaporates freely and air temperatures of about 200° F. are permissible. In the later stages drying is slow and the air temperatures must be kept low enough—about 140° F.—to ensure no heat damage to the product. These conditions can be met by using any of the following air circuits :—

- (1) Single stage counter-flow drying, with low inlet air temperature.
- (2) Parallel-flow drying with higher inlet air temperature, using recirculation, followed by a low temperature finishing stage.
- (3) Multi-stage counter-flow drying, with inter-stage reheating.

These systems can be conveniently compared by means of the psychrometric chart. For the benefit of the traditionalists in drying it is desirable to review briefly the basis of this chart.

### 2. PRINCIPLES OF EVAPORATION INTO AN AIR STREAM

When a wet material is exposed to a heated air stream, evaporation will occur so long as the vapour pressure at the surface of the material is greater than that in the air stream. The hot air tends to heat the material just as it would a metal surface and the heat thus transferred to the material supplies the necessary latent heat of evaporation and may also supply sensible heat to the material. Neglecting the sensible heating effect, we have in any given time and for any small unit surface of the material exposed to the air,



Heat lost by air stream = Evaporation from the area  $\times$  Latent heat per lb. evaporation.

$$\text{or, } h(T - t) = K(P_t - P_a)L$$

where  $h$  = heat transfer coefficient from air to material, B.Th.U./sec./ft.<sup>2</sup>/° F.

$T$  = air temperature, ° F.

$t$  = material temperature ° F.

$K$  = evaporation coefficient, lb./sec./ft.<sup>2</sup>/unit vapour pressure difference.

$P_t$  = saturation vapour pressure at  $t$ ° F.

$P_a$  = partial vapour pressure in air.

$L$  = latent heat of evaporation, B.Th.U./lb.

This assumes that all of the heat lost by the air goes to supply latent heat, the same condition as applies in a wet and dry bulb psychrometer, and therefore under such conditions the temperature of the material being dried will equal the wet bulb temperature of the air stream. Further, in a dryer operating under these so-called adiabatic conditions the wet bulb temperature will remain constant. This assumption may be made with reasonable accuracy in dryer design.

The material being dried, however, will only remain at wet bulb temperature so long as the rate of evaporation approximates to that which would be obtained from a free water surface. This holds in the early stages of drying of high moisture stock but as drying progresses the rate of diffusion of moisture from the interior of the material falls off and the material rises above wet bulb temperature. The material thus absorbs some sensible heat and there is a corresponding fall in the wet bulb temperature of the air. Such effects as external radiation losses from the dryer also cause a fall in wet bulb temperature, but with high-moisture stock these effects can be relatively small.

### 3. USE OF PSYCHROMETRIC CHART IN DRYER CALCULATIONS

The assumption of constant wet bulb temperature simplifies the calculations required for a dryer, particularly when a psychrometric chart is used. On a chart of this type the moisture content per lb. dry air, for various wet bulb temperatures, is plotted to a base of dry bulb temperature. If simple even scales are used constant wet bulb temperature is represented by a straight line. The slope of such a line can be found by considering Fig. 55.

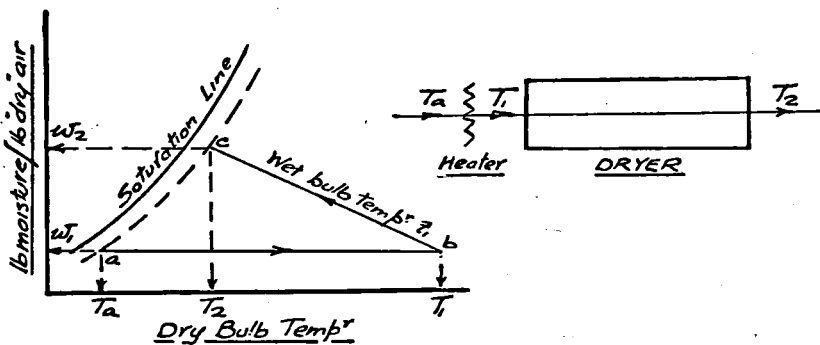


FIG. 55.—Straight dryer, psychrometric chart.

If air at atmospheric temperature  $T_a$  and moisture content  $w_1$  is first heated to a temperature  $T_1$  and wet bulb temperature  $t_1$ , the change is represented by  $ab$  on the chart (Fig. 55). The specific heat of this air, per lb. dry air, is given

by  $(0.238 + w_1 \times 0.48)$  or  $C_{p_1}$ , and the heat added during this stage is  $C_{p_1} (T_1 - T_a)$  B.Th.U. per lb. dry air. If this air, at  $T_1$  is then passed through a dryer in which the material to be dried is at the wet bulb temperature  $t_1$  the air is cooled to an exhaust temperature  $T_2$  and the moisture content per lb. dry air is increased to  $w_2$ . This change is given on the chart by the straight line  $bc$ , representing a constant wet bulb temperature of  $t_1$ . The slope of  $bc$  is got from the following equation, considering 1 lb. dry air :—

$$\begin{aligned} \text{Sensible heat given up by air} &= \text{latent heat of evaporation} \\ \text{or} \quad C_{p_1} (T_1 - T_2) &= (w_2 - w_1) L_{t_1} \\ \text{where } C_{p_1} &= \text{specific heat per lb. dry air, at } b \\ L_{t_1} &= \text{latent heat at } t_1 \\ \therefore \text{ slope of line } bc &= \frac{w_2 - w_1}{T_2 - T_1} = \frac{C_{p_1}}{L_{t_1}} \end{aligned}$$

Using this relationship, any constant wet bulb temperature can be plotted on the chart.

The limiting temperatures  $T_1$  and  $T_2$  would be fixed from several considerations, including heat sensitivity of the material, initial and final material moisture contents and equilibrium air humidities. Having fixed points  $b$  and  $c$  the lb. of dry air required per minute

$$= \frac{\text{evaporation required, lb./min.}}{w_2 - w_1} \quad \text{or} \quad \frac{\text{evaporation, lb./min.} \times L_{t_1}}{C_{p_1} (T_1 - T_2)}$$

$$\begin{aligned} \text{The heat to be supplied per minute in the air heater} \\ = \text{lb. air per minute} \times C_{p_1} (T_1 - T_a) \end{aligned}$$

Hence the efficiency of this simple dryer can be expressed as

$$\frac{\text{Heat to evaporation}}{\text{Heat supplied in air heater}} = \frac{C_{p_1} (T_1 - T_2)}{C_{p_1} (T_1 - T_a)} \quad \text{i.e.} \quad \frac{T_1 - T_2}{T_1 - T_a}$$

This ideal efficiency would not be achieved in practice, owing to the sensible heating of the material and of the fabric of the dryer and also due to air leakage and radiation losses, but it serves as a standard of performance in much the same way as the adiabatic heat drop in steam-power work.

A reliable psychrometric chart is just as essential for dryer design and operation as it is for air conditioning work, and there ought to be a standard chart covering all temperatures used in drying. At present there are some wide divergences in different charts at higher temperatures, and the Ministry of Fuel and Power could perform a very useful service by effecting standardisation.

#### 4. SINGLE STAGE AIR DRYERS

Simple dryers of the type indicated in Fig. 55, in which there is one air heater and all of the air is exhausted, are very commonly used. The air and the material being dried may pass through the dryer in parallel flow or in counter flow, but in either case the ideal thermal efficiency will be given by

$$\text{the ratio} \quad \frac{T_1 - T_2}{T_1 - T_a}$$

To illustrate the effect of varying the inlet air temperature, the efficiency for various values of  $T_1$  has been calculated, using the psychrometric chart and making the following assumptions :—

The air enters the heater at 60° F., 70 per cent. relative humidity.

Drying is at constant wet bulb temperature and the air leaving the dryer is at 70 per cent. relative humidity.

The results are plotted in Fig. 56 and it will be seen how the efficiency increases as the inlet temperature is raised. Substantial gains in thermal efficiency are possible as the initial temperature is increased up to about 400° F. Thereafter the rate of gain is not so marked.

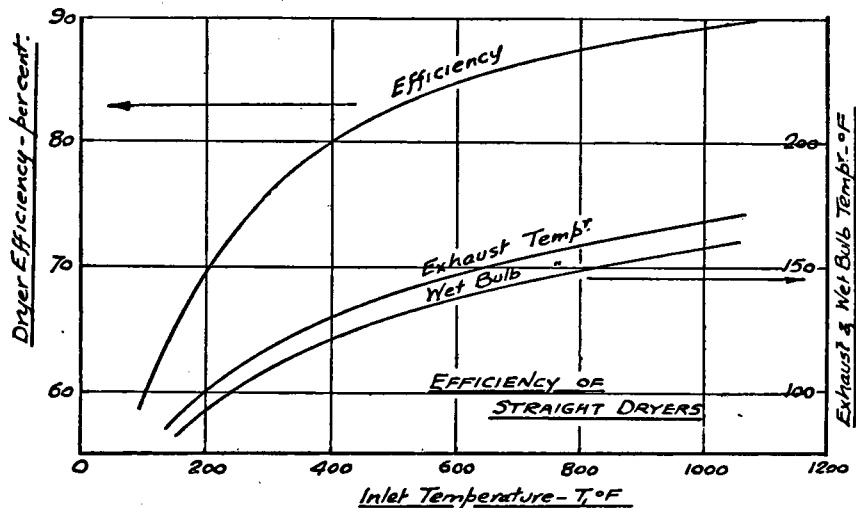


FIG. 56

In the drying of foodstuffs, owing to their heat sensitivity, it is not possible to take full advantage of high temperatures. In any case the drying air, since it has to be free of impurities, must be indirectly heated and with either steam heaters or heaters using furnace gases air temperatures in excess of 300° F. are not practicable. In the drying of waste products there are no such severe temperature limitations.

It is obvious that as the temperature level in a dryer is raised the time required for drying will decrease. In consequence, dryers suitable for low temperatures differ greatly in design from those using high-temperature gases.

Examples of "simple" dryers which have been used for foodstuffs and waste products and which utilise progressively increasing temperatures are :—

- (a) Counter-flow truck and tunnel dryers.
- (b) Parallel-flow rotary dryers.
- (c) Parallel-flow pneumatic dryers.

(a) *Counter-flow tunnel dryers.*—These have been used extensively for dehydration of vegetables in U.S.A. The initial moisture content of blanched vegetables varies from about 80 per cent. for potato to over 90 per cent. for cabbage, and the final moisture content should not exceed 7 per cent. for potato and 5 per cent. for cabbage. The commonest method of drying is to shred the vegetables and spread them on wire mesh trays which are loaded on trucks. These pass through a drying tunnel in which the drying air is circulated over the trays, from end to end of the tunnel.

In the counter-flow tunnel drying is carried out in one stage. The hottest, dryest air meets the outgoing truck and the exhaust air is in contact with the wettest vegetables. The inlet air temperature must be kept low, to avoid scorching. In American practice this inlet temperature varies with the product being dried from 140° F. to 155° F., and the exhaust temperature varies from 95° F. to 125° F., with an average of 120° F. The higher exhaust temperatures occur when the dryer is lightly loaded with the object of decreasing the drying time. With the lowest exhaust temperatures drying may take up to 14 hours, and there is a distinct risk of deterioration in the quality of the product. The thermal efficiency of this type of dryer is reported as seldom exceeding 50 per cent. Under the ideal conditions of Fig. 56, with an inlet temperature of 150° F. and exhaust at 92° F., the efficiency is 66 per cent.

The details of these tunnel dryers call for little comment. They are of simple construction, averaging about 6 ft. 6 in. square and up to 60 ft. long.

(b) *Rotary dryers.*—During the war, surplus potatoes were dried in this country in direct-fired rotary dryers of the type normally used for drying beet cassettes from which the sugar has been extracted. The potatoes were cut into slices about  $\frac{1}{8}$ -in. thick and then dried to 12 per cent. moisture content. The dried product was then ground to a fine meal. The drying time was about half-an-hour.

These, of course, are parallel-flow dryers, the feed chute being at the furnace end of the dryer and under normal operating conditions the temperature at inlet was 800° F. and at exhaust 240° F. The indicated thermal efficiency of the dryer would therefore appear to be  $\frac{800 - 240}{800 - 50}$  or 75 per cent.

The actual evaporative efficiency of the dryer, however, is less than 60 per cent., due to sensible heating, radiation and cold air leakage. In these plants the fan is at the discharge end of the dryer, which is thus under a suction. Hence, unless precautions are taken, considerable quantities of cold air can enter the drying section and give an artificial lowering of the exhaust temperature.

The above efficiency is for the drying stage alone. The overall efficiency, based on fuel consumption, is about 50 per cent., which falls far short of the ideal efficiency.

(c) *Pneumatic dryers.*—These are parallel-flow dryers using direct firing, the gas temperature at inlet to the drying section being usually in the region 1,000°–1,500° F. The material to be dried is finely chopped and fed into a high-velocity stream of gas at the above temperature and very rapid drying occurs as the material is carried forward by the stream. The cooling of the drying gases is correspondingly rapid and the exhaust temperature is normally just over 212° F. The dried material is separated from the exhaust gases in a cyclone.

This type of dryer has been used on the Continent for several waste products, including beet leaves and fish meal, in addition to lucerne drying. In Germany, in particular, about 100 such dryers, with evaporative capacities up to 3 tons per hour, were installed up to the end of the War. Published test data for the German dryer have shown overall thermal efficiencies of 75 per cent., but the normal guaranteed efficiency is about 60 per cent. The overall power consumption is about 25 kW per ton evaporation. This dryer is still in the development stage and these figures will be improved. Control of drying has

been found to be eased by having a rotary drying stage either preceding or following the pneumatic stage.

In the U.S.A. a somewhat similar system is used where material has to be dried and ground. The hot air for drying is passed through the grinding mill and the dried product is carried away from the mill in the gas stream and separated in a cyclone.

Although pneumatic dryers are normally direct fired, they can also be used for lower temperatures with indirect heating by steam or gas. Two such plants were successfully developed during the War in this country for the drying of foodstuffs with an initial moisture content of about 50 per cent.

The possibilities of extending the use of pneumatic drying are worth considering.

5. PARALLEL-FLOW DRYING WITH RECIRCULATION

As has been seen, high thermal efficiencies are possible in single stage parallel-flow dryers where the initial temperature is over 1,000° F. Such a dryer, however, with inlet temperatures restricted to about 200° F. and relatively unsaturated exhaust—to ensure adequate drying—would be very inefficient. A much better scheme in these circumstances is to have two-stage drying with the first stage using parallel flow, with recirculation. The second stage is used for the final stages of drying and the exhaust air from this stage is passed to the parallel-flow section.

This arrangement is commonly used in the drying of fruit and vegetables, which, as already stated, can stand a much higher drying air temperature in the initial stages of drying than in the final stages. In addition, for hygienic and other reasons, it may be desirable to operate the initial stages of drying at a high wet bulb temperature, which can only be obtained by recirculation. An outstanding advantage of parallel-flow drying, compared with the counter-flow type discussed in Section 4a, is that the drying time can be greatly reduced. This follows from the fact that with counter flow the wet vegetables are in contact with exhaust air at about 125° F., while with parallel flow air temperatures up to 215° F. may be used in the initial stages of drying, with the exhaust air at 140° F.

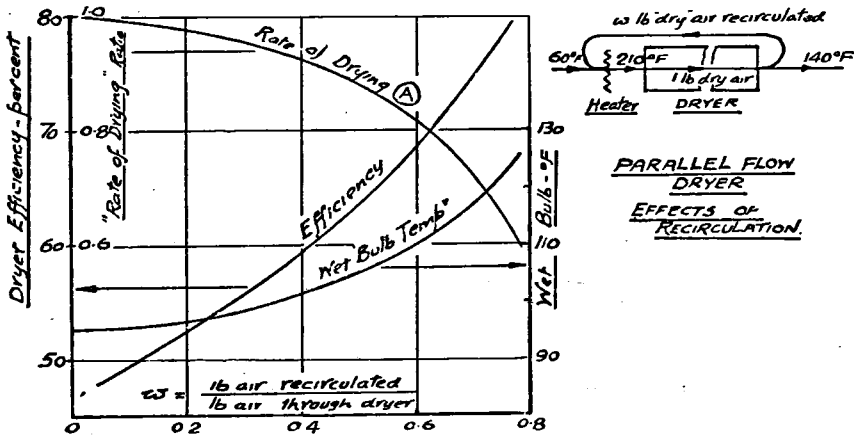


FIG. 57

By recirculating part of the exhaust air in a parallel-flow dryer, as stated, the efficiency is increased. This effect can be illustrated by considering Fig. 57.

For each lb. of dry air passing through the drying section let  $W$  lb. of dry air be recirculated.

If  $w_a$  = moisture content of fresh air entering system, in lb./lb. dry air

$w_e$  = „ „ of exhaust air in lb./lb. dry air

$w_1$  = „ „ at inlet to drying section in lb./lb. dry air

$$w_1 = (1 - W) w_a + W w_e$$

$$\text{or } W = \frac{w_1 - w_a}{w_e - w_a}$$

From this expression the amount of recirculation required to produce given humidity conditions in the dryer can be calculated.

Further, if  $T_1$  = air temperature at inlet to the drying section

$T_2$  = „ „ „ exhaust from the drying section

$T_a$  = atmospheric temperature,

and assuming, as before, that evaporation takes place at constant wet bulb temperature and that  $C_p$  = specific heat per lb. dry air, the thermal efficiency

$$\begin{aligned} \text{of the dryer} &= \frac{\text{Heat utilised in drying}}{\text{Heat utilised} + \text{Heat rejected in exhaust}} \\ &= \frac{C_{p_1} (T_1 - T_2)}{C_{p_1} (T_1 - T_2) + (1 - W) C_{p_2} (T_2 - T_a)} \\ &= \frac{T_1 - T_2}{(T_1 - T_a) - W (T_2 - T_a)} \end{aligned}$$

This assumes that  $C_{p_2}$ , the specific heat at exhaust, equals  $C_{p_1}$  the specific heat at inlet to the drying section.

For the purpose of illustration,  $T_1$  will be taken as  $210^\circ\text{F}$ .,  $T_2$  as  $140^\circ\text{F}$ . and atmospheric conditions  $T_a$  as  $60^\circ\text{F}$ ., 70 per cent. relative humidity.

$$\text{Efficiency} = \frac{210 - 140}{(210 - 60) - W (140 - 60)} = \frac{70}{150 - 80W}$$

Using this expression, the effects of progressively increased recirculation are shown in Fig. 57. If no recirculation is used the efficiency is 47 per cent., while with 80 per cent. recirculation the efficiency is raised to over 80 per cent.

As recirculation is increased, the level of humidity in the dryer is raised and the rate of drying falls off. The rate of drying may be taken as proportional to the difference between the mean air temperature and the material temperature which in this case is the wet bulb temperature. In all cases in Fig. 57, the mean air temperature is  $\frac{1}{2} (210 + 140)$ , i.e.  $175^\circ\text{F}$ ., and the rate of drying is proportional to  $(175^\circ\text{F} - \text{wet bulb temperature } ^\circ\text{F})$ . On this basis, curve A in Fig. 57 has been constructed, taking as unity the rate of drying with no recirculation. The drying time required is, of course, inversely proportional to the rate of drying. It will be seen that with increased recirculation the dryer length will have to be increased for a given output, because of the longer drying time.

It will also be obvious that the first cost of a dryer using recirculation will be greater than that for a simple dryer, as additional ducting has to be provided leading from the exhaust end to the heater inlet. In addition, a system of dampers is required to control the relative quantities of recirculated air and

exhaust air, and the fan power will be increased due to the resistance of these dampers and the extra ducting. With proper design of ducting this additional power should not be severe and in the design of any parallel-flow dryer the possibilities of recirculation should be examined. As already stated it has been successfully used in fruit and vegetable drying, both in America and Britain.

Although a specific case has been worked out in Fig. 57, the same method can be applied in analysing any problem in recirculation.

#### 6. COUNTER-FLOW DRYING WITH INTERSTAGE HEATING

Parallel-flow drying with recirculation is most suitable for tunnel-type dryers with end-to-end air flow. For conveyor drying of high-moisture food-stuffs an alternative system is available which achieves the same aim of high drying rates combined with reasonable thermal efficiency. This alternative is counter-flow drying in stages with inter-stage reheating to graded temperatures. By this means the inlet air can be supplied at a safe temperature for the finished product and then reheated progressively to the maximum temperature which the moister material can stand.

To illustrate the method of calculating the theoretical thermal efficiency in such cases, the example shown in Fig. 58 may be considered. The conditions assumed approximate to those used in a large three-stage conveyor dryer for potato strips. The conditions at each stage can be found from the psychrometric chart as shown in Fig. 58 assuming constant wet bulb drying.

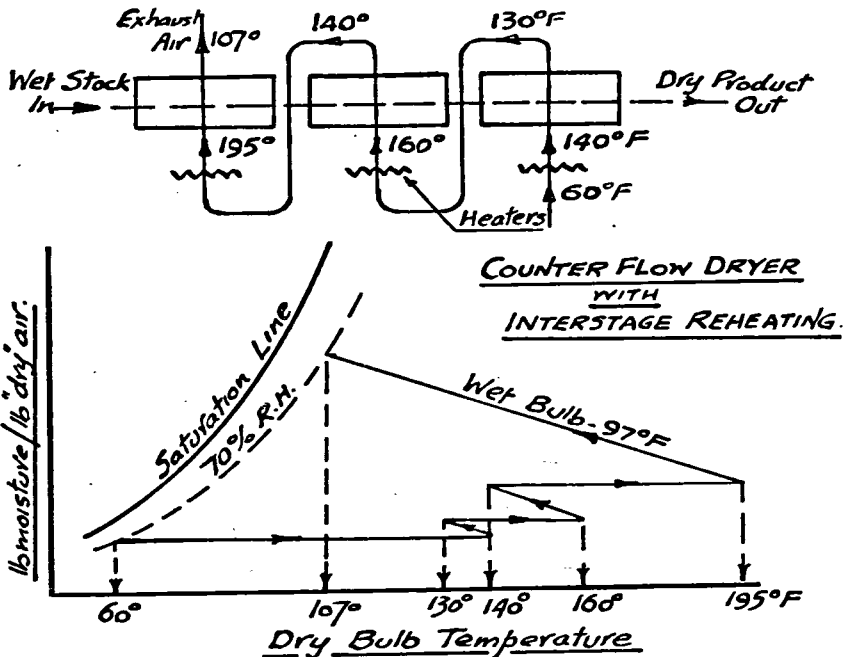


FIG. 58

The efficiency in this case, taking the appropriate specific heat for each stage, is given by :—

$$\frac{\text{Heat utilised in dryer}}{\text{Heat supplied in heaters}}$$

$$= \frac{\cdot 242 (140 - 130) + \cdot 243 (160 - 140) + \cdot 246 (195 + 107)}{\cdot 242 (140 - 60) + \cdot 243 (160 - 130) + \cdot 246 (195 + 140)}$$

$$= 0\cdot 72 \text{ or } 72 \text{ per cent.}$$

In this case three-stage heating has been taken but the number of stages which can be used is limited only by the practical difficulty of arranging the interstage heaters and fans. In conveyor drying of high moisture products the last stage, at the feed end, should cover only a short length of belt, as the air leaving the mat of material, close to the feed point is usually saturated. The humidity of the leaving air quickly decreases as the distance from the feed end is increased, hence the thermal efficiency will be increased by increasing the number of stages, assuming each stage of equal length.

Root vegetables have been successfully dried by through draught on a single belt conveyor dryer, 36 ft. long, using 5 reheating zones. In this case the air leaving each zone is drawn off by propeller fans above the conveyor, passed down over heaters in the side casings of the dryer and delivered to the underside of the belt in the next zone. This probably represents the most compact arrangement possible with a single belt dryer. A similar scheme is possible with cross-flow truck and tunnel dryers but the problems of isolating the zones and obtaining uniform air flow through the trucks present difficulties.

A multi-band dryer with interstage reheating which was developed in Germany for vegetable dehydration is worth mention. In this machine there are four super-imposed wire mesh belts, each with a separate speed control. The wet material is fed to the top belt and cascaded to the lower belts, the dried product being withdrawn at the bottom of the dryer. In the space between the forward and return runs of each belt is a single bank of steam-heated gilled tubes. The drying air enters at the bottom of the dryer casing and passes up through each stage in series, the air temperatures being controlled by the steam pressure in each heating bank. No air circulating fan is used, the necessary draught being obtained by a tall vent at the top of the dryer casing.

Test data showed a steam consumption of 1·6 lb. steam per lb. evaporation. The main feature of this dryer is the extensive use of radiant heat for drying. Since open-meshed belts are used, each heating bank can radiate heat both to the underside of the layer of material immediately above the heater and to the top side of the layer on the belt beneath. There are distinct advantages in such a scheme from the standpoint of compactness and also thermal efficiency. Any drying system in which latent heat is transmitted directly from the steam to the material being dried is more efficient thermally than one in which the latent heat is supplied by air previously steam heated. In roller drying this direct heat transfer occurs by conduction to the film being dried, but transfer by radiant heating is not yet practised extensively in tunnel or conveyor drying.

#### 7. SOME PRACTICAL FACTORS AFFECTING THERMAL EFFICIENCY OF TUNNEL AND CONVEYOR DRYERS

(a) *Evenness of air flow and temperature.*—In designing a dryer the main task is the working out of the air circuit for temperatures and volumes on the lines



indicated above. The design of the air circuit for minimum pressure losses is also important. There are several other practical factors whose bearing on thermal efficiency is not always appreciated.

It is important, for example, to have uniform air velocity and temperature distribution at all stages of drying. These are conditions not always easy to fulfil but they must be attained, for maximum thermal economy. Uneven drying means that the drying time is longer than necessary and the constant heat losses such as external radiation and air leakage, are increased per ton product. Further, in truck and tunnel dryers every care should be taken to ensure that all of the air circulating through the tunnel passes over the drying trays. If air can leak past the sides, top or bottom of the trucks without doing useful drying this, of course, is a direct heat loss. The trays should occupy the maximum possible percentage area of the tunnel and baffles be provided where necessary.

To eliminate the large dead space caused by the truck wheels in tunnel dryers, one U.S. dryer uses wheelless trucks or frames, roller tracks being provided inside and outside the tunnel for transporting the frames. This reduces the mobility of the trucks but ensures that maximum use is made of the tunnel cross section. This same dryer, incidentally, uses back-pressure steam turbines for driving the circulating fans and the turbines exhaust to the air heaters.

In both conveyor and truck dryers it is also essential to have the material evenly spread with uniform loading density.

Control of inlet air temperature by thermostatic valves on the air heaters is now accepted as standard practice on dryers, but greater use should be made of air temperature recorders. In particular, a wet and dry bulb recorder on the dryer exhaust is of great assistance in checking operating conditions. Wet bulb recorders are now available which maintain their accuracy with only a reasonable amount of attention.

(b) *Continuity of Operation.*—One great advantage of conveyor dryers over tunnel dryers is that operation is continuous and uniform temperature conditions can be easily maintained. Some materials, of course, can only be dried on trays, and tray and truck dryers must operate intermittently to allow of admission of the trucks. Such dryers should be arranged to give minimum heat losses when trucks are admitted and withdrawn, by having a very short time interval for these operations. Air locks on all dryer doors also assist greatly but are rather awkward to instal in some cases.

A further solution of this problem of continuous operation of tray dryers is provided by the German spiral-band dryer, in which the trays are virtually carried on an endless conveyor. The loaded trays are conveyed in a single or double layer, to the top of the dryer and descend through the dryer in a close pitched spiral path, being transferred at the bottom to a horizontal tangential conveyor which carries them out of the dryer casing. The drying air is circulated over the trays by three superimposed centrifugal fan rotors mounted on a common vertical central shaft. The gilled heating elements are placed round the outside of the trays, and the air enters at the bottom of the casing and is circulated alternately in over the trays and then outwards by the action of the fans. The exhaust is at the top of the casing. This is a very compact dryer which has been used for foodstuffs and other products.

(c) *Utilisation of Heat in Exhaust Air.*—It has been seen that about 50 per cent. of the heat supplied in the air heater of a dryer may be carried off as sensible heat in the exhaust air from the dryer, and where fuel economy is all-important

steps can be taken to recover some of this heat. In some milk spray-drying plants, for example, the exhaust air is used to preheat and partially concentrate the incoming milk, which is sprayed into a separate chamber through which the exhaust air passes. This system has obviously limited application but in other spray-drying plants the exhaust air is passed through a tubular heat exchanger and used to preheat the incoming air before it passes to the main air heater. Such a system could be applied to any air-drying plant.

There are, of course, drawbacks to the scheme, otherwise it would be more universally applied. Both the heat transfer rate and the available temperature difference are low and the heat exchanger is therefore bulky. For example, to heat 10,000 cubic ft. of air per minute from 60° F. to 100° F. using exhaust air at 150° F. would require a heat exchanger of about 1,000 sq. ft. heating surface. Additional fan power is required and care must be taken to prevent corrosion due to moisture deposition. In spite of these difficulties, however, savings in fuel of about 30 per cent. are claimed by the makers of one spray dryer using such a heat exchanger.

## 5. Spray and Roller Drying

By E. H. FARMER and C. G. SIX

The meaning of the expression "evaporate to dryness" is by no means as simple on the large scale as might be expected. When the problem is merely to recover a solid which will crystallise readily from a concentrated solution, the obvious procedure is to remove water in an evaporator and to allow crystallisation in the same or a different vessel. Where, however, it is necessary to handle a liquid that can be dried down into a solid condition without crystallising, the problem is very different. If evaporation is carried out in pans or trays it is usually slow and difficult to control and may be attended by gross wastage of labour in removing the dried material. Moreover, if the product is sensitive to heat, drying in pans or trays will often cause damage. To overcome these difficulties recourse is often had to roller drying or spray drying. Both methods have their advantages and disadvantages which will be outlined later in the paper.

### ROLLER DRYING

Roller drying consists in the application of the substance to be dried in a thin film to the smooth surface of a continuously rotating heated metal drum. Drying is completed in less than one revolution of the drum and the dried material is continuously scraped off the drum by a stationary knife, known as a "doctor" knife. Roller dryers have been used for very many years and amongst the earliest systems the following found wide commercial application. The Knoch process, patented by Dr. C. Knoch, in 1894, was used with fair success in drying milk and similar materials. This process was largely replaced by the Just process and later in this country the Just-Hatmaker system which is basic for most of the modern twin-drum dryers. The Gathmann process deserves mention as the system consists of a spirally-stepped drum in the form of a cone rotating in the opposite direction to a similar outer shell, the film being kneaded and ground between the two surfaces.

Roller dryers may comprise single or multiple drums. For drying most liquids one or two drums are usually employed; in the paper industry large numbers are used. Almost always the drums are heated by steam under pressure. The roller dryer will always be popular because of its relatively low initial cost, space-saving compactness and simplicity and economy of operation with the minimum of accessory plant likely to introduce complications. With the conditions of operation properly worked out it is capable of a very high evaporation rate and low steam consumption. The steam consumption of a well-arranged roller dryer should not exceed 1.5 lb. per lb. of water evaporated. The capacity will vary considerably with the nature of the material being dried and may be as much as 8 lb. of water evaporated per sq. ft. of drum surface per hour.

The most important variable to be fixed in roller drying is the thickness of the film of liquid carried round on the roller. On a single drum machine the thickness of the film is usually adjusted by means of an additional small spreading roller. Double-roller machines are usually arranged so that the drums revolve in opposite directions, turning downwards towards each other when viewed from above, and the gap between the rollers is adjusted to give the desired film thickness. Sometimes double machines are arranged with the drums revolving away from one another, as seen from above, in which event auxiliary rollers are used as spreaders and the size of the gap between the two heated rollers is unimportant. This method has been widely used for potato drying, primarily, we believe, to overcome trouble due to the presence of stones and other heavy matter which might fall into the gap and cause serious damage if the drums revolved in the usual manner.

#### STEAM PRESSURE, FILM THICKNESS AND SPEED OF DRUM

As the drying period is limited to the journey of the film between the feed and the scraper, usually less than three-quarters of a complete revolution, it is clear that the steam pressure, film thickness and drum speed are three related variables controlling drying for any given diameter of drum. The steam pressure may be determined by external factors, such as the availability of pass-out steam from electric power units. It is generally possible to dry successfully by means of steam at a pressure of 15 lb. to 20 lb. per sq. in., but the low output means heavy capital cost in drying equipment. Higher steam pressures involve a saving in the size of plant but may introduce complications if the material is heat-sensitive. Most drying operations are carried out at steam pressures between 50 lb. per sq. in. and 100 lb. per sq. in. Milk dryers usually operate at 15–16 r.p.m. Other products may require speeds as low as  $1\frac{1}{2}$  r.p.m. For general purposes a variable-speed gear is desirable.

The consistency of the mix fed to the machine is important. If it is too thick it may be difficult to obtain a uniform and thin film. If the feed is too dilute the amount of water to be evaporated is unnecessarily increased. It is interesting to note that it is sometimes possible to double the amount of water in the feed without appreciably affecting the output of dried solid per hour or its moisture content. These conditions arise if most of the time spent by the material on the rollers is occupied in driving off moisture from within the solid ("the falling-rate period of drying") and only a small part of the time in driving off free water from the surface of the solid ("the constant rate period of drying"). The added water may be very useful in producing an easily manageable feed.

#### FEEDING THE MATERIAL TO THE DRUMS

With double-roller machines it is general to feed the liquid into the trough between the rollers. In single-drum dryers there may be a trough carrying the liquid beneath the drum into which this dips ; alternatively the feed may be applied to the drum by means of an auxiliary drum or roller which revolves in the liquid or by spraying it on to the drum.

#### UNIFORMITY OF FILM THICKNESS

Uniformity of moisture content and of composition, with heat-sensitive materials, depends on the maintenance of a uniform film thickness. The uniformity of the film is affected by the uniformity of the clearance between the drums over their entire length, by uniformity of level in the trough, by uniformity of the feed and by the efficiency of removal of the dried film. As the drums bulge slightly under pressure, low steam pressures are an advantage in ensuring a uniform film. To obtain a first-class product it is necessary to pay scrupulous attention to the drum surfaces and these should be rebuffed periodically. If possible, the pH of the mix should be adjusted to minimise corrosion.

#### REMOVAL OF THE DRIED FILM

The usual arrangement for dried film removal consists of a stationary knife which extends over the entire length of the drum. The pressure holding the knife edge against the drum surface is provided by weights or springs or jack screws, and efficient film removal requires careful adjustment of the knife edge and careful selection of the knife angle. Uneven pressures or worn knives result in parts of the film remaining on the drum for more than one revolution, and this usually causes an inferior product. Excessive pressure of the knives may cause particles of metal to be shaved from the drum surface, not only jeopardising the quality of the product but also damaging both drum and knife.

#### AIR VENTING AND CONDENSATE REMOVAL

The air entrapped in the drum and the steam condensate must both be continuously removed to maintain thermal efficiency. Condensate removal is frequently at fault. Condensate is siphoned out as the level inside the drum rises and primes the siphon ; when the siphon breaks, condensate collects inside the drum until the siphon is again started. This layer of condensate greatly reduces heat transmission from the steam. Another source of trouble is siphoning from one drum to the other if the condensate from both drums is taken out through a single trap. The air venting is extremely important since a small quantity of air only in the drum will greatly reduce heat transfer. One per cent. of air in the drum may reduce heat transfer by as much as 11 per cent. Bucket lifters are sometimes employed in place of siphon tubes for the removal of condensate. Small buckets scoop up the condensate from the bottom of the rollers and deliver it to a trough from which it is discharged through a trap in the usual manner.

#### EFFICIENCY AND FUEL ECONOMY

We have already stressed the importance of correct choice of steam pressures and roller speeds, correct selection and careful maintenance of film thickness, good "housekeeping" in the maintenance of knives and roller surface, and careful trapping and air venting. In addition, the basic principles of steam economy must also be applied. In large drying installations it is worth while employing boilers with a working pressure high enough to operate a steam-driven generator, exhausting or passing out steam at the pressure required by

the dryers. It is commonly found that the whole of the power required for driving the dryers and auxiliary equipment can be obtained in this way from a back-pressure engine exhausting at, say, 50 lb. per sq. in., with an initial boiler pressure not higher than 200 lb. per sq. in. It may be practicable and desirable to increase the throughput of the drums by preheating the liquor to be dried, and this can be achieved either by utilising the condensate from the drums or by steam heating. Which ever course is followed the condensate from the drums should be utilised for boiler feeding, appropriate steps being taken to avoid, as far as possible, loss of heat in "flash steam." Attention should, of course, be given to efficient lagging and to the choice of steam lines and valves of adequate diameter. It is not unusual to find cheap and inefficient reducing valves on each individual machine when one relay-operated reducing valve serving a whole battery of machines would represent little more in capital expenditure, but would make for better control and consequently would save steam.

General drying considerations hold for roller dryers as much as for dryers of other types, although they may not have been studied in such detail. As would be expected, the speed of drying, and consequently the output or the thermal efficiency, can be considerably increased by inducing an air current over the surface of the drying film. The rapid removal of water vapour greatly increases the speed of drying and also reduces the temperature of the film. Avoidance of stagnant pockets of water vapour between the rollers underneath the feed trough is important and is sometimes neglected. The hood above the machines must be adjusted in such a way as to give an even flow of air over the drums, and anything in the nature of a local blast avoided. It is not very easy to arrange for a strong air current over the drums of a twin roller dryer, but there are on the market single drum dryers where particular attention has been given to a forced draught. It is claimed that with good air flow over the drum it is possible to work with considerably lower steam pressures, giving less risk of local heat effects on the dried film and permitting lighter mechanical construction. The following figures will give some idea of the increase in efficiency possible with properly designed air flows. Using 50 lb./sq. in. steam pressure in the drum and without forced draught the output of a non-hygroscopic material was 11 lb./sq. ft./hr. and the surface temperature of the film about 115° C. When the speed of air over the drum was increased to 50 ft./sec., the output was increased to 20 lb./sq. ft. and the surface temperature of the film was about 83° C.

#### VACUUM DRUM DRYERS

Dryers can be completely enclosed in stout chambers so that evaporation can take place under reduced pressure. There are mechanical difficulties in removal of the dried product, but these have been overcome successfully in several designs commercially available. These dryers are recommended for heat-sensitive materials and have been used with a considerable measure of success, but it is important to remember that the temperature of the dried solid may approach that of the heating medium in a vacuum dryer just as in a dryer operating at atmospheric pressure. A good deal of nonsense is talked about vacuum drying because it is often overlooked that, whilst the temperature is low during the constant rate period of drying, it rises during the falling rate period; the governing factor must clearly be the time of contact during the latter. In an ordinary twin roller dryer the time of contact is normally very

small, and heat-sensitive materials can usually be dried without damage. For example, unequivocal tests have demonstrated that no appreciable destruction of Vitamin C, the most heat-sensitive of the known vitamins present, occurs when milk is dried by the roller process.

#### SPRAY DRYING

Some interesting notes on the early history of spray drying will be found in a paper by Kenneth Bullock and J. W. Lightbown in the *Quarterly Journal of Pharmacy* (1942), 15, 228.

They state that the process dates back to 1872 when Percy took out a patent in America for "a method of atomising and desiccating fluid and solid substances, also any viscous substance containing water by the use of dried, heated or cooled, air or gas, which forces the substance into atoms, the atoms are thrown forward and forced into a chamber and dried, in consequence of the dried and heated air which propels them into the chamber and also owing to the dried and heated state of the chamber into which they are thrown." Reduced to its simplest dimensions, the art of spray drying is merely one of bringing a stream of finely divided liquid or slurry into intimate contact with a hot gas, usually air, which drives off the moisture, leaving the solid as a fine dry powder to be separated from the humid gas.

In the few published papers on spray drying there is an almost complete lack of data on fundamental design and performance, and the problem of thermal efficiency seems to have been dealt with only superficially. It is therefore extremely difficult to form a reliable estimate of the true drying conditions and the size of the plant, even when given the characteristics of the material to be dried and the known operational variables.

The spray dryer is a versatile plant which can be adapted to a great variety of conditions and substances. It is particularly suitable for the drying of heat-sensitive materials and products required as fine free-flowing powders with fixed limits of moisture content. The great range of products that have been dried successfully in a spray dryer can be illustrated by the following widely differing examples. Anhydrous Glauber salts were required from a solution containing 30 per cent. of sodium sulphate, and a spray dryer was installed to produce this directly at the rate of 10 tons per day. During the early days of Penicillin production the spray dryer was used with success to prepare, under sterile conditions, the dry sodium salt of Penicillin from a solution containing 2 per cent. of solids; in spite of the great heat-sensitivity of the Penicillin then available, there was no appreciable loss of activity, and the moisture content of the dry material was of the order of 0.25 per cent.

There is often little to choose between spray drying and drum drying. The drying time is much shorter for spray drying, about 0.1 sec., compared with 2-3 secs. for drum drying. The surface in contact with the hot drum is hotter than the exposed surface of the material and the product from the drum usually needs to be ground and sieved. On the other hand the drum dryer has a better thermal efficiency amounting to about 1½ lb. of steam per pound of water evaporated compared with 2-5 lb. of steam for the commercially available spray dryers. Moreover the drum dryer is capable of drying types of material like thick pastes and fibrous slurries which are extremely difficult to spray dry. There is little difference in capital cost for large installations,

but the drum dryer is cheaper for small outputs ; where the physical characteristics of the product are not of major importance it would be the better choice. The drum dryer is more economical of space, as the spray dryer requires considerable head room.

In its simplest form the problem of spray drying can be divided for convenience into the following headings :

- (a) Heating of the air or other gas.
- (b) Admission of the air or other gas to the drying chamber.
- (c) Method of spraying.
- (d) Recovery of the dried products.

The plant should be kept as simple as possible and no accessory equipment added without good justification.

#### AIR HEATERS

Air heaters may be of the direct type in which the products of combustion are permitted to enter the drying chamber, and which have a very high degree of thermal efficiency, or of the indirect type where the air does not come into contact with the products of combustion. The thermal efficiency of the latter type will, of course, depend on the size of the heater unit, and consequently has to be balanced against capital cost.

#### DIRECT HEATERS

When there is no objection to the possible contamination of the dried material by the products of combustion, very serious consideration should be given to the employment of direct heating. Any type of fuel may be burned or the flue gases direct from an existing steam-raising plant or furnace can be employed. Flue gas is especially valuable when available in sufficient volume, for the temperature is usually low enough to obviate dilution with cold air and the oxygen content is small enough to make it particularly useful for the drying of easily oxidisable or even explosive materials.

With oil or gas a refractory-lined combustion chamber is required in which the fuel is fired. The temperature of the flame is high and combustion should be complete. The products of combustion are then diluted with atmospheric air to bring the temperature of the mixture of gases and air to what is wanted at the inlet of the spray dryer, usually about 300° C. With coke or coal as the fuel a similar installation is required, with the addition of adequate settling chambers to ensure complete separation of the solid material, ashes, etc.

Indirect heating is generally used for the drying of foodstuffs, pharmaceuticals and fine chemicals because of its superiority in maintaining the purity of the finished product.

#### STEAM HEATING

Steam at 200 lb. per sq. in. is extensively used as the heating medium for indirect heaters up to about 170° C. Heating air by means of steam in pipes is notoriously inefficient and calls for cumbersome heaters unless special attention is paid to design. By the use of finned tubes and careful control of the air flow the efficiency can be very greatly increased and the size of the heater materially reduced. A number of excellent air heaters on the market merit careful consideration. The modern boiler working at a pressure of some

200 lb./sq. in. has a high thermal efficiency and the overall efficiency from fuel to hot air should reach 70 per cent. The problems of boiler design and efficiency need not be discussed here, but it must be remembered that the boiler itself can be, and quite often is, the cause of a low overall thermal efficiency in a steam-heated unit.

In order to maintain the highest heating efficiency with steam it is general to use two, or even three stages, so that low-pressure exhaust steam from prime movers may be used for the preliminary heating and so economise the expensive direct boiler steam.

Superheated steam should not be used for air heating owing to its low thermal capacity compared with the latent heat of saturated steam, and also because the heat transfer coefficient of superheated steam is very much less than that of saturated steam.

#### OIL HEATING

In some instances oil heating has advantages over steam. Higher air temperatures are readily obtainable, as certain grades of oil can be heated to 300° C. or higher and the pressure of the whole system can be maintained below 15 lb. per sq. in. High temperatures can only be obtained with steam by disproportionate increases in pressure. The disadvantages of oil heating are that a special circulating pump and a furnace are necessary.

#### FLUE GAS HEATING

Where an adequate supply of flue gas is available, heating by flue gas is undoubtedly an extremely economic method. Its chief drawback is the necessity for a very large heating surface owing to the low rate of heat transfer between the gases and the metal surfaces. It also calls for the provision of forced draught to the furnace. Serious corrosion of metal may also occur if the gas is cooled to a temperature below its dewpoint.

In this method the air is passed through tubes installed in a furnace and there are several factors to be considered if the full thermal efficiency is to be obtained.

- (1) The escape of furnace gases at uneconomically high temperatures must be prevented. This entails the installation of two or three stages in order to utilise the heat in the gases.
- (2) It is very difficult to prevent local heating which causes rapid deterioration of the tubes. This can be overcome to a certain extent by ensuring an adequate speed of the cold air through the tubes.
- (3) There is no storage of heat such as is obtainable by the use of a boiler and this makes the maintenance of a steady temperature extremely difficult even with the aid of furnace regulators.

#### ADMISSION OF HOT GASES TO DRYING CHAMBER AND SPRAYING DEVICES

The method of admitting the hot air to the drying chamber is necessarily closely related to the method adopted for atomisation of the material to be dried. Rapid and uniform contact between the hot drying air and the atomised particles has been extremely difficult to achieve in practice, and it is in this operation that great thermal losses can occur.



There are three types of atomisers in general use :—

- (1) The pressure atomiser.
- (2) The compressed air atomiser.
- (3) The high-speed rotary disc atomiser.

Each one of these types has both advantages and disadvantages, and careful consideration must be given to the selection of the most suitable type for the particular material to be dried.

(1) The pressure atomiser involves passing the liquid to be sprayed under a pressure of 2,000–3,000 lb./sq. in. through the fine orifice of a pressure nozzle. A variety of different types of nozzles is in use with single or multiple jets, swirling or non-swirling sprays, etc. The disadvantages are that the fine orifice is easily choked by solid particles and it tends to wear rather quickly, necessitating a fairly frequent renewal of the orifice disc, and the method can only be used for liquids or for colloidal or semi-colloidal suspensions.

(2) The compressed air atomiser, though cheap and simple in construction, requires an air compressor and frequently a liquid feed pump as ancillary plant. This method and also the pressure nozzle system have the advantage that the liquid input can be divided between a large number of nozzles, which facilitates the dispersal of the atomised material.

(3) The centrifugal disc atomiser with a high velocity reaching 20,000 r.p.m. requires careful maintenance and operation. The high-speed disc must remain perfectly balanced ; if the material to be dried crystallises or dries on the disc, the atomiser may easily be wrecked.

Whichever method is used to spray the liquid or slurry, the fine sprayed particles lose their momentum almost instantly and float passively in the hot air. In a well-designed plant the liquid particles are evenly distributed throughout the hot air. If they are not, important volumes of air will not come in contact with particles and heat will be wasted. For particles measuring  $3 \times 10^{-3}$  cm. in diameter, as generally produced in a spray dryer, there can be little relative motion between the particle and its surrounding air during the 0.1 sec. normally required for drying. The water content of the particle is completely absorbed by its "boundary layer" of air which supplies the necessary heat to the particle. In our opinion, devices which produce rotary or turbulent motions in the hot air in order to increase the relative motion between the particles and hot air are not needed. It is necessary, therefore, to select the size and shape of the drying chamber and the position, shape and speed of the hot air inlet so that they will fit the size and shape of the cloud of sprayed particles to be supplied by the particular atomiser selected.

The spray dryer has the reputation of having a low thermal efficiency in utilising the heat entering the dryer, and certainly many units in operation bear this out, but a well-designed unit can give thermal efficiencies little below those of other types of dryers. As an illustration of this, a commercial unit, installed and adjusted by the engineers responsible for its construction, was handed over with a maximum thermal efficiency of 18.5 per cent. and this was considered quite normal. A new unit was then designed to replace this uneconomical commercial plant and operated with a thermal efficiency of 70 per cent.

Spray drying does not use counter-current air which would appear to be the logical method of drying. Moreover little more than one-third of the water-carrying capacity of the air is used as against two-thirds with a dryer employing counter-current air. However, it does not follow from this that the spray dryer has only half the thermal efficiency of a good counter-current dryer, because the water-carrying capacity of air increases much faster than the temperature, while the heat consumption increases directly with the temperature of the air. An example will illustrate this point ; air at 75° C. can carry 0.38054 kg. of water per kg. of dry air when saturated, while at 85° C. it can carry 0.82311 kg., an increase to 2.16 times, while the heat consumption has only increased to 1.16 times.

The most general primary cause of low efficiency is the coarseness or unevenness in size of the sprayed particles. The drying time of a particle increases with the square of its diameter, and its speed of fall also increases with the square of its diameter, so that an increase in particle size rapidly decreases the rate of drying and also the time available to dry. This effect of the particle size on the rate of drying shows how important is the function of the atomiser, for even if the majority of the particles are of the right size a few larger ones will compel an uneconomical adjustment of the drying conditions to deal with them.

#### RECOVERY OF DRIED PRODUCTS

In general the bulk of the dry material settles out in the drying chamber, where facilities exist for its removal. The air from this chamber then passes through a cyclone or multiple cyclones and finally through a dust filter which removes the last of the dust. The dust filter may be replaced by a spray tower or by an electrostatic precipitator. In practice there does not seem to be any necessity to use cyclones followed by dust filters. Dust filters are designed on the basis of air throughput alone and consequently no reduction in size would be achieved by prior removal of the greater part of the dust in a cyclone. The principal disadvantage of the cyclone, and more especially of the small multiple units, is that they cause considerable heat losses. Elimination of the cyclone conserves heat, and the increased dust supply to the dust filters need cause no inconvenience if they are of the modern automatic type. In some systems the hot air together with the entrained dust from the cyclones is passed up a tower or chamber into which the liquid to be dried is sprayed. It is claimed that this system preheats and concentrates the liquid to be dried. However, unless the air leaves the dryer at an uneconomically high temperature or low humidity the heat absorbed by the liquid to be dried is balanced by the water condensed in it, as the greater part of the heat in the leaving air is in the form of latent heat.

In an economical plant working with non-hygroscopic material the air should leave the drying chamber at about 70° C. with a relative humidity of 30 per cent., the dewpoint of which is 47° C. The recoverable heat is negligible. For this reason recirculation or partial recirculation of the air is not economically justifiable except when an inert gas must be used instead of air. If recirculation is necessary the humid gas from the dryer can be passed through a condensing tower sprayed with cold water and the cold gas then sent back to the gas heater. Little thermal economy is possible because of the low temperature differences and the very low rate of heat transference in the gas/gas system.

It must be emphasised that when thermal efficiency alone is considered the size and working conditions of a spray dryer must be determined for every material to be dried, for it is very infrequent that a spray dryer designed and operating at optimum conditions for one material can be made to work with another substance without some loss of efficiency.

We have attached to this paper three graphs which may be of value in the design of spray dryers.

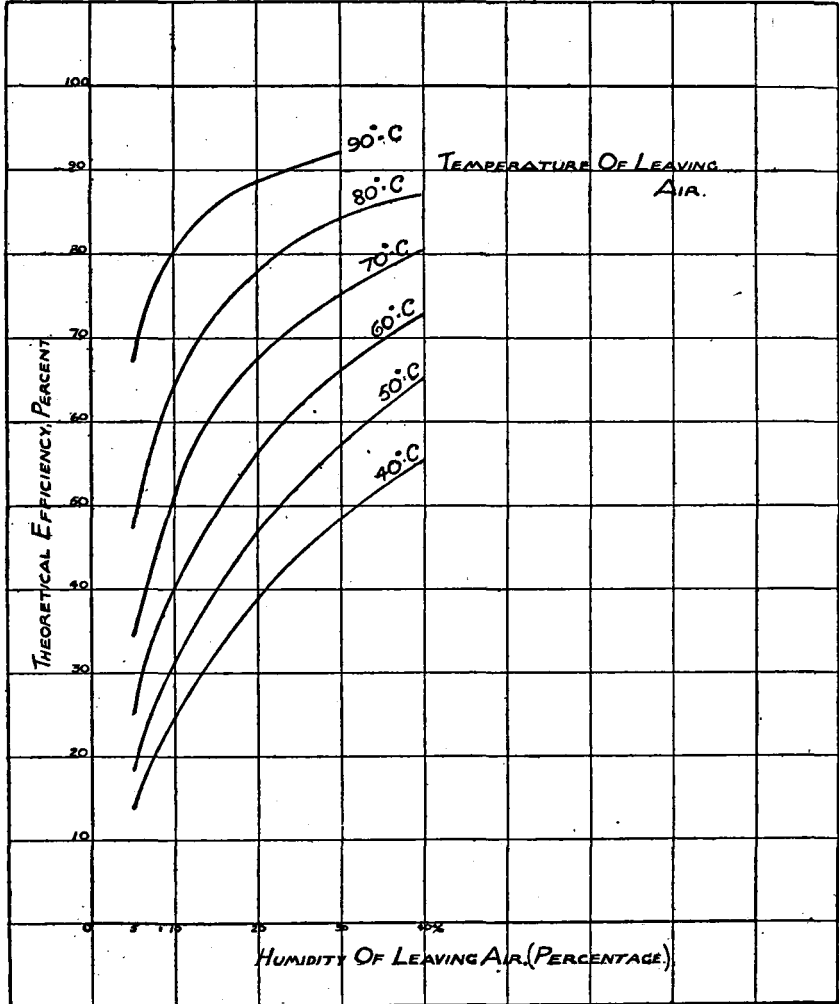


FIG. 59.—Variation of thermal efficiency for different temperatures and humidities in air leaving dryer.

Fig. 59 shows the variation of thermal efficiency for different temperatures and percentage humidities of the air leaving the dryer.

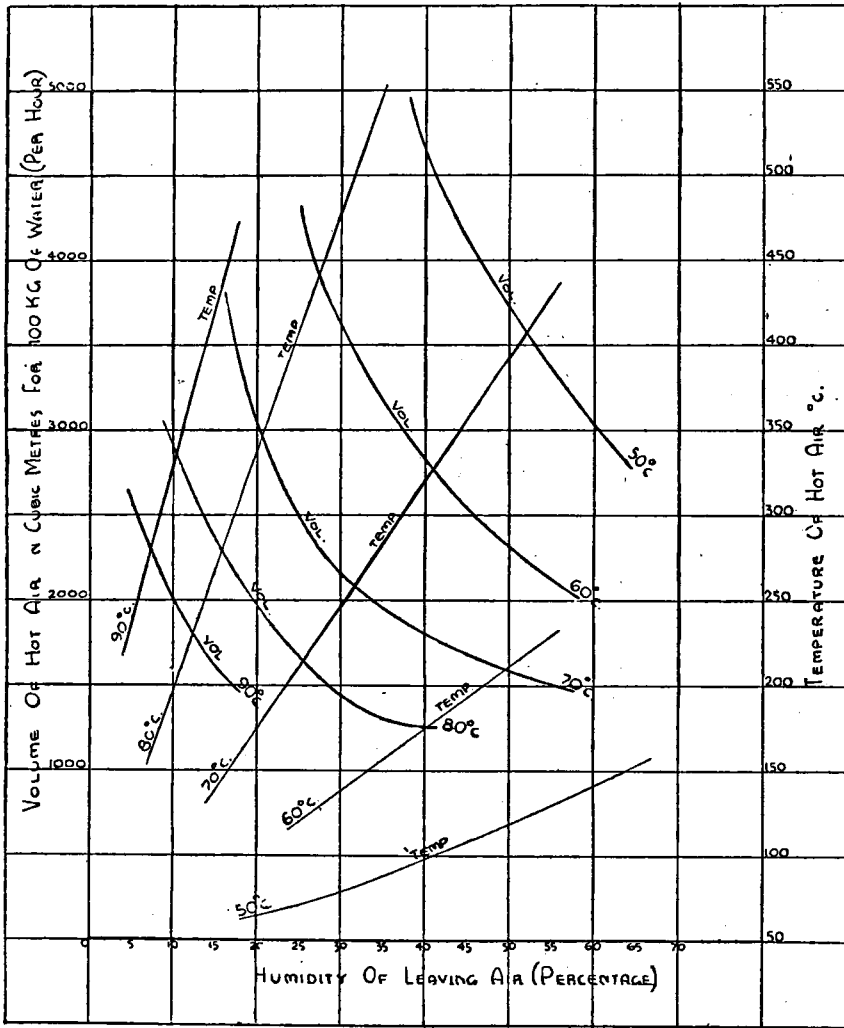


FIG. 60.—Hot air required for evaporation.

Fig. 60 consists of two graphs. In one the volume of hot air required to evaporate 100 kilogrammes of water per hour is plotted against the percentage humidity of the leaving air at various temperatures. In the other the temperature of the hot air for the same duty is plotted against the percentage humidity of the leaving air at various temperatures. The method of using these graphs should be obvious. For example, having chosen an arbitrary leaving temperature and humidity, the operator can estimate for a given duty the quantity of hot air and the incoming temperature required. Having obtained this information he can readily ascertain what fuel economy would result by changing the conditions of the air leaving the dryer.

It should be noted that the figures given in the graphs are theoretical and disregard thermal losses in the plant itself.

## 6. The Drying of Chemical Products by the Atmospheric Tray Dryer

By A. S. WHITE, B.SC., A.R.I.C., M.I.CHEM.E.

There are many chemical products which require special drying techniques either because of their chemical nature or because of their physical nature. Many chemical products are made in quantities large enough to warrant the use of dryers specially designed for them, and these dryers are often of the continuous type. For general utility in factories where materials are made by batch processes in relatively small quantities the atmospheric tray dryer still stands supreme despite the labour saving claims of the small agitated dryers of the pan or cylinder type. There are hundreds of atmospheric tray dryers in this country and there is probably no chemical works that has not at least one and many have no other type. These remarks are therefore confined to the atmospheric tray dryer and in particular to the steam-heated types.

Labour is the greatest single item in the cost of tray drying, a typical split of costs being :—

Labour . . . . .	57.0	per cent. of total cost
Steam . . . . .	38.0	” ” ”
Electricity . . . . .	2.5	” ” ”
Maintenance . . . . .	2.5	” ” ”

The cost of drying is often a small proportion of the total cost ; it certainly is so in the organic chemical industry. Steam saving at the drying stage therefore has only a small influence on the cost of drying and a negligible influence on the total cost of a product, and for these reasons there is little apparent incentive for improvement in steam efficiencies. However, “every little helps” and it is proposed to discuss briefly some factors in design and operation which affect steam usage.

It is difficult to establish a universal criterion of efficiency ; thermal efficiency varies widely according to the degree of dryness required in the product and also on drying temperature. Steam consumption can range from about 2 lb. steam per lb. water evaporated for material dried at 100° C. to 2-3 per cent. moisture content up to 6-8 lb. or even higher for material dried to 0.1 per cent. moisture.

Thermostatic control is, of course, very desirable and the air-operated types are to be preferred, especially for dryers in which the drying temperature is changed frequently, although the direct or relay-operated hydrostatic types give reasonable service. It is important that the steam valve is selected to suit the load and in some cases it is best to by-pass the thermostat control during the heating-up period.

Radiation losses account for a third or more of the total steam used ; a four rack dryer at 100° C. uses about 40 lb. steam/hr. to cover radiation losses. The majority of commercial dryers, however, have the economic amount of lagging and extra lagging rarely repays its cost.

It is rarely practicable to recover heat from the air leaving the dryer, but it is obviously desirable to reduce the amount of heat lost in this way to the lowest possible quantity and this can be done by intelligent use of the dampers. Often it is possible to work with one damper opening, the smallest, throughout

the drying, but with very wet paste it may be desirable to start with a wide damper opening and then close down after a set time.

In the standard type of dryer this procedure can be adopted without difficulty because the fans can take care of the internal air circulation whatever the proportion of air re-cycled. In some cases where exceptional cleanliness is required or where corrosive vapours are present, dryers of all-ceramic construction are being used in which internal recirculation is obtained by the use of a low-pressure air injector. These dryers do their job excellently, but their thermal efficiency is limited by the low entrainment ratios of the injectors which re-cycle only about 25 per cent. of the air ; a standard type of dryer re-cycles 75 per cent. or more.

Damper control from the humidity of the exit air is only worth while when the drying characteristics of the products require humidity control, and such control is rarely required in the drying of chemicals.

The principal defect of the atmospheric tray dryer is that drying is not uniform throughout the dryer ; some trays dry long before others, e.g. in a pigment drying at 100° C. some trays were dry enough after 36 hours but the bulk required 48 hours. The usual cause of this effect is non-uniform distribution of air ; the use of adjustable louvres to equalise air distribution has some effect but by no means overcomes the difficulty. Increase in air velocity at the expense of increase in power consumption also has some effect but air velocity is frequently limited by the dusting characteristics of the product and for general purposes no alteration in air velocity is permissible.

In low-temperature drying, non-uniformity of drying and sometimes spoilage of product can be attributed to direct radiation from the heating elements. External air heaters are the best solution, although hot-water heating can be used as an expedient.

Improvement in uniformity of drying really requires drastic re-design and can hardly be achieved without increasing dryer cost.

Heat is lost in heating up the dryer and its charge and is not recoverable at the end of the drying operation, and it is obviously best to use the largest practicable charge. Trays should be loaded uniformly, and, although one would expect an optimum charge, it is often found in practice that drying time, especially at high temperatures (100° C.), is roughly proportional to tray loading.

Dryers can often be heated with exhaust steam at 10–20 lb./sq. in. gauge, or even with hot condensate, where low temperatures are required.

The biggest savings in steam and in overall drying cost can be obtained by reducing the amount of water charged to the dryer, i.e. by increasing the solid content of the charge. Not only is there a steam saving but an increase in dryer output, too, e.g. the total cost of drying varies inversely as about the 1.25 power of the solids content of the paste for the drying of dyestuffs and pigments at 100° C.

A study of precipitation and filtration conditions to reduce the moisture content of the paste is therefore the most fruitful line for the chemical manufacturer to follow and offers more than mere improvement in dryer efficiency.

In conclusion, a word should be said about the “through-circulation” dryer, i.e. a dryer in which hot air is passed through the mass instead of over it. This type of dryer gives much shorter drying times than the conventional tray type because evaporation of water or solvent is not controlled by diffusion or capillarity to anything like the extent that it is with the latter type. Thus the

heat losses by radiation, etc., are a much smaller proportion of the total heat used—in ordinary tray dryers the amount of water evaporated towards the end of the drying operation is very small compared with the steam used. The through circulation technique, familiar in the Quinan and some commercial forms of band dryer is, however, applicable only to crystalline materials or to materials which can be granulated or otherwise made into small lumps. A batch dryer of this type should be particularly useful and give good thermal efficiencies for the low-temperature drying of small production materials.

## 7. The Drying of China Clay

By C. R. LOVE, M.I.MECH.E.

In years just prior to 1939, production of china clay reached 850,000 tons per annum and is expected to exceed this figure in the near future. The coal consumption for this output exceeds 100,000 tons per annum and represents an important item in the cost of production.

In the early stages the process is entirely wet, and de-watering proceeds by gravity or by pressure filtration to the point where heat is applied to get the required degree of dryness.

About 85 per cent. of the total output is then dried to 10 per cent. moisture and 15 per cent. to 1 per cent. moisture for disintegration and bagging as a powder, and it should be borne in mind that the cost of drying must be reckoned in shillings per ton of product.

The fine particle size, which in certain grades is 55 per cent. below one micron, and the need to avoid calcination by high temperature imposes certain limitations on the methods adopted. The combined moisture begins to be dispersed at temperatures around 400° F. and this must be prevented.

The older, and still the principal method of drying is to settle the clay from a thin slurry to a semi-plastic state containing 45–50 per cent. of water in large rectangular tanks arranged alongside a drying floor. The floor is generally 250–300 ft. long by 15–18 ft. wide and on the opposite side of it at a lower level is the dry store.

The drying floor is composed of porous firebrick tiles laid on flues which are heated by hand-fired coking-type furnaces. The length of flue is sufficient to reduce the gases to 250° F. when correct conditions are observed.

The semi-plastic clay is laid on the hot floor and makes a bed in contact with the tiles. Evaporation proceeds partly by evaporation above the bed and partly in the flue by seepage of moisture through the tile.

Using a high-volatile large coal it is possible to get an overall efficiency of 50 per cent. when drying the clay from initial moisture of 45–50 per cent. to 10 per cent., but inferior fuels have led to less satisfactory results.

Hand labour with scoop, shovel and wagon is used entirely in these kilns.

A later development now being rapidly extended is the use of the filter-press to replace the settling tank. This cuts out the settling period of several weeks and consequent chance of contamination and reduces the moisture content to 28–33 per cent. according to the particle size and other qualities of the clay. The filter-press cakes do not make complete contact with the hot floor and the heat efficiency is reduced to 38 per cent., but in spite of this there is a reduction in the fuel consumption by 40 per cent.

Important as fuel economy is, the producer of china clay cannot disregard other factors in the total cost.

Economy in fuel has been effected by filtration but only by the introduction of other factors and by the use of scarce commodities such as labour, cotton cloth and iron castings, and by use of power for pumping the clay slurry to the filters at 100 lb. per sq. in. The result shows no overall economy over the old methods.

The ever-increasing demand for powdered clay calls for drying to 1 per cent. moisture and for this purpose the hot floor is quite unsatisfactory owing to the need to reduce the temperature to avoid calcination, and by reason of the consequent loss in output. The extra fuel required is out of proportion to the small reduction in moisture.

We are then faced with two main problems :—

(1) To reduce labour costs by introduction of mechanical handling of the wet filter-press cake to continuous dryers and thence to store.

(2) To find a high-efficiency dryer mainly for the total drying of clay for disintegration, but also capable of use for bulk clay dried to 10 per cent. moisture.

Considerable exploration has been undertaken in both these directions during the last few years.

(1) For the first objective an indirectly-fired rotary kiln was required and it appeared that no such machine was readily obtainable in this country and an American design was available. Difficulties in cutting the clay to suitable sizes and feeding continuously were overcome. Under normal conditions, using a hand-fired coke furnace the efficiency is not better than the hot floor, i.e. about 38 per cent. from which has to be deducted the considerable power required for driving the kiln and its auxiliaries.

A large machine with chain-grate stoker using small coal is now nearing completion, and it is hoped that the superior control of combustion and temperature will lead to good results.

(2) For the second problem low temperature is essential and here again a suitable machine was difficult to obtain.

Tests were carried out on a steam-heated rotating shelf machine constructed of a number of shelves with segmental trays. Within the shelf system are placed blowers and the heating elements are arranged around the outer periphery of the dryer. This arrangement permits multiple circulation and reheating of the air. Drying is assisted by repeated turning of the material as it progresses from shelf to shelf on its passage through the machine. The quantity of hot vapour escaping to atmosphere is controlled according to humidity. Efficiencies of 70 per cent. based on steam consumption to moisture evaporated were obtained when drying to 10 per cent. moisture and of 50 per cent. when drying to 1 per cent. moisture. The power consumption of this dryer is low.

These results were obtained using steam at 60 lb. gauge pressure but there is reason to believe that much lower pressures can be used at the cost of reduced output from a dryer of a given size.

At all stages of production electric power is used and it is found that a very close balance exists between the power requirements and that which can be



produced by a correct choice of initial pressure to the turbines and heating-steam pressure when using back-pressure or pass-out turbines.

The obvious course to adopt therefore is to instal electric power plant and dryers adjacent to each other and choose steam conditions most suited to the combination. A large plant on these lines is now in course of construction making use of drying units of  $7\frac{1}{2}$  tons per hour each. Calculation shows that 35–40 per cent. of the total fuel bill can be saved by the adoption of this method.

Considerable practical difficulties must be overcome to concentrate the drying and storage capacity into sufficiently large units to make this scheme applicable to the whole industry, but there is no doubt that along these lines lies the possibility of achieving economies in fuel.

## 8. Leather Drying

by CHARLES STEPHENS, F.INST.F.

Most of us at some time or other have arrived home with our footwear saturated with rainwater. Having removed our shoes we have then placed them in front of a fire for the purpose of leather drying—quite often with disastrous results to the leather by reason of the excessive heat. Had the shoes been placed in a cooler atmosphere the length of time required for drying would have been increased but the damage to the leather would not have occurred.

Leather is a natural product, the quality of which is best assured when the drying can take place under natural conditions similar to those in which existed the animal from which the hide was taken. The leather industry has always endeavoured to make as much use as possible of natural conditions for drying purposes. For this reason, it has been the custom to use drying sheds with louvred sides which provide for a through current of air passing between the hides and skins, thus taking full advantage of suitable weather conditions and often, during the summer months, eliminating entirely the use of fuel for drying. During the winter months, of course, it is generally necessary to close the louvres and maintain the temperature of the room by artificial means. The fact remains that in this country any process dependent on weather conditions must suffer great disadvantage and, at best, results will always be doubtful.

To overcome these disadvantages a new method of reproducing natural conditions under control has been recently introduced whereby existing buildings are insulated and have adjustable inlets at or near floor level for admitting air from the exterior. Heating pipes, thermostatically controlled, are fitted in the vicinity of the air inlets to increase the temperature of the incoming air if necessary, and scientifically designed ventilators are fitted into the roof for the purpose of producing an aspirating effect inside the drying room irrespective of the direction of the outside wind. In this way the conditions under which the leather drying is carried out can be controlled or adjusted to remove the surplus moisture or to increase or decrease the number of air changes necessary

to meet the most suitable requirements for the particular kind of leather to be dried.

With this type of arrangement the maximum fuel economy is effected, as full advantage is taken of the temperature of the outside air which, on entering, is heated up to the requisite level only when required, and merely the excess humidity permitted to escape from the room. No motive power is required for humidity extraction purposes, the leather drying is continuous and spoilage impossible.

The use of excessive temperatures in leather manufacture both for leather drying and tan liquors can result in the finished product being cracky, burnt or tinny, thereby reducing the market value of the leather by 25 per cent. or even ruining it altogether. As a safeguard against such damage, excessive heat must be avoided.

Certain leathers are capable of withstanding more heat than others. For example, chrome tanned leathers are not affected by heat to the same extent as vegetable tanned leathers. Therefore, whilst low temperatures are in the best interests of leather manufacture in general, higher temperatures are sometimes used for appropriate leathers, particularly in the interests of increased production in an attempt to reduce the effect of what is usually the bottleneck of the organisation, namely the drying department.

This bottleneck has been successfully removed by installing cabinet leather drying plants. These need careful manipulation to avoid spoilage. To blow hot dry air on to wet leather can case-harden the surface without the drying effect reaching the interior of the leather. The aim is to reproduce, as nearly as possible, the ideal natural conditions for leather drying all the year round and to maintain these conditions in a properly insulated chamber in which the temperature is controlled whilst maintaining the requisite humidity. In this way the temperature can be increased once the correct relative humidity is assured. This method speeds up the drying time ; it results in a larger production in a much smaller space, and makes it possible for the leather to retain the necessary degree of moisture.

Conditioning of leather is also a necessity as certain processes can be carried out only when the leather is in the right condition, for which it must be neither too wet nor too dry, and in order to provide for this requirement, humidifiers are in use. Leather will take up or throw off moisture according to the conditions under which it is stored, and as sole leather is sold by weight it is advisable that the temperature and humidity conditions inside the warehouse in which it is stored shall be kept as near normal as possible.

No firm in the leather industry can afford to be anything but fuel conscious, particularly in regard to the processes of leather drying and tanning. From long experience in the industry I have reached the conclusion that by the use of low temperatures the quality of the finished leather is definitely improved.

Great strides have been made in recent years in reducing fuel consumption, and to this end tanneries have been furnished with analysis charts showing their fuel consumption in relation to output. With full advantage taken of controlled natural leather drying, of new departures in plant which are pending, and the increased use of temperature and humidity controls for more processes, the leather trade can look forward to an even further downward trend in fuel consumption in relation to output for many years to come.

## 9. Drying, Conditioning and Storing

By A. C. HUTT

### EFFICIENCY OF DRYING PLANTS

The efficiency of a drying plant is most simply expressed—

*Firstly*, in terms of whether it will effectively dry a material with a minimum damaging effect to the structure of the material, or to its physical properties.

*Secondly*, by thermal efficiency, or lb. of moisture evaporated from the material per lb. of fuel used.

Dryers vary very greatly in thermal efficiency, some will evaporate 8 lb. of moisture and others as low as 3 lb. of moisture per lb. of fuel. This variation is not governed entirely by the design of the dryer but is partly dependent on the material being dried, for instance, a particular dryer may evaporate 7 lb. of moisture per lb. of fuel when drying one material, and only 5 lb. when drying another, which gives up its moisture less readily. It is proposed to deal with some factors which affect the thermal efficiency of drying plants.

### DIRECT AND INDIRECT HEATING

Direct drying implies that the hot products of combustion from a furnace are diluted with air to the required drying temperature and passed through the dryer. Indirect drying implies the use of a heat interchanger, such as an air heater, and heated air only is passed through the material to be dried. The efficiency of hot gas production by the direct system is about 85 per cent. to 90 per cent. and by the indirect system 55 per cent. to 67 per cent.

It is too commonly assumed that the flue gases used in direct drying are dirty and are likely to spoil the material being dried, but this is not necessarily so. If a suitable low-volatile fuel is used, the products of combustion contain  $\text{CO}_2$ , traces of sulphur and sterilised dust.

Drying with hot air containing some  $\text{CO}_2$  may be beneficial, for instance, for drying vegetable material. Traces of sulphur may also be beneficial for this is desirable in hot gases for drying hops because it helps to maintain the fresh colour. Direct drying without a heat interchanger is so much more economical than indirect drying that it should not be dismissed without considering whether the constituents of the hot furnace gases are in fact damaging to the material being dried.

### INSULATION AND LAGGING

Much more attention should be paid to efficient lagging of drying plants. The majority of rotary dryers which have rotating drums 45 or 50 ft. long and 4 ft. 6 in. to 5 ft. diameter are usually devoid of any lagging. The heat losses from such a dryer may represent a loss of heat equivalent to half a ton of fuel in 24 hours. This heat loss can be avoided either by lagging the drums or by enclosing the drum in a tunnel or chamber built of low-conductivity brickwork.

Most buyers of new plant consider the best type of plant for the material to be dried, and the cost of the plant. Fuel economy is not often considered when deciding on the type of plant to instal. This is due in many cases to the fuel cost being a small part of the total cost when drying high cost materials.

It is suggested that in order to promote fuel efficiency, all manufacturers, when quoting a price for plant, should state that the price includes a sum

of £X for adequate lagging which amount would be recovered in a given time by the quantity of fuel saved.

#### CONTROL INSTRUMENTS

Drying plants should be fitted with reliable thermometers or preferably thermographs, to record the inlet and outlet temperatures. A humidity recorder should also be fitted to record the relative humidity of the outlet gases ; for efficient operation the relative humidity of the outlet gases should not be less than 80 per cent.

#### THERMOSTATIC CONTROL

It is most desirable to maintain the correct and constant temperatures by means of thermostatic controls and such controls should be regularly serviced by the makers, or by a firm specialising in this work.

It is considered that there is considerable scope for more efficient operation of drying plants on the lines indicated.

## 10. Use of Oil Fuel for Drying

By K. H. SAMBROOK

It is intended to import into this country a greatly increased quantity of liquid fuel and a few remarks on the use of liquid fuel for drying may, therefore, not be out of place.

In considering the field in which these increased imports of petroleum fuels can best be used, it is the opinion of the petroleum industry that, in general, this will lie in the field of high-temperature processes where the high temperature and emissivity of the oil flame results in a higher proportion of heat becoming available for useful work at high temperatures. Nevertheless, there are many applications in the medium and low-temperature fields where oil fuel has special advantages, and, of these, drying is an important example. This is proved by the fact that in this country where, particularly in the past with the imposition of a tax on imported liquid fuel, the cost of oil as compared with solid fuels based on the calorific value has been unfavourable to the use of oil, there are already many well-established applications of oil fuel for drying. These are notably in the food-stuffs and agricultural industries.

In drying processes the general advantages of oil fuel can be made good use of, namely the ability to regulate exactly, and if desired under semi-automatic or fully automatic control, the input of heat and the temperature of the drying medium. A still more important factor, however, as applied to convection dryers used for the drying of delicate and sensitive materials, such as food-stuffs, is that with oil fuel burnt in a properly designed furnace, the fuel can be burned so completely that the products of combustion are innocuous and, after mixing with the necessary quantity of air to produce the temperature required, may be passed directly through the material to be dried without any deleterious effect on the product. This means that, as compared with the use of a heat exchanger necessary when using solid fuels, a considerable proportion of the heat in the fuel otherwise carried away by the exhaust products from the chimney, is saved and utilised completely within the temperature limits of the process. This factor may easily result in a saving of 25 per cent. in fuel consumption.

In order to produce the necessary complete combustion certain points in design must be taken care of and some safeguards incorporated. Briefly, the important points of such a design are that the oil is burned in a refractory combustion chamber where the high temperature necessary for quick and complete combustion can be maintained, and that the oil is completely burned in this combustion chamber without employing more than a normal amount of excess air before the diluting air is admitted and mixed with the products of combustion. In this way, the chilling of the flame before combustion is complete, which would occur if large quantities of diluting air were admitted at an earlier stage, is avoided.

The safeguards provided are generally a diaphragm valve, or similar device, to cut off the fuel instantly should there be any failure or abnormal drop in the pressure of the supply of atomising air to the burner. Secondly, a thermostatic or preferably a light-sensitive device to shut off the oil immediately should the flame become extinguished accidentally for any reason.

Granted complete combustion, the products will consist entirely of nitrogen, water vapour, excess air, carbon dioxide and traces of sulphur dioxide. The sulphur dioxide is generally by no means harmful to food-stuff. In fact, in the drying of hops, comparatively large quantities of sulphur are deliberately burned below the hops at an early stage in the drying, as the sulphur dioxide has a beneficial and preservative action on the product. Providing also that the gases do not come into contact with metal surfaces at temperatures below the dewpoint of the mixture, which with high dilutions will be very little above the dewpoint of pure air under the same conditions, no troubles are likely to arise from corrosion.

The use of these direct-fired dryers employing oil fuel for the drying of hops, grain, malt and grass are already well established in this country. It may not be generally known that oil-fired direct mixing dryers have been used for a number of years in the production of teas of the highest grade in Ceylon and elsewhere. The fact that this principle can be applied to the drying of such a delicate material as tea should reassure anyone who may still entertain doubts as to the risk of contamination of the material with the products of combustion from oil fuel. The products of combustion from oil fuel contain practically no arsenic. This was, for instance, a major factor in hop drying where the choice was either between a heat exchanger with its higher capital cost and lower efficiency, or direct firing with an arsenic-free fuel, which meant the choice either of oil or of the special grades of anthracite low in arsenic.

The further advantage which oil offers, particularly in agricultural dryers, is that it permits the application of regulated and controlled heat to portable machines where connection to gas or electricity supplies would be inconvenient or impossible.

#### *Discussion*

**Mr. Lehmann** stated that oil had been used for some years on direct-fired dryers, but he would like to know whether Mr. Sambrook's remarks applied to fuel oil only, or whether creosote/pitch was included.

**Mr. Sambrook**, in reply, said that the oil used on the plants referred to was Diesel oil. For drying delicate products a distillate oil was preferred with which it was easier to secure perfectly clean combustion.

**Mr. Love** thought it regrettable that the combustion of oil fuel should have to be discussed, as coal should be available.

**Mr. Watson** referred in particular to the first three papers and the modesty of Mr. Lawson's claims. He thought that too much emphasis was given to the time of drying. Other factors had to be considered, and more attention paid to fuel economy. The gas companies were concerned in advising consumers to the consumer's advantage. He did not agree with Mr. Hutt's suggestion that manufacturers should state the amount allowed for the lagging of dryers, as the amount spent on lagging should not be a deciding factor in selecting a dryer. The design of the dryer affected the quantity of lagging necessary. He would like to ask Mr. Hayman the difference in principle of drying between a treble-case oven and a radiant dryer.

**Mr. Hayman**, replying to Mr. Watson, said that there was no difference in principle, as both treble-case ovens and black emitter panels were radiant dryers.

**Mr. Salter** disagreed with the efficiency of indirect heaters given by previous speakers. Losses could be prevented by re-circulation up to the limit of humidity content, and thus show a final saving on direct heating.

**Mr. Melonby** asked for advice on the problem of drying clay drain pipes.

**Mr. Vigers** stated that his firm were drying large clay pots in a tunnel kiln, the pots being placed on bogeys. The temperature was maintained at 100° F. by means of steam-heated coils, and there was no air circulation apart from that caused by leakages through the doors fitted at each end of the tunnel. Referring to Mr. Love's paper, he noted that substantial savings in fuel were to be obtained in drying china clay by the use of back-pressure steam from turbines. He felt that there was a good case for the use of low-grade heat for drying, such as indirect drying by steam, after first using the steam for power generation.

**Mr. Clegg** said that before clay products could be dried, the centre of the material must be heated before drying commences, otherwise the articles would crack. Correct humidity was essential, and temperature and humidity should be brought up slowly. It would appear that "conditioning" would be a more appropriate term in many cases than "drying".

No instruments were available to give complete control of "conditioning".

**Mr. Waldram** pointed out that for the drying of biscuit oven ware, radiant heating had been found the more efficient. The drying of hollow-ware by hot air was found to be difficult, as the current of air passed over hollow goods such as cups, but radiant heating dried these articles effectively. Hot air had been found satisfactory if the moulds were inclined at 45°. He asked if anyone could state the advantages of hot air as compared with radiant heat for drying pottery ware.

**Mr. Sayers**, in reply to Mr. Clegg, mentioned that there were suitable instruments available for temperature and humidity control. The hygroscopic type, in his opinion, was not very suitable for use on drying plants, but the expansion type of instrument such as the mercury-in-steel thermometer, or the electrical resistance thermometer, when used as wet and dry bulb instruments, were suitable for temperatures up to 200° F. For higher temperatures, the electrolytic type of hygrometer as developed by Dr. Gregory was suitable for use up to 300° C. and down to 70° C. but these were expensive.

Suitable instruments for temperature and humidity control were available from any reputable instrument manufacturer.

**Mr. Brian Reavell** asked Mr. Lowson the average life of infra-red lamps, and the general maintenance cost. What was the effect of dulling of the reflectors, and the advantages of the new type of lamp with built-in reflector? Had bar emitters been considered?

He noted that Mr. Six had mentioned the speed of the drum of a film dryer. Ought not the diameter of the drum to be related to the drum speed? Figures of 18.5 per cent. and 70 per cent. efficiency were quoted for spray dryer installations. What were the reasons for the difference in efficiency and how was the improvement brought about?

**Mr. Lowson** stated that the average life of the lamps was 5,000 hours. It was rarely necessary to remove lamps for cleaning purposes, as any surplus dust could be blown off.

In regard to dulling of reflectors, gold did not dull to any appreciable extent, and the vent in the tunnel took the fumes away. The built-in reflector lamp was more expensive, and could be regarded as a useful adjunctive.

Bar emitters, due to the bare source, lost up to 50 per cent. by convection. In some particular cases, bar emitters might be better or necessary, but comparison of the two systems was not available.

**Mr. Arkell** referred to the direct drying of grain, and asked Mr. Hutt for an illustration of the drying of grain by the direct method as compared with electricity.

**The Chairman** replied that this subject would be under discussion in Session C.III.

**Mr. Six**, replying to Mr. Reavell, said that as drum speed was given in terms of revolutions per minute, the diameter of the drum did not matter.

**Mr. Bernard C. Oldham** wrote: In his remarks on the selection of control points for the various stages of drying with interstage reheating, Mr. Lehmann has rightly referred to the need for reliable and comprehensive information on the properties of humid air. He also points out the unnecessary multitude of psychrometric charts extant, each giving scraps of this information with varied results. These seldom give data as to relative humidities below 10 per cent. Very few show how the volume of air varies with temperature, this having a great influence on the output of fans, and thereby on the agreement between design and performance. Attention is drawn to a psychrometric chart which I have produced covering dry bulb temperatures from 0 to 300° F., with relative humidity data down to 1 per cent., and all mixtures of water vapour with air from zero to infinity. This, so far as I know is the only chart in existence giving information on such a wide range of moisture content in a single curve.

**Mr. John Philip** wrote: When considering the efficiency of a drying process it is always necessary to consider the complete process, the condition of the material to be dried and the condition of the finished product.

**Mr. Lowson** and **Mr. Hayman** have dealt with the drying of protective coatings by means of infra-red radiants. It was mentioned that it was an advantage to use coatings based on alkyd varnish rather than on natural resins. It should be noted that twice the heat units are required to produce alkyd varnish as are needed to produce the same quantity of copal varnish. This is entirely apart from the shortage of phthalic anhydride. On the other hand, in the manufacture of phthalic anhydride with a Downs reactor, an exothermic reaction takes place liberating 6,000 to 10,000 B.Th.U./lb. of naphthalene.

In colour manufacture one starts with a precipitate or sludge and requires a dry powder with 99·8 per cent. through 325 Tyler mesh. The normal method being to form filter cake in a filter press, transfer the filter cake to tray trollies, place the trollies in a drying oven, dry in the ovens and transfer the dried filter cake to pulverisers, then grind to the required particle size.

It would appear that the overall efficiency of the process would be improved by passing the sludge to a spray dryer as the powder received from the spray dryer would be not far from the particle size required. This is assuming that the thermal efficiency of the spray dryer is less than the thermal efficiency of the drying oven.

It is generally accepted that it is more economical to reduce moisture content by mechanical means before finally drying, and it would be appreciated if any of the authors of these excellent papers could advise on the best way to accelerate precipitation and to thicken without the use of flocculating agents other than the known methods practiced in the mining industry.

For drying coal slurries, the method of centrifuging used for a long time on the Continent is now coming into use in this country.

**Mr. M. V. Griffith** wrote : The British Electrical and Allied Industries Research Association has found by experiment that the proportion of radiant heat reflected from the walls, floor and ceiling of a fair-sized living room makes a large contribution to the amount of heat quickly available for warmth in the room, if the reflecting power of these surfaces is greater than 0·5. To attain these values of reflecting power it is necessary to use metallic surfaces, but in a factory the aesthetic objections, reasonable perhaps in a householder, would not apply. The aluminium foil with paper backing manufactured for Radar purposes is particularly suitable except for some types where an inferior adhesive has been used to attach the foil to the paper.

The use of this material results in the attainment of comfortable warmth in about one-third of the time required for untreated walls and therefore compares favourably with insulating boards for intermittent heating, and for heating times up to about five hours. In the absence of such boards, this method might well be adopted for fuel saving in factories. It seems particularly suitable for the treatment of comfort zones.

The effect of reflectivity is not directly proportional to the reflecting power,  $R$ , of the surface used, because of the effect of multiple reflections, but is roughly proportional to  $R/(1-R)$  ; this is the reason for the limiting value of 0·5.

**Mr. Musgrave** states that both light-coloured distemper and glass are good reflectors of radiant heat. This is not correct. Glass has a reflecting power of not more than 10 per cent. and distemper of 20 per cent. for the radiation emitted by a source at 1,000° C. The proportion is higher for visible light in the case of distemper, but not in the case of glass.



## SECTION C. HEAT FOR DRYING—*continued*

### SESSION II. Factory Heating and Air Conditioning

*Chairman of Session:* MR. E. A. COUZENS

PRESIDENT, THE INSTITUTION OF HEATING AND VENTILATING ENGINEERS

**T**HE CHAIRMAN: First, I would like to invite the Ministry to examine the economics of balanced electric power and heat load plants for factory space-heating, and if approved, to do what is necessary to encourage industry to adopt such schemes. This system, if applied to single factories and groups of factories, taking a long-term view, would make a very valuable contribution to the efficient use of our fuel resources, as by such means the value of work done by every ton consumed for space heating, is increased by approximately 70 per cent., in addition to which several million tons of coal could be conserved annually.

The next point might be considered as short-term policy. In the nineteenth century most windows of all classes of buildings were fitted with either inside or outside shutters, in those days with the idea that they kept out the cold, but actually they were conserving the heat within the buildings. If it was possible to revert to this practice, or adopt some substitution such as was used to meet the blackout regulations during the recent war, I suggest it would mean saving several million tons of coal per annum. I am not able to present complete data supporting my suggestion that several million tons would be saved, but if the Ministry of Works care to obtain a census of the area of glass in all the centrally-heated buildings in the country, it would be quite easy to calculate the amount of coal which would be saved by such a method, because the heat dissipated in one hour through approximately 1,000,000 sq. ft. of glass windows when the space temperature is at 60° F. with an average outside temperature of 42° F. is equal to the heat obtained from a ton of coal having a calorific value of 12,000 B.Th.U./lb. when consumed in a boiler plant having a thermal efficiency of 65 per cent. If these windows were shuttered, it would reduce the amount of heat dissipated by 68 per cent., which means that 68 tons out of every 100 tons of coal now lost would be saved.

As an example, one factory in which I am interested the glass area in windows and roof lights equals 95,800 square feet. If this glass was shuttered during the dark hours, I calculate the saving over a heating season of seven months would equal 205 tons of coal.

A Canadian educational delegation to this country recently visiting a secondary school in Birmingham commented on the amount of window area provided in our schools compared with what was permissible in Canada, where by necessity they were restricting their window area to ensure warmer schools. I suggest that when a country in which double glazing is standard practice finds it necessary to restrict window area to enable comfort conditions to be maintained, the obvious thing for us to do when it is required to conserve our coal resources is to screen our windows during the periods when they are not required to provide light.

## 1. Factory Heating and Fuel Savings

By OSCAR FABER, O.B.E., D.C.L. (HON.), D.SC., M.I.C.E., M.I.MECH.E.,  
A.M.I.E.E., PAST-PRES. I.H.V.E., PAST-PRES. INST.STRUCT.E.

Before fuel savings can be even considered it is necessary to give a brief résumé of the many different ways in which factories are heated, since some fuel savings lend themselves to some methods to which others would be quite inapplicable.

### COMMON METHODS OF HEATING FACTORIES

#### (A) UNIT HEATERS

Large open spaces where a small amount of noise is not objectionable are often heated by unit heaters owing to their relatively low cost of installation.

The unit heater consists, of course, of a heating coil with a fan which blows the air from the factory through this and directs it either vertically downwards or horizontally, or at any intermediate angles, which can immediately be adjusted by a set of louvres or blades.

The direct downward type is usually restricted to factories where there is a vertical height between the unit heater and the floor of 20 to 30 ft., while the horizontal type can be used for lesser heights.

Unit heaters can be heated by steam, hot water, high-pressure hot water, gas, or electricity.

The great merit of steam is that the coils and the pipes leading to the coils are relatively small and low in first cost, but on the other hand, a condense main has to be provided, and corrosion in this is sometimes a serious difficulty.

Furthermore, steam unit heaters cannot have their temperature regulated according to the outside temperature, but this is overcome by thermostatic control of the on-and-off type, and it is doubtful whether a unit heater can be run without heat on the heating system anyhow, because it tends to set up draughts which are objected to when cold.

High-pressure hot water applied to unit heaters has all the advantages of steam and avoids the trouble with condense mains, though of course a return pipe is necessary, but is not subject to corrosion when the plant is correctly designed.

High-pressure hot water systems frequently work at temperatures of about 300° to 320° F. or any lower temperature above 212° F.

In places where gas is cheap, gas unit heaters sometimes offer a very convenient and economical solution of the heating problem.

They are of two types :—

- (a) Where the products of combustion are delivered into the factory ;
- (b) Where they are taken out by flues.

In large factories of the shed type and where gas is purified to the usual low sulphur content which is now the rule for town gas, there appears to be little objection to allowing the products of combustion to enter the ventilated space, and this of course increases the efficiency of the combustion to nearly 100 per cent.

In many towns, such as Sheffield and Stoke-on-Trent, to mention only two out of many others, gas prices are so low as to make this system quite attractive.

There is a great deal of skill required in the design of a good unit-heater system to get the best results. It is not simply a question of calculating the

heat losses and putting in at random a sufficient number of unit heaters with a total rating to make up the losses in heat previously calculated.

Except where skill and experience have been used to the full, one finds cases where the warm air delivered by the unit heater never reaches the working plane in which the people are situated, so that heat just disappears into the roof space and in such cases there may be a marked heat gradient with the air lying under the roof at a temperature of 20° or so higher than that on the working plane near the floor. There is then loss from the roof far in excess of what would be calculated on the assumption that the temperature in the building is uniform, and in this way great waste can result.

The author has seen and had personal experience of many systems where it could easily be proved that the heat was entering the building in requisite quantity, but unfortunately was not giving the results in the working plane which the operatives had a right to expect.

#### (B) RADIATORS

Many factories are heated by radiators standing on the ground, usually under windows. These radiators can, of course, be fed with steam or hot water.

Steam has the advantage of small surfaces and pipe sizes and the disadvantages of requiring condense mains liable to corrode, and steam radiators are difficult to adjust in temperature to suit external conditions, with the consequence that they generally remain turned on long after they ought to be turned off, and involve waste in fuel. This is partly overcome by the vacuum system, which is, however, not very frequently employed.

The hot water system has the great advantage that it can easily be adjusted to meet external conditions on simple thermostatic control or otherwise, but it requires larger radiator surfaces and larger pipe sizes than with steam. It is also silent in operation, which steam is not, though this probably does not matter much in most factories.

The high-pressure hot water system applied to radiators combines most of the advantages of steam and low-pressure hot water, but ordinary radiators will not stand the pressure and the temperatures are much too high to permit of their being touched by people, so that radiators of the convector type have to be used. In these, of course, the radiator is enclosed in a cabinet and a circulation of hot air is induced past the fins of the coil in the convector and comes out at the top of the cabinet.

These systems are too well known to need further description.

#### (C) PIPES

One of the earliest types of heating, which was a direct development of the heating of greenhouses, is by means of pipes, and it is still in many cases the cheapest and simplest.

Pipes were originally usually of cast iron, which were liable to give trouble, and steel pipes with screwed or welded joints are now usually employed.

Pipes were frequently situated on the ties of roof trusses and round the outside walls and on the sloping roof under the roof lights so as to counter down draughts.

Though heating by pipes probably gives the largest number of square feet of radiating surface at the lowest price, it is sometimes a somewhat wasteful method of heating by reason of the very large temperature gradients which are apt to exist between the working plane, usually some 3 or 4 ft. above the floor,

and the layer of hot air which lies under the roof, which is consequently subject to excessive radiation losses.

With this system it is very essential that the roof should be well constructed to prevent infiltration through leaky joints, and well insulated to prevent excessive loss of heat.

Savings of 20 or 30 per cent. can easily be involved under these headings.

To increase the heating surface of pipes they are frequently provided with gills, though these are very liable to catch dirt and are difficult to clean.

The system of pipes on the roof trusses is considered by some to be objectionable on the grounds of appearance and obstructing lights and collecting dirt.

#### (D) PLENUM OR HOT AIR HEATING

Under this system the factory may be almost free of obstruction by heating appliances, which is greatly appreciated in some cases. Air from the outside is passed over heater batteries, which can be heated by either steam, hot water or high-pressure hot water, and then blown through ducts until it enters the various compartments of the factory. In some cases it will merely enter by a grille in a sidewall, but in large factories it will be necessary to run large trunks along the length of the factory with distribution ducts or outlets at fairly frequent intervals.

The latter have to be carefully regulated in regard to direction, velocity and area, to ensure that the warm air reaches the working plane without producing excessive draughts, and if the velocity or volume are insufficient to reach the ground the system would be subject to the same losses due to excessive temperature gradient as has already been described in connection with unit-heater systems of faulty design.

From the factory, the air is frequently extracted mechanically by extract fans in the walls or gable ends, or even by a separate system of extract ducts so as to give complete control.

In factories where noxious gases or smells are produced in the processes, the extracted air generally has to be discharged to the atmosphere. In these circumstances this system tends to be extravagant in fuel. This applies, of course, particularly in cases where spray painting or the doping of aeroplane wings and processes of this kind are in question.

On the other hand, if one is dealing with a factory where no such noxious smells or gases are released a great saving in fuel can be effected by a measure of recirculation, i.e., by taking a part of the air from the factory into the heating battery for re-delivery into the factory instead of taking it all from the outer air.

For example, in cold weather, air entering a system at, say, 30° F. will be heated in the heater battery to, perhaps, 120° F. and, on entering the space to be heated, will drop in temperature to, say, 60°, at which temperature it will be expelled from the building to atmosphere. The heat contained in the air between 120° and 60°, i.e., a drop of 60°, is usefully employed in overcoming heat losses of the building. But the heat in the air between 60° and 30° is entirely wasted excepting in so far as ventilation is necessary.

In this example it will be obvious that the loss is  $\frac{30}{90}$ , i.e., one-third of the total heat supplied, which loss may be entirely avoided by complete recirculation and proportionately less by partial recirculation.

#### (E) RADIANT HEATING

In the last twenty years or so there has been a great development in the heating of factories by various forms of radiant heating. This usually consists

of panels of various types from which radiant heat is directed towards the working plane and where a feeling of warmth is transmitted to the occupants by direct radiation and is, therefore, less dependent on the actual temperature of the air.

Radiant heating may be classified according to temperature. At the high temperature end we have porous brick and other forms of gas-heated luminous radiant heaters, and their electric counterparts consisting of wire-wound elements with reflectors giving a beam of luminous heat in any desired direction.

Next come the non-luminous plate type radiant heaters, working with a surface temperature of about  $400^{\circ}$  to  $600^{\circ}$  F., heated by either electricity or gas.

At a lower temperature still are radiant panels heated by high-pressure hot water or steam working at temperatures between  $200^{\circ}$  and  $300^{\circ}$  F. These panels, which comprise metal plates with pipes welded to the back, may be fixed 20 ft. or so up on the walls at an angle to the floor, or may be arranged horizontally overhead so as to direct the bulk of the radiant heat downwards.

The same type of panel, and other forms made of cast iron, are commonly used at lower mounting heights at ordinary radiator temperatures of  $160^{\circ}$  to  $180^{\circ}$  F.

At the bottom end of the temperature scale comes the low-temperature embedded-panel system in which water at about  $100^{\circ}$  F. is circulated through pipes embedded in the structure of the ceilings, walls or floors. Whilst suitable for multi-storey buildings, this system is not often applicable to single-storey factories and industrial buildings generally.

Advocates of radiant heating claim that they get a beneficial warming of the working plane with a lower expenditure of heat than by any other system, and there is frequently a good deal of justification for this claim.

The system is frequently associated with a very small temperature gradient and as it is less dependent on air temperature the system is less affected by accidental openings of large doors than a pure convection system, which is dependent on the actual air temperature only.

Radiant heating is also very responsive to rapid changes of temperature and, therefore, frequently enables a greater saving to be made by good thermostatic control. For example, as when the factory is suddenly subjected to bright sunshine after a period of dull cold weather.

In connection with any system for electric heating it must not be forgotten that though the efficiency of the appliance may be 100 per cent. or approximating thereto, the conversion of the heat of coal into electrical energy involves a loss of 70 to 80 per cent. at the generating station and the transmission system, and from the point of view of conservation of fuel it is not usually economical for the continuous heating of large factories or buildings.

The inefficiency of another system is, therefore, merely transferred to the generating station out of the factory and the efficiency in the factory may be more apparent than real.

The same thing applies to a much smaller extent when using gas, as the overall losses of gas generation are only about 24 per cent., which compares reasonably with the losses involved in boilers and mains on a high-pressure hot-water system for distributing heat to high-pressure panels.

The heating of factories by radiant heating, though comparatively new, is unquestionably one of the developments about which more will be heard in the immediate future, and is likely to be as economical of fuel as any other system.

## AIR CONDITIONING

Air conditioning, in its widest meaning, relates to the adjustment of air conditions necessary to make them fit for certain specific purposes. In ordinary office and factory buildings the purpose may be simply that of maintaining a pleasant and healthful atmosphere for human comfort.

On the other hand air conditioning may relate less to the personnel than to the requirements of certain specific processes with which the factories are concerned, in some of which, for example, close limits of temperature and humidity are essential.

It may be said generally, therefore, that air conditioning necessitates means for adjusting humidity and temperature both up and down so as to give any conditions required whatever the outside weather may be.

The lowering of temperature and humidity is unfortunately much more difficult and expensive than the raising of them, and many people loosely speak about air conditioning in connection with a plant in which the temperature and the humidity can be raised, but in which they cannot be lowered. This is not, in our view, correctly termed "air conditioning" and should really be referred to as "heating and ventilation."

To reduce the humidity, two processes have been used. The first is by the use of silica gel, which is material having a great affinity for moisture. Two banks of silica gel are necessary so that one can be desiccated by heat while the other one is in use as a humidity adsorber.

The second method, which is the more commonly used, is by means of refrigerating plant, whereby the air is passed through washers containing sprays, the circulating water of the latter being kept at a very low temperature by refrigerating plant. Under these circumstances moisture from the humid air is deposited in the finely divided spray and the air leaves the washer saturated at the temperature of the washer. By subsequently warming it up to the required temperature, the relative humidity is naturally depressed and can be kept down to any required figure by lowering the dewpoint of the washer sufficiently. The lower limit is, of course, reached by the consideration that this dewpoint cannot be kept below freezing point, and it would be an exceptional application that required it.

An alternative application of refrigeration to de-humidification is that of passing chilled water or brine, or even the refrigerant gas itself through coils over which the air to be cooled is delivered. In its passage part of the moisture in the air is condensed on the coil surfaces, and the dry-bulb temperature of the air is at the same time reduced. Where the refrigerant gas is itself the cooling medium in the coils this is known as the "direct expansion" method, the coils being, in effect, the evaporator, thus saving loss of temperature head in another heat exchanger.

Another aspect of air conditioning relates to the elimination of dust, since air cannot be considered suitable for many processes if it is heavily charged with dust from the outside atmosphere.

Unfortunately the elimination of dust when large volumes of air are dealt with is very difficult. Earlier methods in common use consisted of various types of oil filter in which the air is made to pass through a tortuous path where it impinges on surfaces kept sticky by special oils and in which the dirt particles are caught and collected.

Some of these oil filters have oil periodically pumped from a tank at the base up to the top for the purpose of washing down the accumulation of dirt

into the lower tank, from which it can be periodically removed. Others consist of portable sections which are from time to time removed from the filter and cleaned in caustic soda or otherwise and then washed, dried, and redipped in suitable oil and replaced. Both these types will remove a high percentage of the dirt, but not all of it, the percentage depending on the size of the particles and their density, the larger and heavier particles being more readily caught than the light flocculent particles which float along the air stream and are difficult to collect.

Other types of air filter include various arrangements of cotton wool and various kinds of fabric which have to be replaced when they are heavily charged with dirt.

There are other types of "throw-away" filters containing sticky glass silk and other similar materials which, as their name implies, have to be thrown away when they are sufficiently heavily charged with dirt.

None of the above types can be said to give perfect collection of dirt, though a high degree of elimination can be obtained with a sufficiently elaborate filtration plant.

In recent years, however, the electrostatic filter may perhaps be said to have superseded other types in certain specific applications, though at present its cost limits its use to cases where the utmost cleanliness is essential. There is, however, good reason to think that in the future its use will become more common. With this type of filter, dust elimination is nearly perfect, even with very light and fine particles, as the principle is not dependent on the deflection of masses, but on electrostatic attraction and repulsion.

As far as refrigerating plant is concerned, this is very unusual in connection with the air conditioning of factories in this country for purely comfort purposes owing to our climatic conditions seldom reaching excessive temperatures and humidities for more than a few days in the year. The conditions are, of course, very different in the States and in tropical and sub-tropical countries where full air conditioning involving refrigerating plant is increasingly common and pays for its high cost by the increased efficiency of the personnel who enjoy its results. Thus, in many parts of the Far and Middle East such as in India, Turkey and parts of China, no modern ventilation system would be considered to deal adequately with the problem without means of lowering temperatures and humidities by refrigerating machinery.

Air conditioning for industrial purposes so as to achieve a temperature and humidity best suited to particular processes has long been in common use. At one time it was thought that cotton goods could only be produced in places like Lancashire where the humid air was favourable to these processes. It was, however, soon discovered that these conditions can quite easily be produced artificially and textile factories are now in common use throughout the world where the natural conditions are far removed from those of Lancashire.

#### FUEL SAVINGS

In order to deal with the imperative need for saving coal in the coming winter, and probably in subsequent winters, we must consider all possible savings which can be effected. Some of these lend themselves to a short-term policy and others to a long term policy, but as no dividing line can be given no attempt has been made to separate them into these two categories, though a consideration of each will probably make it obvious into which category it falls when once it has been established how many years are in question.

**(1) REDUCTION OF TEMPERATURE BY 2° TO 5° F. IN THE FACTORY**

Whether this is practical politics may be a political question outside the scope of this paper, but it is at any rate worthy of note that a big fuel saving can be effected with a comparatively moderate reduction in temperature. If, for example, a factory is designed for a 30° temperature rise, say, from 30° to 60°, a reduction of 5° would appear on the face of it to effect a saving of one-sixth, or 16·6 per cent.

Actually it effects a much greater saving, of about 30 per cent., because only a small proportion of the heating season will require a rise of temperature from 30° to 60°, and there will be a large number of days when the temperature is about 45° outside, when the heating load is reduced from 15° to 10°, i.e. a 33½ per cent. reduction.

Again, there will be some days when the temperature is 55° when no heating will be required, when, with the higher temperature demanded, a small amount of heat would still have to be supplied.

On the average it works out that a reduction of 5° represents about a 30 per cent. saving.

It is of course not for the author nor the Institution to express any views as to whether something on these lines should or should not be asked for, and no doubt factory inspectors, shop stewards, etc., will be consulted in a matter of this kind. It is perhaps only for us, on the technical side, to give some indication of what savings can be effected if certain temperature reductions can be agreed, and leave the rest to the authorities concerned.

This reduction, if agreed, could, of course, be instituted at once, and is, therefore, definitely a short-term policy.

**(2) PREVENTION OF HEAT ESCAPING THROUGH LARGE DOORS LEFT OPEN**

The author has had many examples where this has proved to be a very serious loss of heat and where a whole factory has been lowered in temperature by 10° or more by the design and use of the factory being such that it was difficult to prevent enormous currents of cold air blowing through the factory by open doors, sometimes open simultaneously on the two sides of it. This is liable to occur particularly where heavy mechanical transport in the shape of railway trucks, lorries, etc., has to have frequent or continuous access into a factory, and the problem then may not be an easy one to overcome, but it is so important that it can hardly be over-stressed.

In some cases a replanning of the entrances may make it possible to devise a system of air-locks under which a lorry can enter a loading bay, which is then cut off from the outside by a roller shutter or otherwise before, another roller shutter is opened on the other side, and the lorry permitted to enter the factory. Where this cannot be done a great deal can be effected by mechanical equipment to the doors, so that they can be opened and closed quickly with the minimum of exertion or loss of time.

It is found in practice that large doors which are heavy to move, get opened and left open, and no amount of supervision seems to get them closed immediately the lorry has passed.

Large roller shutters operated by hand may take so long to open and close that when once opened they are liable to be left open.

Efficient mechanical equipment, where all that is asked of the operator is that he presses a button, is found in practice to lead to a rapid closing of the shutters as soon as the lorry has passed and in that way a lot of completely unnecessary air changes in the factory can be avoided.



Where doors of this type are liable to be opened on both sides of the factory, one may have a 30 mile-an-hour wind blowing right through the factory, and no amount of heat or fuel will cope with this situation, and it is almost useless to try.

This is, therefore, a matter of really primary importance if fuel is to be saved and factories are to be warmed.

### (3) THERMOSTATIC CONTROL

It is found in practice that a heating system not so provided is liable to waste fuel. A stoker or boilerhouse attendant is liable to fire to get the temperature up in the early morning, when it is very cold, and having got the factory up to the requisite temperature he frequently fails to lower the fires in strict accord with the increasing temperature of the outside air.

The employees will then frequently have a temperature in excess of what is the minimum to give reasonable comfort conditions, which to a certain extent they may even appreciate, but which cannot be permitted in times of austerity when the utmost coal has to be saved.

When carried to excess they, of course, usually get immediate relief by the opening of windows, but this is only evidence of still further waste.

All this can be avoided by thermostatic control, which automatically shuts off heat as soon as the requisite temperature is reached.

So much has already been written about the savings to be effected in this way that it is not considered inside the scope of this paper to go into this matter in further detail, except to say that the cost of a good thermostatic control is normally saved many times a year in a suitable application.

### (4) BETTER USE OF WASTE HEAT

One sees a large number of cases where, in one part of a factory, heat is belching out into the open air, while in other parts coal is being burnt in boilers to supply heat for space heating. Obvious examples are furnaces discharging gases at temperatures of 1,000° F. and more.

In some cases these go up through stack pipes 30 ft. or 40 ft. in height, which could be encased by an outer casing with air drawn through the latter and blown into the colder portions of the factory in a kind of plenum system.

Even if this did not reduce the first cost of the installation, as the heating might have to be on at times when the furnaces could not be relied upon, it would nevertheless reduce the fuel consumption whenever the furnaces were working.

Some of these heat gains can be a big percentage of the coal used for space heating.

It is impossible in a short paper like this to consider every case where waste heat could be used to better advantage, and nothing less than an individual survey of any particular factory will enable a decision to be made as to where savings of this kind can in practice be effected.

### (5) INSULATION OF BUILDINGS

Some buildings are so constructed that the heat losses by radiation are quite prohibitive. Buildings of corrugated iron or corrugated asbestos come under this heading, and the lining of such buildings by a  $\frac{5}{8}$  in. thickness of insulating board can easily have the effect of halving the heat losses and so saving 50 per cent. of the fuel used in overcoming fabric losses.

Roofs of slates or tiles or even thin concrete slabs are nearly as bad and equally justify insulation if fuel saving is to be treated seriously.

In this matter there is frequently a conflict between Ministries, in that the Ministry of Fuel would gladly encourage the saving of fuel, while the Ministry of Works may be unable to issue the necessary licence for the work to be done, or for the materials to be employed.

These matters are outside the scope of this paper, but are well worthy of serious attention by the Minister of Fuel.

The insulation of buildings in suitable cases can always be shown to be worth while from a financial point of view, apart from the intrinsic fuel savings which it is our imperative need to achieve in these particular years.

#### (6) PREVENTION OF INFILTRATION

It is frequently not sufficiently realised that constructions, such as corrugated iron, corrugated asbestos, slate and tile roofs, to mention only a few, leak so seriously at the joints that a strong wind will cause a number of air changes to pass through the building, which may increase the heat and fuel requirements by anything up to 100 per cent. Though this is greatly reduced by the provision of suitable insulating boarding it is also desirable to take particular care in the bedding of the sheets and the construction of good tight joints.

Particularly in corrugated iron and corrugated asbestos the workmanship is very important, and the differences between good work and bad make an enormous difference in the amount of infiltration.

The inclusion of a felt strip at the joint can make a considerable difference, as well as the tightening up of the joints by a really adequate number of bolts or screws. In some cases a good combination of insulation and prevention of infiltration may be effected by a layer of roofing felt put over the porous material with sealed joints prior to the application of some other coating such as insulating board or a second layer of asbestos or corrugated iron.

Heating engineers in their calculations frequently allow one or two air changes, but in some constructions a figure more approaching 8 or 10 would really have to be taken if full allowance is to be made for the actual infiltration which one gets with some forms of corrugated iron or asbestos badly erected.

Under this heading perhaps comes the question of guarding against excessive ventilation whereby a factory is unnecessarily cooled. For example, some factories are provided with large ventilators in the roof which are left open not only for the eight hours in the day, when the factory is occupied, but also for the 16 hours of the night, when it is not. A simple shutter worked from the floor should enable all these to be closed whenever they are not actually needed.

The same applies to roof lights, jack roofs, etc., where the fullest ventilation may be necessary when a particular process is in full swing, but where it is quite unnecessary to allow the factory to cool down all night because no provision has been made for closing these large openings.

#### (7) INCREASED BOILER EFFICIENCY

One still occasionally sees boilers under-rated for their duty being forced, with the result that the gases come out at a far higher temperature than is consistent with good boiler efficiency. Coupled with this one must mention the cases of boilers of essentially inefficient types.

A boiler can hardly be considered efficient if the gases enter the flue at temperatures of more than 500° F., and any temperatures in excess of this where the size and so on warrant it, are clearly cases for the installation of economisers or a better type of boiler.

To achieve reasonable fuel economy in these days of shortage every boiler installation should be capable of an efficiency of 75 per cent. to 80 per cent. on test, when it is certain to be a good deal lower than this taking it on an average over the whole heating season.

The difference between an efficient boiler installation and a poor one can often be of the order of 20 or 30 per cent. of fuel.

#### (8) RECIRCULATION

Where some form of plenum system or mechanical ventilation is installed, the savings to be effected by recirculation are sometimes very great. This has been briefly referred to under the item (D) of the first part of the paper.

The extent to which recirculation can be permitted is a matter which can only be dealt with in each case on its merits.

Theoretically it would not be right to recirculate the whole of the air except for the warming-up period before the workpeople arrive, when complete recirculation is very valuable for heating up much more quickly, but in some cases it is even possible to design for complete recirculation during occupation. This is particularly the case where the concentration of personnel is relatively low and where the accidental infiltration of air through the opening of doors or through leaky walls, roofs, etc., will in fact provide more than a sufficiency of fresh air.

In the Institution's Code of Practice a figure is given of 1,500 cu. ft. of air per person per hour. No doubt this represents good practice and should be approached or exceeded in normal times and under normal conditions. But the present conditions are not normal in that we have by hook or by crook to save coal, and it is the author's personal view that to meet the present demand for economy it should suffice if, say, 500 cu. ft. of fresh air per hour mixed with 1,000 cu. ft. of recirculated air per hour are passed through a factory, provided there are no processes making considerable heat or fumes requiring special consideration.

If in severe winter weather 1,500 cu. ft. of fresh air per person have to be blown through every factory under circumstances where there are no smells and no special conditions requiring more ventilation than usual, then the Ministerial demand for saving fuel is not likely to be successfully achieved.

Plenum plants without recirculation must be looked upon as grossly extravagant in fuel and can only be excused in cases where really noxious gases have to be evacuated. Even in such cases it is frequently possible by an extraction of these gases at the points where they occur, by hoods and extract fans, to prevent their mixing with the general air of the factory and then enable partial recirculation to be applied.

## 2. Air Conditioning

By J. W. COOLING, M.SC. (TECH.), M.I.MECH.E., M.I.H.V.E.

Heat is used in a winter air conditioning plant in two stages. *Firstly*, heat is used in warming either the incoming fresh air or the sprayed water or both in order to increase the relative humidity of the entering air whenever the outside wet bulb is below the requisite internal dewpoint. For comfort conditions in this country the dewpoint should be approximately 53° F. and

from records over a period of four years the outside wet bulb is below 53° F. on at least 180 days, i.e. for six months in the year. Heat is therefore added to the system over the temperature range of 30° F. to 53° F., the average being 41½° F. Therefore any fairly low-grade heat can be reasonably efficiently utilised in supplying the heat required for humidification. I hope to indicate later a profitable source of this low-grade heat in all winter air-conditioning systems.

*Secondly* heat, and consequently fuel, is used in raising the air circulated from the dewpoint temperature up to the final temperature necessary to balance the heat losses of the building and to maintain an internal temperature of, say, 65 to 70° F. The air is then exhausted from the building at, say, approximately 67° F. It is this exhaust air that provides a useful source of low-grade heat which can be used in several ways :—

(1) By circulating the exhaust air directly back to the building full heat recovery is obtained. There is one major objection to this method, namely that the exhaust air is partially vitiated and possibly contaminated. Much can be done by the use of filters, deodorisers, ionisation and the like, but it is certain that even with such treatment the recirculated air will not be acceptable to all.

(2) The heat in the exhaust air may be partially recovered by passing it through a heat exchanger of the tubular or plate pattern in which the fresh incoming air is partially warmed. The objection to this method is that these heat exchangers are exceedingly bulky and the efficiency of the heat transmission is not high.

(3) A third method of recovery is to warm the water which is circulated through the humidifier by means of a suitable extract air-to-water heat exchanger and this seems to present the most efficient method without contamination.

In order to gain some idea as to the magnitude of possible fuel savings, consider a typical cinema or theatre air-conditioning installation.

Let us assume an average seating capacity of 1,800 and a fresh air ventilation rate of 1,000 cu. ft. per person per hour with exhaust at 75 per cent. of this.

The total air input will be  $\frac{1,800 \times 1,000}{60} = 30,000$  c.f.m. and the exhaust air will be 22,250 c.f.m. Assuming the exhaust air temperature to be 67° F. and taking an average winter fresh air intake temperature of 41½° F. then by the method just outlined it will be possible to recover heat from the exhaust air equivalent to a temperature drop of 9° F. This means a heat recovery of  $22,250 \times 9 \times 1.07$ , or 214,000 B.Th.U. an hour. Taking the useful heat obtained from coke at 8,000 B.Th.U. an hour, running time at 9 hours a day, 6 days a week and 180 days a year, the fuel saving becomes :—

$$\frac{214,000 \times 9 \times 180}{8,000 \times 2,240} = \text{nearly 20 tons for the whole cinema.}$$

I do not know the total number of such installations in this L.C.C. area fitted with humidifying apparatus but it is probably of the order of 1,000. The annual fuel saving on the L.C.C. area over the 1,000 cinemas might thus be 20,000 tons a year.

Other sources of waste in winter air-conditioning systems that deserve attention are :—

(1) Considerable heat is wasted owing to the lack of closeable louvres on main air intakes and exhausts. Where such louvres are not fitted, there is considerable internal flow of cold air from outside through the duct systems when the plant is shut down at night. The colder the weather, the more rapid is the natural circulation. This means that the plant has to be started up earlier the next day with consequent waste of fuel.

(2) Another source of waste is due to loss of heat from exposed thin sheet-metal ducts in roof voids. These ducts convey air at 80°–90° F. often through spaces which in winter have an ambient temperature of 35°–40° F. In such conditions the ducts should either be thoroughly insulated or the air heaters should be removed to positions nearer to the actual room inlets.

Fuel savings are also possible in summer air-conditioning installations. In most summer air-conditioning systems the maximum amount of recirculation is usually adopted in order to reduce the amount of refrigeration necessary, but too much stress cannot be laid on the economy of good building insulation. A well-insulated building not only saves fuel in the winter by reducing heat losses but it saves considerable power (both fan and refrigeration power) in the summer by reducing heat gains. In summer air conditioning in factories there are many considerable sources of high-temperature heat gains such as clusters of bunsen burners, and gas or electrically-heated furnaces. These should be localised by means of efficient hoods, and an exhaust plant used in order to remove the heat before it is transferred into the main body of the factory.

### 3. Temperature Gradients

By H. H. BRUCE, M.I.H.V.E.

Dr. Faber has referred to a temperature gradient of 20° F. between floor and ceiling in factories warmed by unit heaters. Unfortunately such gradients are so common that there is a tendency to regard them as inevitable and a margin to cover the extra heat loss is often provided. In severe weather the gradient is estimated at not less than 10° F. in the first ten feet from the floor and rather more than 0·5° F. per foot above this level. One authority<sup>1</sup> puts the gradient at an average of over 2° F. per foot for the entire height of the building in an extreme case. A difference of 20° F. between floor and ceiling in severe weather is therefore by no means exceptional. A gradient of this sort may account for one-third of the total fuel consumption for heating a factory because of the increased heat loss from the roof and the high temperature of the air escaping from the building at roof level. Hence temperature gradients represent a very serious waste of fuel, and in present circumstances we are bound to ask : are they really unavoidable ?

As Dr. Faber has pointed out, even worse temperature gradients may occur with overhead coil systems. Bad gradients can also be produced by radiators. Indeed, it is on record<sup>2</sup> that a multi-column steam radiator produced a temperature gradient of over 18° F. in a room which was less than

10 ft. high, or roughly the  $2^{\circ}$  F. per foot of height observed with unit heaters. A flat, wall radiator, extending the whole length of the window, in the same room and under the same conditions, produced only one-tenth of this gradient. Thus, temperature gradients can almost be eliminated by proper distribution of the heat supply.

Parts of a certain unusually tall building are open to the roof 100 ft. or so above the floor, and in it there are some large windows not much short of 50 ft. in height. I believe it is true to say that no normal factory could present a worse problem from the temperature gradient point of view, yet there is remarkably good temperature distribution throughout this rather unusual building. There were at one time, both bad temperature gradients and cold draughts in one part of the building. Small hydrogen-filled balloons, among other things, were used in tracking down the cause of the trouble. From this it is clear that down-draughts were involved. The cure was the proper distribution of heat to offset local cooling effects.

There is nothing new about this. Overhead coils under lantern lights in offices and under north-lights in factories are or, more properly, *were* commonplace. The advent of unit heaters has caused many to lose sight of some of the first principles of heating; or, maybe, competition has been so keen, and the assessment of schemes and tenders has been such that the cheapest scheme has too often been adopted. Alternatively, fuel may have been too cheap, relatively, to justify additional capital cost. Whatever the cause, too large a proportion of the total heat load has often been attempted with unit heaters, and expensive temperature gradients and cold draughts have resulted.

Draughts or air movement and temperature gradients are closely related. Quite apart from its effect on temperature gradient, excessive air movement can be quite expensive on its own account.

Air moving at 100 ft. a minute or approximately one mile an hour—the rate at which one might stroll slowly along a crowded pavement—feels  $4^{\circ}$  F. cooler<sup>3</sup> than air moving at the more normal indoor rate of 25 ft. a minute. Many unit heater systems produce draughts considerably in excess of 100 ft. a minute at body level, and from one of Dr. Faber's comments it will be seen that the extra  $5^{\circ}$  F. that may be required to compensate for the draught may increase the fuel consumption by as much as 30 per cent. Clearly, it is better to eliminate the draught than to raise the temperature to compensate for it. The temperature gradient may well be improved in the process.

I have never been able to convince myself that it is economical to use overhead unit heaters which throw streams of warm air down to the floor. In theory, the high temperature of the stream compensates for the air movement and the draught should not feel cold. In practice, at the fringe of the stream of warm air, cooler air is moved by induction or injection and the general temperature must be raised a few degrees to compensate for it. I have known several cases where operatives have shut off unit heaters because the heaters have caused them to feel cold. Such an action may seem to be a grave indictment of a heating system, yet the temptation may arise in any factory, if, in severe weather, the unit heaters are not started up sufficiently early to ensure that the general temperature is about  $65^{\circ}$  F. before the operatives arrive. Even with overhead units it would seem more reasonable to draw cool air from near the floor and discharge the warm air more or less horizontally at a high velocity.

Floor-mounted units, especially when over-large and so located that recirculated air returns at floor level along narrow lanes, can likewise produce draughts that require elevated temperatures by way of compensation.

In both cases, the draughts at body level are most objectionable and are particularly wasteful in fuel when accompanied by steep vertical temperature gradients.

Let us try to picture the air currents that are likely to occur in a typical factory that is heated by uniformly distributed warm air released at low velocity near floor level at frequent intervals over the whole of the floor area. Assume that the air is released at a temperature only a few degrees above that at floor level so that it has no great tendency to shoot up to the roof. This, at first sight, may seem to be the ideal method of heating—something vastly superior to the average unit heater system. But let us suppose that it is 30° F. outdoors and that the factory is of north-light construction with thin walls and roof. Air in contact with the walls is chilled and streams down the wall. The stream may reach the floor at a temperature of, say, 45° F. Similarly, cold air cascades down from the north-light valleys. Cold air from outdoors enters the building and sinks to the floor. All this cool air drifts along at low level, picking up only a limited amount of heat before it reaches the various points where it is fully warmed and gently rises to the cold roof to be chilled and initiate other streams. What will be the air temperature near the roof when it is 60° F. near the floor? The designer must ask himself this question and must face the gloomy picture we have outlined if he wishes to find the best solution to a given factory-heating problem. Doubtless there are many factories that can be satisfactorily or even economically warmed by unit heaters alone, provided they are skilfully applied; but there are also very many factories indeed, especially those of light construction, where supplementary heating by other means would be a sound investment on present-day fuel costs.

Clearly there should be pipe coils under the lower edge of all north-lights, and at the valley or eaves of sloping roofs if they are of thin material. Equally clearly the heat emission by convection from these coils should not greatly exceed the amount necessary to prevent down-draughts. Preferably there should be a strip of insulation board immediately above the pipe to intercept upward radiation that would otherwise be wasted. (Incidentally, small-scale tests<sup>4</sup> indicate that the fitting of inverted timber troughs immediately above overhead coils may reduce the fuel consumption by as much as 30 per cent.).

There should also be pipe coils along the walls if these are likely to cause cold down-draughts and the emission from these coils should equal the heat loss from the wall and windows above. The coils should be not larger than 1½ in. diameter so that the convection emission is at least as much as the radiation emission. When the wall is of thin material, a strip of insulation board may again be employed to advantage between the coils and the wall. If a work bench is fitted along the wall, all or most of the pipes should preferably be fitted immediately above the bench top; otherwise the pipes should be from two to three feet above the floor.

The required amount of fresh air for ventilation should preferably be drawn into the building and warmed on its way in by passing it through suitable heaters. Recirculating unit heaters might be used for part of the air-change loss. Unit heaters should no more be used for severe roof and wall losses than overhead coils should be used for the air-change loss. From the

point of view of fuel economy, either method might be equally unsuitable for the entire heat load.

In conclusion I wish to refer to the investigation<sup>5</sup> carried out by the Industrial Fatigue Research Board in various factories. Systems discharging hot air at high level produced gradients of 11° to 21° F. in the first ten feet from the floor, compared with only 2° F. with long, low radiators under windows.

If, as a result of this conference anyone is moved to hang up thermometers in search of temperature gradient, there is one important point to be remembered: outdoor temperature should be taken at the same time. When the outdoor temperature is 35° F. the gradient is likely to be double the amount indicated when 50° F. outdoors.

#### References

- 1 H. M. Vernon. *The Principles of Heating and Ventilation*, 1934, p. 191.
- 2 A. C. Willard and M. K. Fahnestock. *Heating, Piping and Air Conditioning*, 1930, p. 185.
- 3 Dr. Bedford. *The Warmth Factor in Comfort at Work*, 1936, p. 151.
- 4 A. F. Dufton. *Proc. I.H.V.E.*, Vol. 33, p. 44.
- 5 H. M. Vernon and T. Bedford. Report No. 35. Industrial Fatigue Research Board, p. 78.

## 4. Radiant Heating

By J. L. MUSGRAVE, M.I.C.E., PAST-PRES. I.H.V.E.

Dr. Faber has referred to the economies arising from the increasing use of radiant heating in factories. It may be appropriate to comment in a little more detail on various applications of radiant heat which may use electricity, gas, low or high-pressure hot water or steam; no doubt high-frequency current eventually will be utilised. Potential users have a wide choice from which to select a method suited to their requirements and each has its appropriate sphere.

It is generally accepted that with all types of heating apparatus, the lower the temperature of the heating surface in relation to the air temperature, the greater is the relative economy in fuel consumption; this is one of the reasons for the efficiency of the embedded system of radiant warming by which heat is diffused by radiation from large surfaces at low temperature, generally about 90° F. In multiple-storey factories the warming panels are usually embedded in the soffits of ceilings. In single-floor factories the coils may be embedded in the floor several inches below the surface; in these cases the circulating water temperatures are regulated to produce surface temperatures of 65° F. to 70° F.

When low-temperature radiant heating is employed, convection currents are small. Therefore, air temperatures remain reasonably constant throughout, and little loss is caused by the escape of heated air through windows and crevices in the upper parts of the building.

In substantial buildings, fuel is saved by continuing the heating day and night.

In small buildings where it is not possible or convenient to instal or to run a boiler, fabric of plastic or other material wired for electricity may be applied to the ceilings; the loading of this fabric is generally from 14 to 18 watts a sq. ft. producing a temperature on the surface from which heat is radiated of from 85° F. to 100° F. This system should be thermostatically controlled.



While the cost of electricity per therm is necessarily higher than that of coal, there are many instances in which, with internal sources of heat arising from machinery or processes, a direct electric system fitted with thermostatic control is less costly to run than a solid fuel system, because when the casual heat is sufficient to warm the building the heating system is automatically shut down completely—there are then no standby heat losses.

Records taken in some buildings heated by low-temperature radiation indicate an input over the heating season varying from 35 per cent. to 75 per cent. of that which would appear to be required by normal calculations. No equipment using boiler plant and distributing pipes can effect such instantaneous control.

Gas-heated radiants are in many instances giving good service in similar circumstances.

In existing buildings, and some new buildings in which the form of construction does not lend itself to the application of the usual methods of low-temperature radiant warming, which necessarily require a relatively large area of radiating surface, independent units heated by gas, electricity or hot water may be used ; for larger buildings, hot water is generally the most economical, these units being operated usually at about 160° to 170° F. in cold weather. If the units are distributed so that heat is properly radiated where needed, comfort is secured at fairly low air temperatures and air-change losses are small.

For large factory buildings such as foundries, steelworks, etc., large radiant units using high-pressure hot water or steam operating at about 300° F. or more may be employed effectively, particularly when the buildings are lofty or not of massive construction, or in which large doors are opened frequently.

Gas radiants at high temperature may be used in such buildings in certain circumstances, such as where the price of gas is low or there is no boiler installation.

In the use of high-temperature radiants the placing of the units is of vital importance ; radiant heat needs to be directed into the working space, either by positive radiation or by reflection of the heat rays, to give uniform diffusion as far as possible. Effective reflectors of radiant heat are glass and bright metallic surfaces. Buildings of galvanised steel which are notoriously difficult to heat by convection, are heated reasonably economically by high-temperature radiants. Asbestos sheets, if clean or washed with a light distemper, also reflect radiant heat but to a lesser extent, having a matt surface, but as asbestos is a slower heat conductor than steel, less of the heat is absorbed. Adequate insulation, where possible, should not be neglected.

Reference has been made by Dr. Faber to the serious heat losses due to the large air change in factories which may be caused by the extraction of large volumes of air for dust removal, or in factories in which, owing to the processes involved, a high degree of ventilation is needed. It is found that the temperature gradient between high and low level is relatively small in buildings heated by direct radiation as distinct from convection, and that the occupants may be comfortable in a lower temperature than is needed with some other forms of heating. It necessarily follows that the amount of heat carried away by extraction is considerably reduced where radiant systems are installed.

In factories in which air conditioning is required, fuel is saved if provision is made for balancing the direct heat losses due to structure exposures, by the installation of radiants, preferably of low-temperature type ; the incoming air in cold weather need then be heated only to the ambient temperature

required in the building. Care must be taken to distribute the incoming air through suitable draughtless diffusing terminals.

Another advantage which indirectly affects fuel economy is, that with the combination of low-temperature radiants and low-temperature air supply, extraction can be taken from high level without serious heat loss, thus facilitating the easy removal of fumes and objectionable odours which are usually warm and therefore tend to rise.

In factories in which cooling is required in hot weather, embedded warming systems may be used to reduce temperature by circulating cooled water through the embedded coils. Thus heat is absorbed directly from the fabric thereby substantially reducing the load on the air-conditioning plant; power and therefore fuel is saved and there is less risk of chills and discomfort due to cold draughts.

Thermostatic control is advisable with all these systems. With systems heated from a central source the regulation should be of a type which raises or lowers the circulating temperature according to the requirements in relation to the external temperature; this is more satisfactory than cutting out individual units.

Radiant heat systems may involve greater initial expenditure to instal than more usual systems of convection heating, but if properly designed and fitted with suitable controls, the savings in fuel, added to the greater efficiency of the workers due to the comfort factor in the factories so heated, pay a handsome return on any extra capital cost which may be incurred.

## 5. Insulation and Heat Loss (Air and Structure Losses)

By L. COPELAND WATTS, M.I.MECH.E., M.I.H.V.E., A.C.G.I.

When considering fuel economy in connection with the heating of factories detailed consideration should be given to reducing to a minimum losses (1) from the structure and (2) due to air change which have to be made good by the heating system.

### (1) STRUCTURE LOSSES

Many modern factory buildings are constructed with sheeted walls and roofs on light steel frames. Such buildings are very extravagant from the heating point of view as the heat transference through the walls, etc., of such buildings is very high. The heat transmittance coefficient varies from 0.9 B.Th.U./sq. ft./hr./° F. difference for flat asbestos cement boards to 1.2 B.Th.U./sq. ft./hr./° F. for corrugated iron for walls, and up to 1.50 B.Th.U./sq. ft./hr./° F. for roofs. By lining the walls and roof with at least  $\frac{1}{2}$ -in. thickness of insulating board having a conductivity of not more than 0.4 B.Th.U./hr./° F./in. thickness the heat transmittance coefficient will be reduced by about 55 per cent. if the board is applied direct to the sheeting and by nearly 70 per cent. if fixed to battens giving an air space between the insulating board and the sheeting.

Such insulation, while reducing the fuel consumption, has the further advantage of reducing the capital cost of the heating installation. In fact, for new buildings the cost of the insulating material is generally less than the saving effected by its use on the cost of the heating system. As an illustration,

reference may be made to a recent investigation into a factory building having a floor area of about 35,000 sq. ft. and a volume of about 900,000 cu. ft. Here the application of insulating board reduced the total heat loss by one-third and the total capital expenditure for the building plus heating installation by about £400 while at the same time saving 60 tons of coal a year (or over £200 a year at the price ruling at the time for coal in the particular district concerned).

This example is for a new building but some savings can also be made with existing buildings. Additional capital expenditure may be involved but the fuel saving will more than pay the interest charges on the capital expenditure. In existing buildings critical examination should be given to the structure so as to ascertain where the greatest reduction of heat loss can be made with the least expenditure on insulation. Where the walls are of brick probably the saving to be effected by insulation will be relatively small, but in such buildings the roof loss is often considerable and the application of insulating board to this part will be well worth while. In buildings having pitched roofs with a ceiling below, the loss can often be reduced by placing a layer of slag wool or similar material over the ceiling.

Another aspect which merits consideration in existing buildings is where the heating system does not give the desired results. The obvious method of providing more heating surface may not be the best. Very often the reduction of heat loss by the application of insulation will enable the existing installation to give the desired degree of warmth at no greater expenditure of fuel. A further economy will also result where intermittent heating only is required since the heating-up period will be reduced as compared with the uninsulated building.

#### (2) AIR LOSSES

The biggest single loss of heat from a building is that due to the air change and steps should be taken to ensure that the amount of air passing through the building is not more than that required to keep the working conditions satisfactory. Much can be done to this end by stopping up leaks from the building. In lightly constructed buildings there is often considerable leakage at the joints or laps of the sheets, and particularly at the eaves. Incidentally the application of insulating board usually helps materially in reducing air leakage so that the gain due to its application is out of all proportion to the insulating effect.

Many buildings have roof ventilators provided which, while being of considerable benefit in summer, often allow too much warm air to escape in winter unless proper provision is made by means of dampers to enable some to be closed during the heating season. The advantage of being able to close all these ventilators at night has already been discussed. The position is more difficult in factories where fumes are given off during special treatments of the articles being manufactured as closing the roof ventilators may then have a serious effect on working conditions. It will often be found, however, that the provision of proper extract ventilation adjacent to the source of the fumes will localise the distribution and enable the total amount of air removed by this means to be reduced very considerably as compared with the more general application of roof ventilators.

Reference has already been made to the serious loss of heat that often occurs when large doors are left open, and the recommendation made that air-locks should be provided and mechanical equipment for operating the doors installed. It frequently happens that in addition to the entry of lorries

or railway wagons there is a continuous traffic of small mechanically-driven trolleys in and out of the factory. It is often found that the large doors are left open continuously for this purpose when the provision of smaller doors would be quite adequate for the requirements and their installation would reduce the air change considerably. Further, the provision of air-locks for these smaller openings in conjunction with the institution of one-way traffic will do much to improve conditions adjacent to the doors. In some factories, covered ways linking the various buildings can be arranged, instead of air-locks, for the passage of these smaller vehicles.

When dust-collecting systems are installed the amount of warm air discharged from the system can considerably increase the fuel consumption. A system of recirculation of the air may be possible although this is often impracticable owing to the impossibility of filtering the air satisfactorily. In certain cases particularly with fume extraction where the temperature of the air removed may be considerably higher than room temperature, the possibility of providing a heat interchanger for preheating the entering air should be investigated. In other cases the delivery of unheated air can be arranged in such a way as to avoid taking air from the factory space to make good that extracted by the fume removal system, and yet not make working conditions unpleasant for those in the vicinity.

There are few factories where a careful survey of the present conditions will not show possibilities of fuel saving and it is hoped that these remarks will indicate some of the lines of approach to enable these savings to be made.

## 6. Application of Instruments to Boiler Plant

By F. R. L. WHITE

Unlike locomotive firemen, operators of stationary boiler plants do not generally know what load they may be called upon to meet. Instruments are essential to provide this knowledge and to enable the plant to be worked efficiently.

There are two classes of information which the boiler attendant should have. First, the minute-to-minute readings of steam pressure, chimney draught, feed-water temperature, and the temperature and the percentage of CO<sub>2</sub> in the flue gas. Second, there is the type of information such as the recording of steam output, feed-water input, and the weight of fuel used, which in addition to giving an indication of the general efficiency of the plant, provides invaluable data as to the incidence and extent of normal and peak load requirements.

Instruments are commercially available to fulfil all these duties. By combining a recorder or an integrator with an indicating mechanism, it is possible to operate instruments such as draught gauges, CO<sub>2</sub> recorders, distance reading thermometers, steam pressure recorders and feed-water recorders to give both minute-to-minute readings and charted records.

Coal meters with integrating mechanism are available in various forms and when properly calibrated will give results which are as near correct as is practically possible.

The temperature of the flue gases gives an indication of the extent of one of the major heat losses. Temperatures above 350°–500° F. should be regarded as unduly high. Because low temperatures may be due to air in-leakage, flue

temperature readings must be studied in conjunction with the  $\text{CO}_2$  content of the gases.  $\text{CO}_2$  gives a measure of excess air, thus

Excess air—per cent.	. . . 25	50	75	100
$\text{CO}_2$ in flue gas—per cent.	. . . 14.2	11.3	9.4	8.3

A  $\text{CO}_2$  content of about 12 per cent. may be considered satisfactory in normal practice.

Where two or more boilers operate in battery form, the knowledge of the anticipated load from time to time would enable the operator to assess the number of boilers likely to be necessary at any particular time and so ensure economical operation.

Boiler operators cannot be expected to get good efficiency from their plant without instruments. With a little expenditure on instruments, considerable economies in the quantity of fuel used are possible. The psychological effect upon the fireman should not be overlooked. If he can see and understand the results of his labours, he is bound to have a greater interest in his job, and his contribution to fuel economy will undoubtedly be increasingly evident.

## 7. Thermostatic Control

By J. R. KELL

Thermostatic control as applied to space heating is a means for achieving constant internal temperature so avoiding under or over-heating. Heating systems in this country are generally designed to maintain a certain internal temperature such as  $60^\circ\text{F}$ . or  $65^\circ\text{F}$ . when the outside is at freezing point or thereabouts. When the external temperature is higher than this basic temperature, as it generally is except for a few weeks in the year, the heat supply must be reduced, otherwise the temperature inside will rise above what is necessary, with consequent waste of heat and fuel.

Waste of heat and fuel depends on a number of factors such as :—

- (1) The construction of the building, whether light or heavy.
- (2) The kind of heating system, whether steam, hot water or warm air.
- (3) The adequacy of the heating system, whether it has a good reserve or whether barely sufficient to meet heat losses.
- (4) The period of use, whether one, two, or three shifts a day.
- (5) The presence or absence of process heat which may be partially or wholly sufficient for the heating of the building, once the temperature has been raised initially.
- (6) The kind of boiler plant, whether hand fired or automatically fired.
- (7) The glass exposure liable to heat gains from the sun even in winter.

In one combination of the above factors there may be a greater potential waste of heat if the system is uncontrolled than in another.

For instance, a steam-heated single-storey sheeted factory will have big heat losses and require a correspondingly large heating system, but the thermal capacity will be low. Hence in mild weather when the correct temperature is reached it will be very easy to overshoot the mark, and a great waste of heat will be possible.

On the other hand, in a substantial building with brick walls and concrete roof having a hot-water system and a high *flywheel* effect, the heating system

will be of much smaller dimensions, and the possibility of over-running of temperature much less.

This means that in the first example there will be possible a much more substantial saving in fuel with thermostatic control than in the second example. It is impossible therefore to say that thermostatic control will save in general a definite percentage of fuel, since each case has its own characteristics which need to be taken into account.

It is equally impossible to generalise about the method of application of thermostatic controls.

In the sheeted building referred to previously, where the system is steam, there is little to be gained by varying the steam pressure at the boiler, and it will probably be best to control at the point of use, such as by motorised valve in the steam feed to the coils, etc., or, in the case of unit heaters, by on-off switching of the fans.

If the heat is supplied by hot water, control of temperature of the water at the boiler or calorifier according to external weather conditions will probably be the most suitable method, coupled possibly with zone control of various circuits or of individual rooms, if the system is large enough to warrant it.

For new buildings, the heating system and its thermostatic control can be designed together at the outset, and the cost of the control equipment may be recovered several times over in a year in a suitable application.

On the other hand, the fitting of thermostatic controls to an existing installation may be difficult without considerable alteration to the piping lay-out, which means greater cost and a longer period for repaying by fuel savings.

During the fuel economy campaign, it was found, in general, difficult to make out an economic case to justify the expenditure in any short period such as  $2\frac{1}{2}$  years which was then the limit. More cases could be found repaying expenditure over 5 years or so, but managements were on the whole loath to go in for such schemes where, after all, the savings were only estimates with no guarantee. Had some relief of taxation or other financial encouragement been given more schemes would have materialised, and this is probably true also today.

These difficulties should not be glossed over. Thermostatic control as applied to an existing installation means more than just buying a valve and fitting it in a pipe line. If it is to make any worth-while contribution to fuel saving, some real financial inducement must be given to industry to spend money, not only on thermostatic control, but on the more radical re-piping and modernisation of old heating systems generally, which is often an essential concomitant.

Apart from thermostatic controls there are other controls which can make for fuel saving. For instance, except in three-shift factories, most works in these days of fuel economy shut off or reduce heat at night. This means starting up again some time ahead of the employees' arrival if the requisite working temperature is to be obtained. The length of this preheating period depends amongst other things on the outside temperature. On a cold day an earlier start is needed than on a warmer day.

It is possible to obtain an automatic control which will take over the duty of starting up early or late according to the weather, provided, of course, that

there is a corresponding supply of heat to meet the demand, such as a boiler-house kept constantly under steam, or some other means of automatic firing whether by coal, oil, gas or electricity.

In fuel saving, it must be remembered that it is hours of running that count as much as anything else, and if the system is started up at a regular time irrespective of outside temperature conditions, there are most likely wasted hours of heating every week.

Thermostatic controls, by giving a constant temperature in the working space, undoubtedly create better working conditions. This must have a beneficial effect on both the output and health of the operatives.

Similarly, steadiness of temperature in process plant is often essential if consistency of quality is to be secured. Hand regulation inevitably allows variations leading to wasted time and rejects. Thermostatic controls can make for better working of the equipment, and most modern heat-consuming plant is, of course, fitted with such controls at the outset.

This kind of application of controls is, however, not done primarily for fuel saving, but for improvement in results, a point which should be borne in mind when dealing with industrial applications. Fuel savings may be made, but they are incidental.

## 8. Fuel Economy in its Relation to Atmospheric Conditions in Factories

By G. P. BARNETT

The papers have dealt concisely, though comprehensively, with the heating of factories, the steps necessary for obtaining suitable atmospheric conditions and the various methods whereby it is suggested fuel may be saved. My contribution must necessarily therefore be by way of recapitulation, regarding the question from the point of view of the provisions of the Factories Act. It must always be realised that legal requirements represent a minimum standard of observance and that much higher standards of compliance are often achieved in the best regulated factories than is actually laid down in the letter of the law.

The Factories Act, 1937, and the Regulations made under it deal with the safety, health and welfare of persons employed in factories and so far as temperature, ventilation and purity of the atmosphere are concerned the physiological aspect is the important one and has to be reconciled with the requirements of various processes. Where the atmospheric conditions most suitable for any particular process might tend to be deleterious to health the law may have to step in and regulate such conditions to prevent them from becoming a physiological hazard, as, for example, the humid textile industries.

The general provisions of the Factories Act with regard to heating are of necessity framed to cover industry in general and to meet such extremes as employment in an iron and steel rolling mill on the one hand and an ice factory on the other. Section 3 requires :—

*Temperature.*—(1) Effective provision shall be made for securing and maintaining a reasonable temperature in each workroom, but no method shall be employed which results in the escape into the air of any workroom of any fume of such a character and to such extent as to be likely to be injurious or offensive to persons employed therein.

(2) In every workroom in which a substantial proportion of the work is done sitting and does not involve serious physical effort, a temperature of less than sixty degrees shall not be deemed, after the first hour, to be a reasonable temperature while work is going on.

Whether or not a temperature is reasonable is ultimately a matter for the Courts to decide. It is dependent upon all the facts in any particular case as indeed is the question whether the means taken to attain such a temperature do or do not in fact interfere with the purity of the atmosphere.

Premises subject to the Factories Act are in a specially favoured position in that by virtue of the fact that statutory requirements already regulate heating they are not subject to the ban on the use of central heating which the Ministry of Fuel imposes twice yearly at those rather vicarious and elusive periods which are supposed to indicate the change from winter to summer and vice versa. Whilst we in our offices may be shivering because of the ban, reasonable temperatures are maintained in the best regulated factories in accordance with their legal obligations. It behoves factory occupiers, therefore, to ensure that proper economical use is made of fuel and all possible wastage of fuel and power avoided.

In dealing with unit heaters, Dr. Faber refers to the type using coal gas as a means of heating and mentions two types, the one provided with a flue and the one without, suggesting that where the gas is purified to the usual low sulphur content there appeared to be little objection to dispensing with a flue in large factories of the shed type, in which case there would be a very definite economy in fuel. The criterion under the Act is of course whether or not there is interference with the purity of the atmosphere in consequence. Such can only be ascertained by a test at the working level and cannot be dependent merely on low sulphur content. Although, therefore, it may appear attractive from the point of fuel saving, each case would certainly have to be carefully considered on its merits.

Much has been said on the question of temperature gradients and clearly a great deal could be done to eliminate high values in that respect without encroaching upon any legal requirement. The Factory Department is not concerned with the temperature of the air in the roof of the factory but with the comfort and satisfactory working conditions of the persons carrying on their work at their machines and benches. As has already been pointed out, there is no doubt that much fuel is wasted in a failure to appreciate this fact. The warm air from unit heaters often finds its way to the roof instead of the floor of the shop and similarly with some methods of heating by means of steam or hot water pipes.

Radiant heating is undoubtedly developing and it is possible to produce the same sensation of warmth with lower air temperatures when radiant heat is employed. Its use in factories is being carefully studied particularly where there are large doors which have constantly to be opened. Its advantages there over a purely convection heating system have already been indicated.

So far I have only dealt with heating without linking it up with the question of ventilation. Clearly the two are very closely connected and the two other forms of factory heating referred to by Dr. Faber combine the two, the plenum system with or without exhaust ventilation and air conditioning.



The general provisions of the Factories Act with regard to ventilation apart from specific requirements in respect of special processes are :—

*Ventilation.*—Effective and suitable provision shall be made for securing and maintaining by the circulation of fresh air in each workroom the adequate ventilation of the room, and for rendering harmless, so far as practicable, all fumes, dust and other impurities that may be injurious to health generated in the course of any process or work carried on in the factory.

*Removal of dust or fumes.*—In every factory in which, in connection with any process carried on, there is given off any dust or fume or other impurity of such a character and to such extent as to be likely to be injurious or offensive to the persons employed, or any substantial quantity of dust of any kind, all practicable measures shall be taken to protect the persons employed against inhalation of the dust or fume or other impurity and to prevent its accumulating in any workroom, and in particular, where the nature of the process makes it practicable, exhaust appliances shall be provided and maintained, as near as possible to the point of origin of the dust or fume or other impurity, so as to prevent it entering the air of any workroom.

Both sections are directed towards obtaining purity of the atmosphere and in so far as fuel economy is concerned the provisions of the latter section have special significance since, if poisonous or noxious gases, fumes or dust are prevented from escaping into the general atmosphere of a workroom by the application of exhaust ventilation at the particular points where they are liable to escape, the provision of such localised ducts as are then necessary means the removal of a much smaller volume of air than is necessary if other more general means of removing dust or fume-laden air are applied. There is a tendency sometimes to attempt to tackle such a problem by specifying a ventilating plant to deal with a certain number of changes of air per hour, which in effect only dilutes the impurity, never properly removes it and renders recirculation quite impossible. Obviously where large volumes of air have to be removed and replaced entirely by air from outside the continual heat loss is enormous. The question of such a loss of heat is a major problem in the matter of dealing with dust in cotton card-rooms. This dust, which causes the industrial disease known as byssinosis, escapes from the carding engines and no satisfactory practical method of preventing its escape or intercepting it efficiently has yet been found. A committee of which I have the privilege to be chairman is reconsidering the problem and experimental and research work is now being carried out. Some recent tests on a plant where the air from a card-room was filtered primarily by a dry filter and then thoroughly washed gave promising results and if further tests support the results then found it may be possible to recirculate the air and thus avoid the excessive use of fuel necessary to raise the temperature of the incoming air. The use of electrostatic precipitation has, of course, not been overlooked as a means of removing the dust from the air and experiments are now in hand with the unit-type collector and useful information, being compiled.

The committee which is considering the conditions in the cotton trade has also had under consideration the desirability of a wide use of air conditioning plants in cotton mills. In the cotton industry temperature and humidity are important from the manufacturing point of view ; most spinning and weaving processes are best performed in a relatively high temperature and a higher

degree of relative humidity than normally exists even in Lancashire. Relative humidity can be altered either by a change of temperature or of moisture content and unless there is proper control of both, the physiological effects may well be most unsatisfactory. In dealing with such conditions the important temperature to be considered is that of the wet bulb thermometer. The Cotton Cloth Factory Regulations, for example, prohibit any artificial humidification when a wet bulb reading of  $72\frac{1}{2}^{\circ}$  has been reached. These regulations also deal with the question of preventing an undue rise of temperature by requiring all steam pipes used for artificial humidification to be adequately lagged and insulated with a suitable material having a standard of performance such that the amount of steam condensed in the covered pipe does not exceed one-fifth of that condensed in the bare pipe. This, in itself, in preventing undue loss of heat results in economy in fuel.

In these regulations too the minimum temperature is specified as  $50^{\circ}$  during the first half-hour of work and  $55^{\circ}$  thereafter: in fact where minimum temperatures are specified in any other regulations, e.g. the Woodworking Machinery Regulations, they are of this order.

Fuel economy in the factories therefore must result from close attention to such matters as insulation of buildings, temperature gradients and like matters so ably expressed by Dr. Faber, since the legislative requirements leave no scope for general reduction of temperatures below the statutory requirements.

#### *Discussion*

**Mr. R. P. McCulloch:** In Fuel Efficiency Bulletin No. 25, "Steam for Process and Heating", the importance of using the lowest possible pressure for process and heating has been stressed. The main reasons for this are, I think, fairly obvious. Firstly, the boiling point of water decreases with reduced pressure, and secondly, the latent heat, the full abstraction of which is vital in heating and process usage, increases with reduced pressure.

There is one other reason, particularly with a large-scale steam-distribution system, which makes the lowest possible pressure desirable. Where some hundreds or even thousands of steam traps are in use on a system, together with very large numbers of joints, valves, etc., it is too much to expect that all these items are functioning correctly at any one time. The system losses, therefore, are very much reduced on lower steam pressures.

The control of pressure on a very large industrial heating and process steam system is one which requires considerable thought and I should like to describe to you a method for such control which has been in successful operation since 1943.

The steam demands on this system reach about 40,000 lb./hr. in the winter period, and steam is transmitted for distances up to about one mile from the source.

For several years up to 1943 heating and process steam was expanded through back-pressure turbo-alternators, and the back pressure was governed at the turbine, at a constant pressure of 15 lb./sq. in. gauge. The low-pressure steam at this point has in addition about  $100^{\circ}$  F. of superheat in view of the long transmission distances. This arrangement functioned quite satisfactorily up to the outbreak of war, when large additional steam demands were made at the remote ends of the system. The bigger demands so increased the pressure

drop on the main that some trouble was experienced in remote parts with water-logging. With the maintenance of an all-the-year-round constant pressure at the source, the pressures at the terminal ends were very fluctuating and depended on loads. Insistent demands were therefore made that the back pressure be increased from 15 to 25 lb./sq. in. gauge.

This led to a review of the control system. So far, you will note, the system had been controlled by a constant pressure at the source, with the pressure at the ends left to vary according to the load on the mains. It was immediately considered that if this process could be reversed, i.e. to maintain a constant pressure at the ends by varying the pressure at the source, all immediate difficulties would be overcome. At the same time, big economies would be made, particularly during the lighter load periods, by running the system at lower pressures and thus reducing system losses.

As a first step to this end, long-distance pressure recorders were installed to indicate the pressures at two selected points at the terminal ends of the system. The pressure recorders, which are of the electrical impulse type, were installed in the company's power plant control-room. Tests were then carried out to find the minimum pressures which could be maintained to keep the whole system in satisfactory operation. A pressure of 7 lb. was eventually found to be satisfactory, and it was also found that during certain light-load periods this pressure could safely be dropped to 4 lb. These pressures were incidentally considerably lower than we had expected prior to the installation of the long distance recorders, when we were, so to speak, running blind and relying on tests carried out by various individuals at different times. The recorders, therefore, immediately gave us continuous evidence which in itself led to immediate saving.

The next phase was to consider how the control of this pressure could be centralised and placed in the hands of the control-room attendants. Two schemes for this were considered :—

- (1) The fitting of remote control to the pressure governors of the back-pressure turbines.
- (2) The installation of butterfly reducing-valves on the two points at which the steam mains leave the power station, and the maintenance of sufficient excess pressure on the low-pressure steam range to give satisfactory control from the reducing valves, which would be arranged for operation from the control room.

It was found that the second scheme was the more practical and was accepted, although it was realised that there would be a slight loss in energy by the use of reducing valves. In practice the excess pressure required to take care of all normal pressure fluctuations has been found to be not more than 1 lb./sq. in. gauge and therefore any loss from this is small.

Should this figure be exceeded by a reduction in steam load, the turbine drivers immediately make the required adjustment to the back-pressure governors.

The adoption of automatic pressure-control was provided for, but has not been put into practice as no operational difficulty has been experienced with hand control. It will be appreciated that on a steam main of about one mile in length the time lag before any adjustment of the reducing valve at the source, shows results on the terminal pressure is considerable, particularly on raising

the pressure, and therefore any automatic control would have to have a damping device to prevent hunting.

The arrangement in the control room is simple and compact. The back pressure is recorded together with the two terminal pressures, and the butterfly valves are operated remotely by electrical controllers with electrical valve position indicators alongside the long-distance recorders. The control-room attendants soon adapt themselves to the time lag by knowing what variation in pressure is effected by a given change on the valve position indicator.

Tests have been carried out on the system to assess the savings made with such a control arrangement, and the results of one individual test should be sufficient to indicate its value.

On test 1, the system was operated at a constant back pressure at the turbines of 15 lb./sq. in. At this pressure the steam demand was 81,000 lb./hr. The terminal pressure was 8.8 lb./sq. in. Immediately following this test the terminal pressure was reduced to  $7\frac{1}{2}$  lb./sq. in. by reducing the back pressure at the turbines to 13.4 lb./sq. in. gauge.

The steam flow was reduced from 81,000 lb./hr. to 73,000 lb./hr. and on the reduced flow the kVA generated on the back-pressure turbines was reduced by 127 kVA. This load was, of course, thrown on the condensing turbines running in parallel with the back-pressure turbines, and thus the net reduction in steam flow is 6,700 lb./hr.

As this system has been in continuous operation for three years we have estimated that, taken all variations into account, the introduction of this method of control has saved 4,000 lb./hr. of heating and process steam at an equivalent fuel saving of 1,620 tons per annum.

The total cost of the whole scheme was £1,200 so that the capital outlay was recovered in six months, added to which the modifications have given a much improved service.

Mr. Salter spoke of the considerable fuel economies obtainable in factory spaces if occupied areas only are heated to produce "zones of comfort". He quoted achievements at his own factory where comfort zones had been maintained at 55°/60° F. when temperature just below the roof (indoors) was 30° F. The zones required a higher rate of heat input per cubic foot of space than normally, but the net saving was substantial—zones equal to one-twentieth of total cube required three-twentieths of fuel necessary to heat the whole factory.

Mr. Foyle explained a method of heating-plant control whereby a factory of 200,000 sq. ft. floor area given to various printing processes was heated with 50 per cent. less fuel than ordinarily. The method described was essentially one of time control, steam being put on or off at certain times before building occupancy and evacuation, in relation to the outside temperature.

In practice the method used was to fit a recording thermograph in the boilerhouse, measuring outdoor air temperature. The pen was not inked but acted as an instantaneous indicator, moving over a scaled temperature chart. On this chart a guide line was clearly marked showing the outdoor temperatures at which steam might safely be turned off at different times of the day, such temperatures having been determined previously by experiment.

The boiler operator observed the pen position from time to time. If it were below the guide line steam was turned on, but whenever it reached or moved above the line, steam was turned off.

This system provided a reliable regulation of the length of the morning heating-up period and ensured the turn-off of heating steam at the point when the residual heat in the building and heating system, together with the normal fortuitous heat gain from machinery and occupants, would maintain an adequate temperature in the factory up to the time of work ceasing. In a season of 200 days, steam was used in the afternoon only on 60 days.

**Mr. Ackery** suggested that a combination of hot water or steam central heating giving a background temperature of, say, 50° F. together with high-temperature radiant heaters to provide zones of comfort for individual workers or groups, would be well worth investigation as a measure of reducing fuel consumption, and which at the same time would provide equal or enhanced comfort for the worker.

He deplored the lack of factual evidence available on the relative fuel consumption of various types of system and pointed out the need for more full-scale investigations in the field. In comparing results from such investigations, it was necessary to know the heat losses or "heating size" of the building and he suggested that such data should be collected relative to all buildings of reasonable size and made available for reference, possibly at the Institution of Heating and Ventilating Engineers.

**Mr. Holmes** recommended that automatic temperature controls should operate independently as between unit heaters and direct heating surface (where these two methods of heating were used in combination in one room) since the requirements for air and fabric heating were not in constant proportion to each other. In connection with mechanically-operated doors to loading ways, air locks, etc., he expressed the opinion that even these "automatic" devices were subject to human neglect and that automatic floor pad switches, operated by the traffic offered the most successful method.

**Mr. Chase** said that where boilerhouse instruments were used, it was essential to have recording equipment. His experience with plain indicating types was that operators waited for a good reading before making a log. In reply to his questions, **Mr. Kell** recommended that thermostatic control of medium-sized canteens could be actuated conveniently and successfully by the air in the exhaust ventilating duct, but where such an "averaged" sampling point is not available, the room should be controlled in zones. Intermittent heating of such buildings was usually more economical than continuous heating though each case required individual consideration.

A further question was answered by **Mr. Barnett**, who explained that there was no conflict between the heating ban and the factory regulations, the former being inapplicable to workshops.

**Another speaker** asked that the Ministry of Fuel and Power might give financial assistance to factory owners in the insulation of their buildings, and suggested also that the shortage of insulating board might be solved by international exchange of fibre board from Sweden for a portion of the coal saved here by insulation.

**Mr. Longworth**, concluding the discussion, referred to earlier remarks on the fuel savings resulting from small reductions of indoor temperature and pointed out how much greater this effect is when air-conditioning apparatus is in use or where artificial humidification of any form is employed. He called attention to his paper on "The Selection and Application of Air Conditioning

Plant with Special Reference to Cotton Mills " which, *inter alia*, gave figures on this subject, and he explained that, whilst the paper was written primarily for the guidance of the cotton industry in fixing and maintaining standards of air conditions, it was applicable in principle to all industrial air-conditioning and had been circulated to delegates for that reason. Industrial air-conditioning would, he thought, be applied on an increasing scale in the future and the careful choice and control of indoor conditions in proper relation to those outdoors was essential if extravagant fuel and power consumptions were to be avoided.

Mr. John Philip wrote : Mr. Copeland Watts has indicated the advantages of proper thermal insulation of buildings. It would seem, however, that at the present time in this country we are not permitted to build new factories with proper thermal insulation or to obtain permits for materials to insulate the roofs of existing factories. Generally, with equal working floor area, the heat losses from multi-storey factories are less than from single-storey buildings, particularly when the single-storey factories are built with structural steel framing covered with cement asbestos sheeting and unlined. Often the mean height of single-storey factories is 21 ft., which means that two-thirds of the cube to be heated is ineffective taking the effective height of interest to the worker to be 7 ft. from the ground. This can sometimes be dealt with by constructing an intermediate floor, thus increasing the factory floor area, and using the top floor for storage, the ground floor only being heated. New factories under construction abroad are nearly all multi-storey.

In a survey of a number of factories in this country in connection with the fuel efficiency campaign it was often found that space heating was taken from the same source as process heating. Where these were separated considerable fuel savings were effected, as the source of heat for space heating could be shut down during 22 weeks in the year and sometimes longer. Where the space-heating load was changed over from a steam system to a medium-pressure hot-water system further savings were effected. In medium-size single-storey factories it has been found unnecessary to instal high-pressure hot-water systems if proper attention is paid to the design of the system to eliminate as far as possible the drop in temperature between the boiler and flow main. With rare exceptions, there seemed to be no case for generating steam for space heating. Where engines were used for power, a vacuum return was fitted and the exhaust steam used for space heating.

## SECTION C. HEAT FOR DRYING—*continued*

### SESSION III. Heat for Agriculture and Horticulture

*Chairman of Session :* MR. JAMES TURNER  
PRESIDENT OF THE NATIONAL FARMERS' UNION

**T**HE CHAIRMAN : The agricultural industry is anxious to do nothing that will aggravate the fuel position. The purpose of this session is to find ways and means to effect further economies while maintaining production. Agriculture has been described as being very conservatively-minded in its approach to technical matters. It is now becoming much more progressive and agriculturists are, in fact, becoming efficient users of raw materials.

#### 1. "How Glasshouse Growers can Save Fuel"

Mr. W. H. Gamble then introduced Fuel Efficiency Bulletin No. 46 having the above title. He pointed out that fuel is used in agriculture and horticulture by a large number of small users, and included both solid and liquid fuel. The tonnage of solid fuel used is estimated as—

Nurseries and glasshouses . . . . .	750,000 tons per year
Soil sterilisation . . . . .	50,000 " " "
Threshing and ploughing . . . . .	380,000 " " "
Grain drying . . . . .	10,000 " " "
Grass drying . . . . .	7,500 " " "
Hop drying . . . . .	10,000 " " "
Miscellaneous (malting, farm dairies, pig swill boiling, flax, orchard heat- ing, etc.) . . . . .	120,750 " " "
	<hr/>
	1,328,250 tons per year

The bulletin, in the preparation of which the National Farmers' Union gave considerable assistance, was not a scientific treatise but was primarily a collection of facts.

Mr. Gamble quoted a letter from the Agricultural Correspondent of the "Daily Telegraph" pointing out the desirability of erecting central drying plants under the direction of the War Agricultural Executive Committees, a step which could save most of the harvest in wet seasons. These dryers could be kept going for several months in each year to produce high-grade cattle foods. Individual farmers could not provide the capital required, however, and the venture would have to be a co-operative effort.

The fuels chiefly used in horticulture were now in short supply. There were great differences in fuel-using practice in glasshouses, so that in the south of England consumption varied between 100 and 400 tons of coal an acre for similar crops. The speaker suggested a target figure of 180 tons an acre for main crops, e.g. tomatoes. This, he said, was perhaps not the true criterion of efficiency and a much better basis would be the output per ton of coal used. Thus if 50 tons of tomatoes were produced per acre of glass, a consumption of

180 tons an acre represented 3·6 tons of fuel consumed per ton of tomatoes. This basis of comparison might also reveal that winter lettuce was worth more than its weight in coal.

#### BOILER PLANT

The requirements of the grower as regards boiler plant could be summarised as :—

- (1) Reliability.
- (2) Minimum labour.
- (3) Reasonably robust construction.
- (4) Moderate first cost.
- (5) Capable of rapid and accurate temperature control.

The system should be used to give a measure of control of climatic and humidity conditions. Observations just taken in the Lea Valley area in houses of the normal type and about 15 ft. high and 30 ft. in width, showed :—

- |                               |       |  |
|-------------------------------|-------|--|
| (1) Sunny day—no wind         | . . . | 86 per cent. relative humidity<br>at floor level.<br>83 per cent. relative humidity<br>7 ft. from floor level.<br>65½ per cent. relative humidity<br>outdoors. |
| (2) Sunny periods—slight wind | . . . | 90 per cent. relative humidity<br>at floor level.<br>82 per cent. relative humidity<br>7 ft. above the floor.<br>69 per cent. relative humidity<br>outdoors.   |

The atmosphere near ground level had such a relatively high humidity that it could be termed saturated. In these conditions diseases and mildew occurred and control of air circulation was required to reduce risk of loss from these troubles.

#### HEATING CIRCUITS

The usual system was gravity circulation through 4-in. C.I. pipes. Growth of a nursery over a period of years sometimes led to 10 to 20 separate boilers over an area of, say, 4 acres. A central plant might then be desirable and this would involve the services of an engineer.

(Slides showing correct and faulty layout were shown.)

#### BOILERS

The tubular boiler generally used was designed originally by a grower specifically for nursery conditions and while its efficiency under controlled test conditions was comparatively high, under nursery conditions it was frequently low. Although the efficiency was moderate, it had advantages in the comparative ease with which repairs could be effected, and in the fact that this type of boiler would stand up to the conditions ordinarily encountered in nursery boilerhouses. In the Channel Islands recently the equivalent of an economiser section had been fitted on top of a tubular boiler. Frequently ash-pit doors were found to be missing or in bad repair. Draught control dampers should be used. (Slides were shown of this type of boiler.)

The need for maintaining the glasshouse temperature in the early hours of the morning following a period when little heat was needed suggested the use of a forced-draught fan fitted to a closed ash pit and a correctly designed grate,



the forced-draught fan being controlled by a thermostat, to ensure that the night variation in house temperature could immediately be countered by an increase in draught but only when this was required. The need for burning a wide variety of fuels today might limit the use of mechanical stokers.

The sectional boiler designed for use on low-pressure hot-water systems was sometimes used for glasshouse heating. It had a high efficiency but was not capable of withstanding rough usage.

#### CIRCULATION

Normal gravity circulation could be used with a water head of 8 ft. to 10 ft. It became unreliable if the pipe run was badly designed or became air locked. Accelerators were available and one design permitted the continuance of gravity circulation if the motor stopped. In one instance with a gravity system the temperature difference between flow and return water was 40–45° F., but with the introduction of a circulator the difference dropped to 20–25° F. This might economise fuel to the extent of 5 per cent. and result in substantially improved growing conditions.

The latest development in the United States of America was the forced circulation system having 1½-in. pipes instead of 4-in. pipes coupled with on-off thermostatic control. This type of control could be applied similarly to certain steam systems and results in certain engineering advantages. Steam systems might result in local temperatures being too high.

#### FUEL SAVING

Mr. Gamble pointed out that fuel could be saved by constant supervision of the operation of boilers. There could be no question that a night fireman was frequently advantageous and in view of the enhanced prices and shortage of supply of fuels the relative value of fuel should be balanced against labour costs. Adequate maintenance of boilerhouse lagging, and attention to pipe joints, air vents, correct ventilation and the replacement of broken glass would repay attention. One degree of over-heating within the glasshouse would result in a 3 per cent. to 5 per cent. increase in fuel consumption. Records should be kept of fuel consumption and house temperatures in order that these may be much more closely related to the growing requirements. Future developments might be the application of the vacuum steam systems and of forced circulation systems, but such installations must be treated as an engineering problem so that whenever practicable for areas of 5 acres or upwards a correctly balanced and well-designed system should be prepared by specialists or consultants familiar with the growers' needs. What might aptly be termed "catalogue engineering" should not be applied to large heating installations where fuel efficiency was desired.

## 2. Grain Drying and the Combine Harvester

By C. B. CHARTRES

This year about 7,500,000 acres of corn were grown in Great Britain. Fully 90 per cent. of this large crop was harvested with binders—machines which cut and tie the crop into sheaves. The sheaves are stooked to mature and then stacked to await threshing during the winter months.

Threshing is generally done by a contractor with a travelling threshing mill which visits farms in rotation. Until fairly recently all these mills were hauled and driven by steam traction engines which consumed from 1 to 1½ cwt. of coal per acre threshed, depending on the weight of crop and the number

of moves between farms in a week. Owing to the great rise in the price of coal many contractors are replacing their steam engines by large tractors on rubber tyres which consume 1 to 1½ gallons of vaporising oil per acre threshed.

Nearly 10 per cent. of the total crop this year was harvested by combines—machines which cut and thresh the grain in one operation. They are driven by petrol engines and require slightly more fuel than the binder method, but in harvesting costs fuel is not nearly such a large item as labour. The binder method requires from 24 to 54 man-hours per acre as against 10 to 19 man-hours for the combine, depending on the weight of crop and weather conditions. In view of this great saving in labour, combines are increasing in numbers each year. They demand a special technique and the grain harvested by them generally needs drying to render it suitable for storage.

#### FUEL USED IN HARVESTING

No separate statistics are available to show the amount of fuel used for the grain harvest, but the numbers of horses and tractors on farms are known and they would suffice for the work to be divided as shown in Table 1.

On this basis the cost of fuel for handling the 1946 harvest is over £2,000,000.

TABLE 1

Method of harvesting				Fuel used per acre				
Ref. No.	Cutting corn	Carting	Threshing	Acres	T.V.O. at 1s. per gal.	Petrol at 2s. per gal.	Coal at 3s. per cwt.	Coke at 3s. 6d. per cwt.
1	Horse-drawn	Horse-drawn	Steam engine	2,500,000	—	—	1·25	—
2	Binder, tractor-drawn	Tractor trailers	Steam engine	2,300,000	3·75	0·1	1·25	—
3	Binder, tractor-drawn	Tractor trailers	Tractor-driven and hauled	2,000,000	5·00	0·1	—	—
4	Combine	Tractor trailer or wagon	Combine and dryer	700,000	2·50	2·25	—	$\frac{0\cdot5^*}{2}$

\* Only about half the grain combined is dried on farms.

#### Total fuel used for harvesting.

Ref. No.	Acres	T.V.O., gallons	Petrol, gallons	Coal, tons	Coke, tons	Fuel costs	
						Total	Per acre
1	2,500,000	—	—	156,000	—	£468,000	s. d. 3 9
2	2,300,000	8,620,000	230,000	144,000	—	886,000	7 9
3	2,000,000	10,000,000	200,000	—	—	520,000	5 3
4	700,000	1,750,000	1,572,000	—	8,750	275,300	7 10
Total	7,500,000	20,370,000	2,002,000	300,000	8,750	2,149,300	5 9
Fuel cost.	—	£1,017,500	£200,200	£900,000	£30,600	£2,149,300	5s. 9d.

An estimate of the fuel used for the 1946 harvest is given in Table 1. It is interesting to note that as harvesting technique has improved the fuel requirements have changed from solid to liquid fuels.

The change-over from steam engines to tractors for threshing reduces the fuel cost from 7s. 9d. to 5s. 3d. per acre. This is a saving of 32 per cent. and indicates strongly that more big tractors should be made available for threshing. When the change-over is complete there will be a saving of about 300,000 tons of coal per annum, but by then the number of combines will probably have increased to over 10,000 cutting about 2,000,000 acres and requiring 25,000 tons of coke—or 15,000 tons of oil—for drying the grain.

Grain dryers should be installed on farms where the grain crop is big enough to justify the capital outlay. Alternatively, central dryers of large capacity with adequate storage may be installed to deal with all grain from combines over a wide area.

Farm dryers may be of the tray type in which the grain is carried on a perforated tray, but are more generally of the vertical type in which the grain falls by gravity through two or more narrow columns formed by perforated metal sheets. Drying is effected by blowing hot air through the grain, and it is highly important that this be done in such a manner that the delicate germ of the grain is not damaged in the process. The recommended maximum working temperatures for the hot air are shown in Table 2.

TABLE 2  
RECOMMENDED MAXIMUM AIR TEMPERATURES FOR GRAIN DRYING

	° F.
Barley and seed corn 24 per cent. and over . . . . .	110
"    "    "    under 24 per cent. . . . .	120
Linseed, mustard and oil seeds . . . . .	115
Milling wheat . . . . .	150
Oats and dredge corn for milling . . . . .	180

The fuel required to provide air at the temperatures given in Table 2 is not a large item in the cost of drying and for this reason perhaps little attempt has been made by manufacturers of farm dryers to avoid radiation losses. The plants work only a short season and the aim has been to keep down capital cost. On central dryers much more care is taken to prevent radiation losses.

Farm grain dryers range in size from 1 to 3 tons an hour when removing 6 per cent. of moisture from the grain. This is equivalent to evaporating 143 lb. of water from each ton of grain dried. When drying wheat with air at 150° F. and an atmospheric temperature of 60° F. the moisture in the grain is evaporated and carried away at a temperature between 85° F. and 110° F. Under these conditions the total heat required to evaporate 1 lb. of water would be 1,454 B.Th.U. if the hot air left the dryer saturated.

Unfortunately the necessity for keeping the columns of grain in the dryer very narrow in order to keep down the power consumption of the fans means that the air leaving the dryer is never saturated, and this fact, coupled with radiation losses, reduces the thermal efficiency considerably so that dryers may use 3,000 B.Th.U. and more instead of the theoretical 1,454 B.Th.U. per lb. of water evaporated.

Early farm dryers used coke. The furnaces were of the "Pot" type arranged for hand firing. With careful stoking they proved satisfactory, but

in view of the great importance of steady and reliable control of the temperature of the hot air it is most desirable that thermostatic control should be used in all grain dryer installations. This cuts out the human element and provides a safeguard against damage of grain. The "Pot" furnace, therefore, will probably give way to a gravity-fed coke furnace to which it is easier to attach thermostatic control.

When using solid fuels the overall consumption must include amounts for heating up after banking overnight and during other shut-down periods, which may mean a considerable weight of fuel in broken weather conditions when a long run is impossible. On the other hand, oil, gas, or electricity start with full heat directly they are turned on, and they shut off entirely when the dryer is stopped. They also have the decided advantage of more simple and reliable automatic control, thus saving labour and making it possible for one man to look after quite a big plant.

The quantity of heat required to provide hot air for a dryer is generally calculated for dealing with atmospheric air at 60° F. If the air temperature is much lower than this, as often happens at night, the total heat—and consequently the consumption of fuel—may be increased by 20 per cent. to 30 per cent. Consequently it is not possible to compare tests of dryers unless the atmospheric temperature is known. It should be recorded hourly at all drying plants.

There are many published tests of dryers but none seem to show the division of heat losses as between furnace and dryer. Instead, the consumption of fuel is given for a run of a few hours. An average figure over the season will be about 56 lb. of coke per acre of grain dried. This figure might be reduced 10 per cent. to 20 per cent. by lagging, but that is the best we can expect with coke.

With oil or gas firing it should be possible to have the furnaces placed nearer the dryer in order to minimise radiation losses. Electricity is even more favourable in this respect as all heat losses external to the dryer should be avoidable with properly placed heating elements. In Table 3 a range of comparative results is given for operating a dryer with different fuels.

The figures given for coke and oil are selected from a range of results on different sizes and types of dryers. Gas has not much significance as most dryers are remote from gas mains. Electricity is widely distributed but if its use for heating is to be made attractive to supply companies, and a low rate obtained for current, the dryer should be specially designed to avoid heat losses, and the whole arrangements at the plant laid out to run 24 hours a day when drying. This will mean storage of the combined grain in a ventilated bin designed to take the daily output of the combine and keep the grain from heating until it can be passed through the dryer. A plant of this type could be 50 per cent. smaller than the usual dryer, would run long hours without any attention and thus be economical in labour. A set of bins would receive the grain after drying and sacking-off would be done only from these dry bins.

As the cost of fuel is generally less than 10 per cent. of the cost of drying, the small differences between the costs of coal, coke, oil, as shown in Table 3, are scarcely significant. If due allowance is made for the good thermostatic control, and the lower labour charge made possible by oil fuel, there is a very strong case for using it on new farm dryers. The cost of converting the existing coke-fired dryer to oil firing may range from £140 to £200.

TABLE 3  
COMPARISON OF RESULTS WITH DIFFERENT FUELS

Fuel and cost at dryer	Calorific value per lb.	Fuel used per ton of grain dried	Fuel used per hour per 1 per cent. moisture removed	Water evaporated from grain per lb. of fuel	Overall efficiency	Fuel costs per ton of grain dried
	B.Th.U.	Lb.	Lb.	Lb.	Per cent.	d.
*Coal, 49s. a ton	14,200	54.5	9.1	2.75	28.2	14.3
†Coke, 70s. a ton	12,500	36.0	6.0	4.0	46.2	13.5
	—	42.0	7.0	3.6	42.0	16
	—	48.0	8.0	3.1	37.0	18
†Oil, 8½d. a gallon, 172s. a ton.	18,000	24	4.0	6.25	50	18.5
	—	27	4.5	5.30	43	21.0
†Gas, 8d. per therm	1 therm 100,000	4.5 therms	0.75 therms	33.4 per therm	50	36
†Electricity, ½d. per kWh.	1 unit 3,415	110 units	18 units	1.36 per unit	58	82

\* Coal used for raising steam in a boiler. Drying is done by steam heating. This gives excellent temperature control on dryer.

† These fuels used for direct heating.

Central drying plants should have large dryers with a preheating section. Steam heating gives excellent control. The boiler to supply this steam should be fitted with an automatic stoker to burn the cheaper grades of screened coal.

Drying in ventilated bins with a large volume of slightly heated air offers an alternative which at first glance is attractive to the farmer who cannot afford a dryer but wants to combine his grain and keep part of it over winter for feeding to stock. The thermal efficiency of the process is higher than on a dryer because the air will leave the bin nearly saturated, but this improvement is offset to some extent by having to blow and heat the larger volume of air required to remove moisture at relatively low temperatures. On the other hand, the installation will cost less than a dryer and set of bins. Tests are in progress to ascertain commercial results.

At present there are nearly 4,000 combines in the country. The N.F.U. anticipate that within a few years this number will rise to 10,000. The drying capacity in the country today can barely keep pace with the rate of cutting by combines, and existing bin storage is being used to the full. In a wet season like the present when combines are doing such great work for the national economy by saving grain in the condition in which it is cut instead of leaving it out to be spoiled in the stooks, it is not out of place to plead here for an energetic lead to tackle properly the question of additional central dryers. Now is the time to plan the work and to arrange finance before the flood of new combines sets in. One central dryer could easily serve 50 or 100 combines if properly designed, and the fuel consumption at this one plant would be much less than if each of the combine owners put in a dryer on his farm.

#### SUMMARY OF RECOMMENDATIONS

(a) Many more large tractors on rubber tyres should be provided for threshing contractors. A winch should be fitted to each such tractor for use in difficult conditions.

(b) Attention should be given to radiation losses on grain dryers. It is a simple matter to insulate the furnace and hot air pipes.

(c) All grain dryers should have thermostatic control of the hot air temperatures. For this reason there is a strong case that all new farm dryers should have oil-fired furnaces.

(d) Electricity can be justified as a source of heat only if the drying plant be specially designed to keep the maximum demand on the mains at a reasonable figure. This may be made possible by using bins ventilated with cold air in which to keep grain from the combine and feed it slowly to a small electric dryer.

(e) Drying grain without a dryer may be possible if the experiments now in progress on bins ventilated with warmed air prove successful. The amount of heat required at one time is much less than with a dryer, but it is applied over a much longer period. Consequently this system would have a more suitable type of load for electric operation.

(f) It is all-important that any drying arrangements on farms should be such that grain can be dried safely. Central dryers offer the best means of ensuring this, and they save fuel compared to a number of smaller individual dryers. More central dryers should be built to keep pace with the expected increase in the number of combines.

### 3. Grass and Herb Drying

By DAVID FAIRCLOUGH

There is no other material grown in this country which will give a balanced ration of such high food value per acre as dried grass or lucerne from properly managed pastures. There is no other material which can give such a high record of milk per acre as grass. In addition to the nutritive value of grass it has been found that the carotene content of the material is extremely valuable. Carotene is the precursor of vitamin A and is relatively stable. Its value lies in the fact that it can be converted in the animal's body into vitamin A, a vitamin which is essential for adequate nutrition, stamina and health.

Dried grass, therefore, is produced for three distinct markets :—

- (1) As a vitamin concentrate for manufacturers of animal foodstuffs.
- (2) As a balanced food for direct feeding to livestock, usually on the farm where it is produced.
- (3) For chemists and others who are desirous of extracting the chlorophyll—the colouring matter which is used for soaps, cosmetics, etc.—and also the carotene and traces of other elements.

By 1936 a new industry had been created in this country for drying foods, one of which was grass. Dryers consisted at that time of simple tray dryers of the batch type, which since 1936 have been largely superseded, except on small farms, by the continuous or conveyor type of dryer. In the meantime, continental workers, taking up the idea from this country, applied the experience obtained in other fields, and introduced pneumatic dryers.

There are roughly three categories of agricultural dryer operators in Britain :

- (1) The farmer-producer-consumer who feeds all the material dried to his own stock.
- (2) The farmer-producer-salesman who feeds a proportion of his output to his own stock and sells the balance.
- (3) The factory unit.

(1) The farmer-producer-consumer on a small acreage requires only a relatively small output from a machine which must be operated by the minimum number of persons, and the system must be fitted into the ordinary farm routine. By far the largest number of dryers operating in this country are in this category, and almost invariably the choice has been a tray batch dryer.

(2) The farmer-producer-salesman in most instances concentrates on carotene production, and is desirous of obtaining high outputs in the season, necessitating a continuous dryer. It has been shown this year, with the appalling weather conditions that the modern continuous dryers have a higher output on the same material as tray dryers, even when operated by the same management.

(3) Factory units are generally operated by the largest type of farmer, or by groups of individuals working as a company, drawing their raw material from airfields or purchasing their grass from neighbouring farms on a long-term contract. Almost without exception, conveyor dryers are used, limited in their season by weather conditions which determine the commencement and termination of growth of grass or lucerne, as the case may be.

One of the major considerations in this process is that of fuel and power.

*Fuel costs*, at the moment, are rather high. As a rough guide, the differing types of fuel required to give one ton of dried grass of good quality are as follows :—

Coal . . . . .	12 cwt.
Coke . . . . .	18 cwt.
Oil . . . . .	90 gallons

The present price of electricity is such that it is quite uneconomical for producing heat for grass drying on the present system. With the present fuel situation, coupled with distribution costs, etc., it is very difficult to give a fair figure for the cost of any of these fuels, other than oil, delivered on the farm.

Experience over the last two years has shown that in certain instances the solid fuels delivered resemble more an explosive mixture than fuel as we used to know it. It is seldom that two deliveries of solid fuels are the same, either in texture or calorific value. It will be appreciated that if the fuel used is liable to produce sparks when fired by the ordinary labourer or with automatic stokers, such sparks are liable to go through the air-circulating mechanism, and into the drying grass which, in turn, is liable to catch fire. Many such instances have occurred during the last two years, resulting in reduced output and considerable loss to the operator concerned. During this season one of our largest dryer operators in the country has had three such outbreaks of fire in 36 hours.

Various requests have been received by dryer operators from Ministry Area Officers to include percentages of slack, and in one celebrated case, flax shives as a diluent. Dryer operators just cannot utilise such admixtures. We are up against fumes tainting the grass, and also excessive wear and tear on the furnace, quite apart from the additional labour required for handling such material, and quite apart from the fire danger.

For these reasons, interest has changed considerably on to oil fuel. Present indications are that on a modern plant with adequate mechanical handling gear for the raw material, coupled with oil-firing of the furnace, the services of one man per shift may be dispensed with. When it is realised that only three men, and sometimes four men per shift are required, the reduction of one man per shift represents a very considerable saving in labour costs. The

price adjustments on fuel oils announced on 1st October, 1946, may alter completely the choice of fuels for grass drying.

Before one is able to discuss the reduction in fuel which has been effected in the grass drying process one must first of all understand the problems connected with our raw materials—grass and herbs. Speaking generally, growing vegetable matter contains not less than 75 per cent. of moisture on the one hand, and up to 93 per cent. on the other. Although when expressed as a percentage this is a range of 18 per cent., which does not appear to be large, when expressed as a water ratio a different picture is presented :—

75 per cent. equals 3 : 1 water ratio

93 per cent. equals over 13 : 1 water ratio

a difference of 10 parts of water to one of dry matter.

A short sharp shower of rain may increase the water ratio by one part in the matter of a few minutes.

If fuel is to be saved, one must either increase the efficiency of the furnace as a heat-producing unit, increase the efficiency of the dryer, and/or reduce the moisture content of the raw material prior to drying.

*Furnace Efficiency.*—It would appear that there is very little information available on the subject of direct heating of air in an oil-fired furnace. Design of such furnaces is as yet in its experimental stage. Economies may be made, however. In my own plant recently I have shown a saving of  $7\frac{1}{2}$  per cent. through more careful control of the secondary air, and this is only the beginning.

*Dryer Efficiency.*—It would seem that there is a good deal of waste heat emanating from a grass or green-crop dryer. Designers of plant have been studying this problem for many years. The determining factor is the point at which additional capital cost of heat-recovery apparatus or insulation material ceases to affect the reduction in fuel consumption.

Whilst economies may be made in this direction, far greater economies may be made as a result of a reduction in the moisture balance of the raw material.

*Raw Material.*—If the weather is settled, partial wilting of the material in the field after cutting or mowing will reduce the water ratio from 4 : 1 to 3 or even 2 : 1 without affecting the protein material or colour. This reduction is obtained at the expense of a loss of vitamin A through the carotene loss.

Where vitamin A is the main consideration wilting is not practicable. Where protein for direct feeding to animals is required, field wilting can reduce the drying cost considerably.

Where super-hay is required, barn curing as practised in the U.S.A. and Sweden would appear to be practicable provided a source of heat is available.

So far, no mention has been made of the power requirements of the process. Where the dried grass is produced for sale, the material must be ground down to a powder which will pass through a screen of 2 millimetre perforations or less. The power required for this process is relatively high, 8 to 12 h.p. is required for each hundredweight of finished material produced per hour. A normal plant with an output of 4 cwt. an hour would therefore require, say, 15 h.p. for the dryer and 40 h.p. for grinding.



This is a completely new industry founded in 1936. It is only ten years old even now. In those ten years there has been a six years' war when all progress was inevitably at a standstill. We have a long way to go but it is remarkable that in the period under review so much progress has been made.

To me it is a source of great concern that so few people realise the value of the material which we walk upon. If the authorities in this country would only grasp the potentialities of the subject, the reduction in imported feeding stuffs would not worry us in the slightest. If Sweden, Switzerland, Holland and Germany could carry on in complete isolation from 1939 to 1946 with the aid of green-crop dryers, why could not we do likewise ?

#### HERB DRYING

Largely as the result of the war the culinary and medicinal herb industry of France had a serious setback. Progressive farmers in this country seized their chance and it would appear that many types of herbs need never be imported again.

The governing factor of the success or otherwise of the industry is that of an efficient system of drying. Colour, preservation of leaf, retention of aroma, are the governing factors. Clean, dry, warm air are the requirements for an age-old hobby now becoming one of Britain's latest industries.

There is a world shortage of essential oils, both edible and industrial vegetable oils. They can be produced in this country. The pioneers are working at it. With the present rate of progress it will be only one or two years before we regain once more the pride of place in green crop conservation by artificial means which we had to give up through the advent of this last war.

In the national interest, therefore, may I say :—

(1) Give us fuels upon which we can rely.

(2) Help us to get out new machines and processes quickly. You all know how that may be done. It has something to do with the word *controls*.

## 4. Engineering Aspects of Grass Drying

By A. W. SCOTT, PH.D., B.SC., M.I.MECH.E.

#### INTRODUCTION

The objects of this short paper are (1) to review briefly some of the engineering problems of grass drying, (2) to describe some research work on the subject and (3) to indicate how fuel consumption could be decreased by the adoption of alternative methods of drying—by power alone and by waste heat utilisation.

Most of the information was collected in the course of engineering investigations for the Crop Preservation Committee of the Agricultural Research Council during 1935–1940. This work included field tests on farm dryers, experimental work on small-scale drying plant at the Royal Technical College, Glasgow, and also analyses of proposed new drying plants. Free use has been made, in the paper, of material from reports submitted to the Agricultural Research Council.

VARIATIONS IN RAW MATERIALS

Compared with most drying processes grass drying starts with a severe handicap in the variability of the raw material. Grass varies in percentage of leaf and stalk, each with widely different drying characteristics, in length of cut and, most important of all, in initial moisture content. In addition, there are wide seasonal variations in the daily quantity of grass available for drying on a given farm, which requires a compromise on dryer capacity.

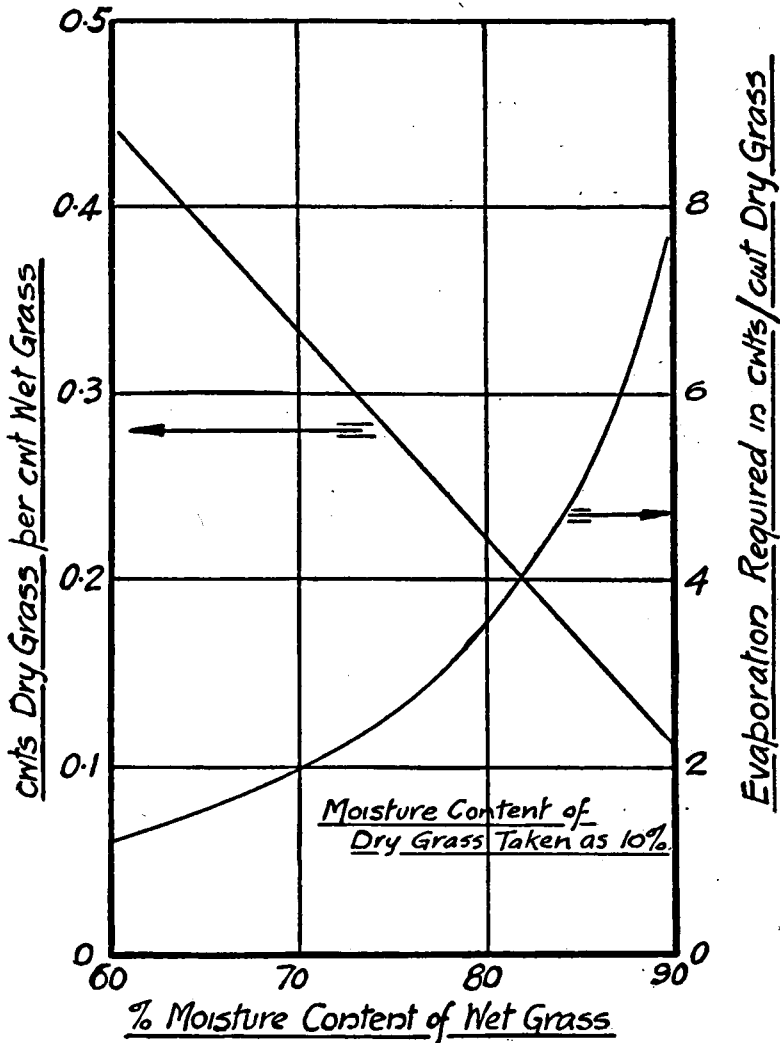


FIG. 61

Fig. 61 shows how initial moisture content affects the evaporation required for a given output of dried grass. A rise from 70 to 82 per cent. doubles, and from 70 to 87 per cent. trebles the evaporation per ton dried grass. Fig. 62 gives average moisture contents on different days of testing and also the variation during a single day of testing. In the latter case the high moisture content of

the grass at the beginning of testing was caused by dew which dried off in the course of the morning.

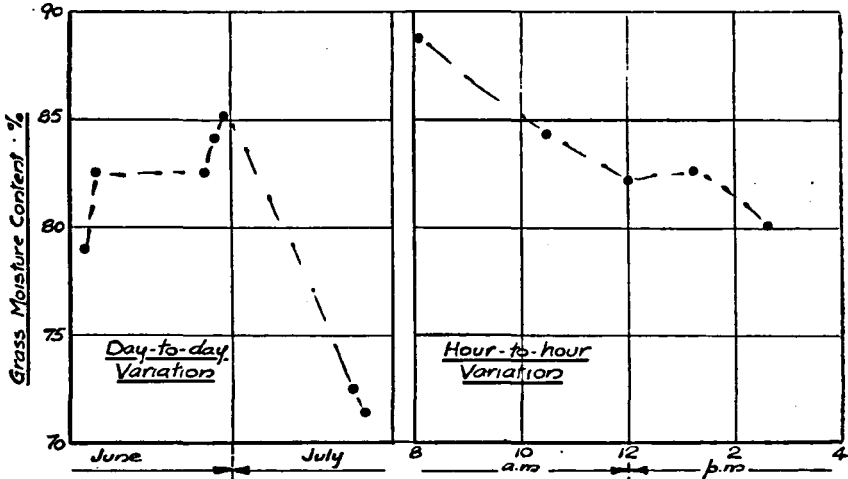


FIG. 62.—Variation in moisture content.

Such variations raise the engineering problem of a machine of widely varying duty. A dryer cannot be designed to give consistently high thermal efficiency under such conditions. One method of evening the duty of the dryer would be to standardise the material fed to it, at least for moisture content, but so far this has only been attempted by the wasteful method of field wilting.

#### STANDARD OF PERFORMANCE FOR DRYERS

The thermal efficiency of a dryer is the ratio of the heat used for evaporation to the heat supplied to the furnace. The maximum possible efficiency for a given inlet air temperature is obtained when the exhaust air leaves fully saturated and there are no radiation or other losses. This ideal efficiency can be calculated and is shown in Fig. 56 on page 270. It is seen that this ideal efficiency increases with temperature, and it has been found from test figures from actual grass drying plants, using inlet air temperatures ranging from 800° to 1,500° F., that on an average the actual efficiency is about 60 per cent. of the ideal.

This loss of efficiency is due to a variety of faults. In all cases the exhaust is well above saturation temperature. Other heat losses are due to incomplete combustion in the furnace, poor insulation, leakage of cold air into suction spaces, blow holes in tray and conveyor dryers and general lack of uniformity of operating conditions. In addition it has been observed that with continuous dryers the operators prefer to over-dry the grass, which can lead to considerable waste of heat.

#### TYPES OF DRYERS

[At this stage, the author briefly described with lantern slides various dryer designs, in particular :—

Recirculation dryers—(1) two-stage band type, (2) band dryer with alternate up-and-down air flow through the grass mats, and (3) batch tray dryer.

Pneumatic dryers, in which the grass is first converted into chaff and then carried forward in the gas stream.

Regenerative dryers—not yet built commercially, in which attempts are made to recover some of the latent heat in the evaporated water.]

Dryers are being developed along varied lines and a wide range of problems has to be faced in design and operation.

Furnace design, combustion and control problems are common to all types. For efficient designs the relationships between circulating air conditions and drying time must always be known, and, particularly in pneumatic dryers, a sound knowledge of the aerodynamic characteristics governing the rate of drying is essential. Even in tray and conveyor dryers savings in fan power can often be effected by careful design of air flow passages. Apart from the thermal aspects there are also problems raised by the use of potentially corrosive gases containing sulphur dioxide.

#### RESEARCH WORK

The problems involved and the lack of precise data were fully recognised by the Crop Preservation Committee of the Agricultural Research Council, and on their behalf research work was started on a small-scale drying plant installed in the Engineering Laboratory of the Royal Technical College, Glasgow. A fair amount of work was carried out on this plant in 1939 and the results have already been published.<sup>1</sup> Among the more important points which emerged, it was found that through-draught drying was not feasible above 350° F. owing to the ease with which local charring could develop in the weaker parts of the grass layer.

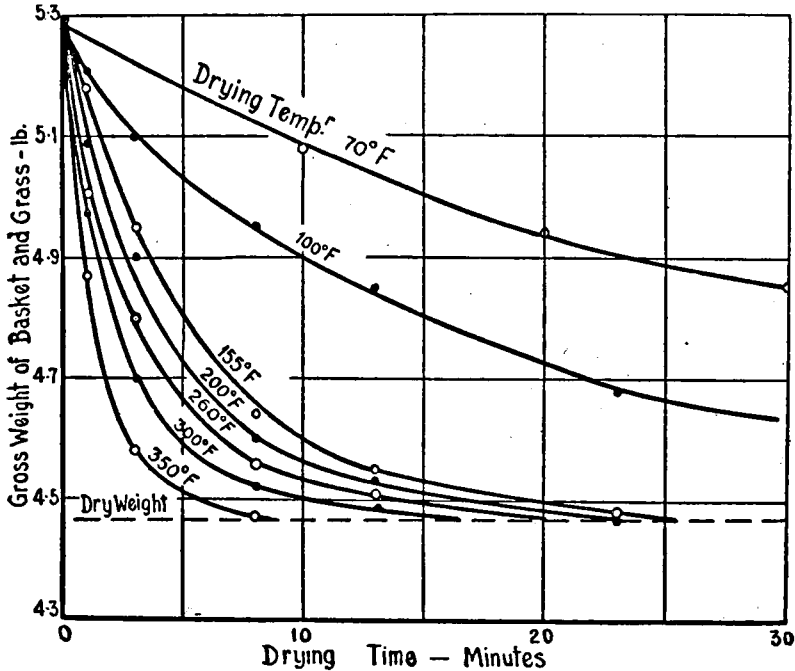


FIG. 63.—Rates of Drying.

Rates of drying were studied at temperatures ranging from 70° F. to 350° F. A typical set of results is given in Fig. 63 for a 3-in. thickness of grass and an air

speed of 5 ft. per second. The curves give the weight of the grass at different stages during drying, for various temperatures. The initial moisture content in all cases was 89 per cent. and it was always found that the rate of drying in the moisture content range 89–70 per cent. was much higher than at lower moisture contents. The effects of temperature were interesting and an outstanding feature was the degree of drying which could be effected by atmospheric air at 70° F. with an average relative humidity of 60 per cent. As can be seen from Fig. 63, with air at 70° F. the moisture content of the grass could be reduced from 89 to 80 per cent., i.e. 40 per cent. of water removed, in the same time as it took to effect complete drying at 260° F.

#### POWER DRYING

These results led us to suggest the idea of power drying or forced wilting, using atmospheric or slightly heated air at least for the earlier stages of drying. This would save fuel and standardise the raw material fed to the main dryer, thus increasing its output and decreasing the cost per ton dried grass. Wilting in the field achieves the same object, but at the expense of some of the valuable constituents of the grass, due largely it appears to the action of light.

In power drying large volumes of atmospheric air would be blown through the grass, preferably in the absence of light. The rate of drying would, of course, depend on the humidity of the atmosphere. The temperature drop available for drying is the difference between the dry and wet bulb temperatures, i.e. the wet bulb depression.

A further step, however, suggests itself. The fan supplying the air for power drying could conveniently be driven by an internal combustion engine, and all of the heat in the fuel could be utilised for drying, by drawing the fan suction over the engine and also leading the exhaust gases into the fan suction. In this way an air temperature always above atmospheric would be assured and the portable power unit would be available for purposes other than drying. This suggestion is put forward mainly as an alternative line of thought to the orthodox furnace fan and dryer system, and is envisaged as applying only to small farms. It holds out possibilities which are worth exploring. As an example it might be possible to power dry the grass to the stage at which it could be chopped and passed to a grinding mill supplied with heated air, and in which the final stages of drying could be carried out. Such a scheme could be arranged for recirculation of the stalky portions and give a selective action in removing the more easily dried leafy portions.

#### UTILISATION OF WASTE HEAT IN GRASS DRYING

In many industries considerable quantities of waste heat in the form of flue gases are available which are suitable for grass drying and could conveniently be utilised for such a purpose.

As an example of what is possible in this direction, reference may be made to a grass-drying plant near Dunfermline, Fifeshire, which utilises the heat in the flue gases from a continuous brick kiln. Previously these gases, at a temperature of 700° F., passed direct to a chimney but now they are drawn off by a fan and led through a lagged sheet metal duct to the combustion chamber of the grass dryer furnace and then after dilution to the dryer. The dryer is a continuous conveyor type. This scheme has been in operation during the past season and has proved most successful.

There is no reason why similar schemes should not be extensively adopted. Many large power stations, for example, are located in country districts and the flue gases rejected from one of these could supply all the heat necessary for several large grass-drying plants.

*Reference*

<sup>1</sup> "Temperature Effects in Grass Drying." A. W. Scott. Journal Royal Technical College, Glasgow. Vol. 4, Part 4, 1940.

## 5. Hop Drying

By A. H. BURGESS, D.SC.  
WYE COLLEGE

Hop cones when ripe contain from 75 per cent. to 80 per cent. of moisture. In order that they may be stored without too much deterioration this moisture is reduced by kiln drying to about 6 per cent. It rises subsequently, during storage, to about 10 per cent.

The cone consists of a central "strig", or axis, closely enclosed by leafy bracts. The leafy bracts dry easily but they protect the strig from contact with the drying air and, consequently, the strig takes a long time to dry.

A typical hop-drying kiln consists of a circular, or square, brick building containing a slatted floor at a height of about 16 ft. above ground level. This floor is covered with a loosely woven horsehair cloth, upon which the hops are placed for drying in a layer 10 to 24 inches in depth.

A current of heated air, the temperature of which must be under complete control, is passed upward through the bed of hops and thence out of the kiln through a cowl, or louvre opening, in the roof.

Some kilns still depend upon natural convection for their draught, but all modern kilns are equipped with fans, which produce a draught of air about 25 ft. per minute velocity through the kiln.

Each kiln load of hops takes about 10 hours to dry; and drying continues at night so that two loads are completed in 24 hours.

Various methods are employed for heating the air, viz., open anthracite fires; open-flame oil burners; stove heaters (either coal or oil fired), and steam radiators. Of these the open fires, in which the products of combustion mix with the air and pass through the hops, have, naturally, the greatest thermal efficiency, heat being lost up the flue pipes where indirect heating is used.

The annual fuel consumption probably corresponds to 10,000 to 12,000 tons of coal.

The problem of air heating is one of considerable importance for many purposes; I do not, however, wish to discuss that aspect of the subject but to confine my remarks to the employment of the already heated air for the special purpose of drying hops.

The market value of hops can easily be very adversely affected by the use of incorrect air temperatures. To obtain the best value it is necessary to commence drying at about 100° F. and gradually raise the temperature, at the rate of about 10° F. per hour, to 140°–150° F. The lower the maximum temperature the higher will be the market value of the dried hops.

At the commencement of drying, when the hops contain their full moisture content and the temperature of the drying air is low, the air as it leaves the hops is about 75 per cent. saturated with moisture, and it continues to carry

a reasonable amount of moisture from the hops for the first hour and a half of the drying process but, as the temperature is increased and the hops become drier, the degree of saturation of the emergent air falls rapidly until, during the later stages of drying when the temperature of the air has been raised to 140° or 150° F., it is only about 12 per cent. saturated and, of this moisture, about 11 per cent. is due to moisture already normally present in the atmosphere. So the moisture removed from the hops at this period raises the humidity of the air by only about 1 per cent.—removing about 1 gm. of moisture per cubic metre of air ; only about 1/90th of its drying capacity being utilised.

It is thus very obvious that the present system is not at all thermally efficient. The cost of fuel consumed in hop drying represents only a very small percentage of the cost of production of hops, and although hop growers, like all other good business men, desire to work on the most economical lines and would welcome a more efficient system of drying they have not viewed with great concern the heat losses in their kilns. What they are keenly anxious about is that the quality of their hops shall not be adversely affected in the process of drying, and this is reasonable when we realise that a kiln load of hops may be worth, say, £130 and the cost of the fuel required to dry the load, using the present system of drying, less than 20s.

In considering how the efficiency of the hop kiln can be increased the idea of recirculation of the air during the later stages of drying immediately presents itself. This has, however, already been tried but has been found to be ineffective for the following reason :—

The “strig”, or axis, of the hop cone contains a considerable amount of moisture long after the bracts have become dry and it is the removal of this moisture from the strig which occupies the later period drying. Owing to the fact that the dry leafy bracts are very hygroscopic, they will actually absorb moisture from the air unless it is of very low relative humidity, and if air is recirculated this re-absorption process takes place and drying is greatly retarded.

It is, therefore, necessary to look in other directions for a more efficient system of drying. In my opinion, the solution lies in the use of a continuously acting dryer instead of the batch drying kiln at present in general use. This would also result in more uniformly dried hops. At present the hops in the lower part of the load are dried to a greater extent than those in the upper layers of the load.

In such a dryer the hot air would enter at the point of exit of the dried hops and would leave, with a high degree of saturation, at the point of entry of the undried hops.

The design of such a dryer is an engineering problem. Points which have to be borne in mind in designing a dryer of this kind are :—

*Firstly* : Hops require a certain minimum time to dry due to the fact that they are still living when placed in the dryer and, also, to the fact that time is necessary for the moisture to diffuse from the strig into the air stream. Under the temperature conditions which are essential to obtain a product of high market value this minimum time is about 5 hours. Hops would, therefore, need to remain in the dryer for this period, which would entail either a considerable length of passage through the dryer or a very slow rate of movement.

The rate of drying could be speeded up if it were possible for the hops to be killed before drying, but at present no satisfactory method of doing this without detriment to their brewing value has been found.

*Secondly* : The temperature of the air will fall as it passes through the dryer and, as its temperature falls, the hops, which it meets coming in the opposite direction, will have increasingly higher moisture contents. This combination of circumstances is to be desired, but it will be necessary to design the dryer so that this fall in temperature of the air will correspond with the temperatures which are most suitable for hops with their different moisture contents in course of passage through the dryer.

*Thirdly* : The hop-drying season lasts only about three weeks ; it is, therefore, of importance that the capital cost of the dryer should be kept low. If, however, a dryer could be devised which would be capable of dealing with other farm products, e.g. grass, grain and fruit, as well as hops, a greater capital expenditure could be justified.

## 6. Power Saving with Special Reference to Tractors

By H. J. HAMBLIN

NATIONAL INSTITUTE OF AGRICULTURAL ENGINEERING

The most important power unit in agriculture is the farm tractor. Tractors use something like 200,000,000 gallons of liquid fuel a year and I want to consider briefly the practical approach to economy in the use of this fuel. I propose to deal only with the use of the tractor in the field, because, on the one hand, this is where a large proportion of the fuel is used and, on the other, it is in the field that wastage of fuel can most easily pass unnoticed.

I am not going to discuss the relative merits of different fuels, because I think it would only confuse the issue. At the same time it may not be out of place just to mention that the advent of jet propulsion may affect farmers, since jet power units run on the kerosene for which, up to the present, no one appears to have envied the farmer. It remains to be seen how great the demand will be or what effect it will have on the supplies available for farm tractors.

Two essential differences between farming and other industries must be borne in mind in considering fuel economy on a farm. Firstly, the farmer has not by any means complete control of his manufacturing conditions. This is, of course, very obvious (especially this year), but not, I think, always really appreciated by those outside the industry. How would the management of a motor-car factory get on if the programme for a given day depended not only on the weather prevailing at the time, but also on what it had been like for the past few months ? This is, admittedly, a fanciful idea, but it serves to emphasise the difference between farming and industry. The second essential difference is that the farmer has no administrative staff, and he cannot be expected to be an expert fuel watcher ; he has neither the time nor the specialised knowledge. He is already Jack of all the trades that go to make up farming. These considerations argue that the right approach is along broad general lines.



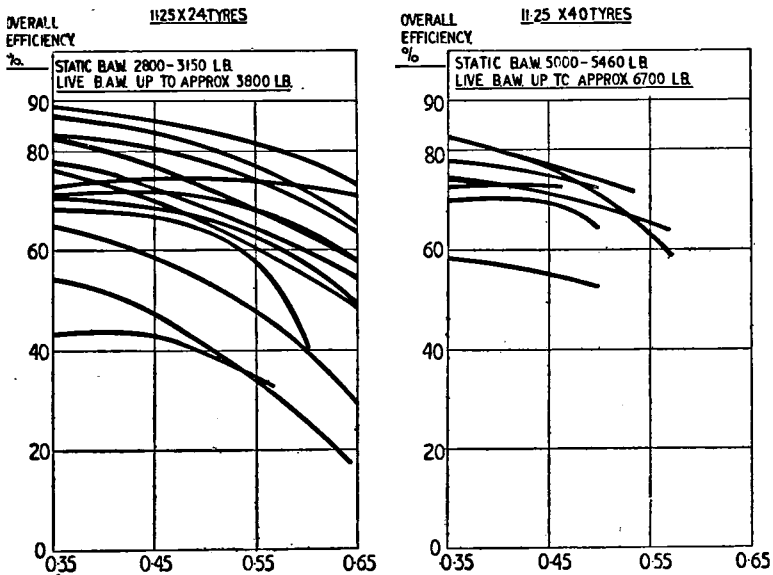
Efficient tractor operation depends on three things :—

- (1) Loading the engine economically.
- (2) Getting good tractive efficiency.
- (3) Using efficient implements.

A study of each of these will show the guiding principles which give efficient operation.

For example, to load the engine economically the operator should regard his gear lever not as a device for changing the forward speed but as a means of adjusting the load on the engine. He should work in the highest gear possible and then get the correct speed by means of the variable speed governor. To enable him to do this the designer should provide as good a choice of gears as possible and a flexible engine with the right characteristics—in particular, with a peak torque at a slow speed.

To get good tractive efficiency, particular attention should be made to the use—or misuse—of pneumatic tyres, since they can be very inefficient if used incorrectly. (I do not propose to say anything about tracks or half-tracks because they give good efficiency on the heavy work for which they were designed.) The two points about pneumatic tyres that need emphasising are, firstly, that they can only be relied upon to pull about half their weight and, secondly, that it pays to use the right amount of ballast.



DRAWBAR PULL ÷ ESTIMATED LIVE B.A.W.  
(N.A.I.E. Diagrams).

Fig. 64.—Overall efficiency at various values of P/W.

Fig. 64 shows the sort of performance obtained in practice. The family of curves on the left relates to 11.25 × 24 tyres carrying a static load of about 3,000 lb.; that on the right, to 11.25 × 40 tyres carrying a static load of 5,000 lb. Each individual curve shows the efficiency of one of the tyres for various values of the P/W ratio on one set of ground conditions, and the curves

cover a very wide range of conditions. Practical values for the P/W ratio to give a reasonable all-round performance are only about 0.4 for the smaller and 0.5 for the larger tyres.

The problem of balancing engine power, size of tyre and weight so as to produce an economical unit is, of course, a matter for the tractor designer. The second point—of adjusting the ballast to the job—affects both operator and designer, since the designer should provide easily adjusted ballast for the operator to use. Fig. 65 shows the effect of weight on the efficiency of  $11.25 \times 24$  tyres. The maximum efficiency is much the same in each case, but it occurs at a drawbar pull of just over 1,000 lb. with the lighter weight and at a pull of not much under 2,000 lb. with the heavier. At a pull of 500 lb. the efficiency with the lower back axle weight is almost 60 per cent. as compared with about 45 per cent. for the heavier. At a pull of 1,900 lb. the position is reversed; the heavier gives 68 per cent. efficiency and the lighter only 46 per cent. Thus it is obviously worth while to make the ballast suit the job and the provision of easily adjusted ballast is evidently a desirable feature from the point of view of economy.

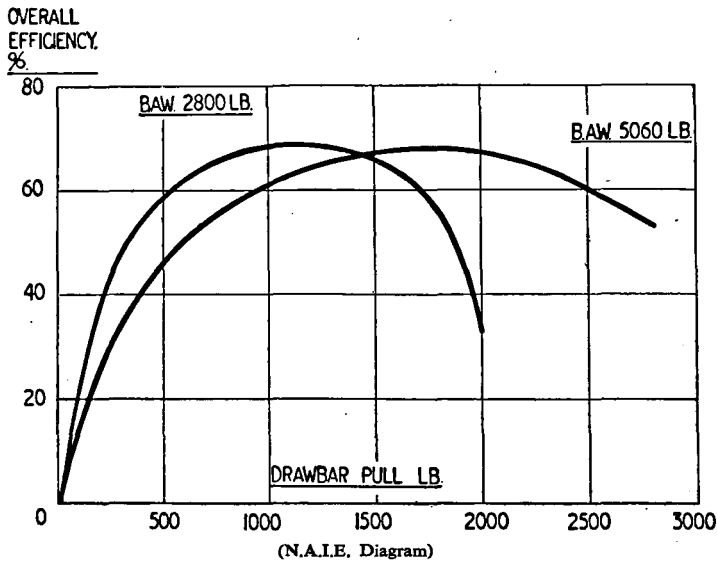


FIG. 65.—Heavy land. Grass. Wet and soft.  $11.25 \times 24$  tyres.

Before leaving the question of tractive efficiency, two examples may be mentioned of methods which have been used in overcoming adhesion difficulties. The first is that used on a marl spreader developed by Rotary Hoes, Ltd. Their problem was to haul 5 tons of marl across a field of fallow, and they overcame it very satisfactorily by taking a drive from the tractor to the axle of the spreader. The second, used by the N.I.A.E. in demonstrating how a small horticultural tractor could be used for deep ploughing, was a revival of the old cable ploughing with the important difference that the winch was mounted on the plough so that only one operator was required.

The third factor affecting fuel economy is the use of efficient implements. One aspect of this is correct maintenance and setting, and using the correct

width or type of implement to provide an economical load for the tractor—or ganging implements together for the same purpose. This aspect is stressed by the Machinery Instructors attached to County Agricultural Executive Committees.

A longer-term objective is the development of new machines or methods of working to give the same results with the expenditure of less power. In Germany, there is an interesting trend towards light design in agricultural machinery, for example, a 3-ton trailer which weighs only 10 cwt. There is room for a good deal of development on these lines ; the eventual result would be an appreciable saving in fuel on account of the reduced tonnage of machinery moved over the land. The N.I.A.E. built a 3-furrow mounted reversible plough solely to determine whether any saving of time and fuel could be obtained by using it rather than any of the types already in production.

These are the general lines on which an approach can be made to power saving and fuel economy in the use of farm tractors. At the present time much can be done by the operator keeping in mind such points as working in the highest possible gear, varying the ballast for light and heavy work, maintaining and setting his implements correctly and so on. Looking further ahead, such problems as improvements in the matching of power units and wheel equipment on a tractor, lighter methods of construction and new methods of working await the attention of the designer and research worker.

## 7. Dairying—Fuel Economy in Sterilisation

By H. S. HALL

NATIONAL INSTITUTE FOR RESEARCH IN DAIRYING

Milk is an important factor both in the economy of British agriculture and in the health of the nation. In the interests of the producer it must reach its market in a sweet condition. In the interests of the consumer, not only must milk have a reasonable keeping quality but bacteria responsible for disease or processing difficulties must be eliminated as far as possible. The most important factor in the control of bacterial growth is the proper cleaning and sterilisation of the utensils used on the farm. Opinion in this country over the past 25 years has favoured sterilisation by means of steam because it offers a reasonably simple technique with an adequate margin of safety. Probably over 50 per cent. of the milk produced in England and Wales comes from farms equipped to use this method.

### STEAM PRODUCTION

Farm conditions generally are not conducive to the high efficiencies of steam production which the industrial user expects and attains. The equipment necessarily is of small capacity and operated only for an hour or so either once or twice a day, a factor which results in unavoidable heat losses particularly where a solid fuel is used. The operator is not usually skilled in boiler maintenance : accommodation for both the equipment and the fuel is often deficient in more than one respect. The results obtained must therefore be judged with these factors in mind.

The object of the sterilisation process is to heat the surfaces which may come into contact with milk to a temperature which is lethal to bacteria.

The fundamental problem, therefore, is one of supplying an adequate number of heat units to do this. Since some 80 to 90 per cent. of the total heat of steam is latent heat of formation, the object is to create conditions where the steam readily condenses on the surfaces to be sterilised, so giving up this latent heat. It is convenient and satisfactory to carry out this operation at approximately atmospheric pressure, consequently it is not necessary to produce steam at high temperatures or pressures—fairly dry saturated steam at very low pressures is all that is generally required. Indeed generation at high pressures, and therefore high temperatures, necessarily leads to greater heat losses, and steam so produced is much more easily wasted under working conditions on the farm. Sterilising equipment may consist of a boiler supplying steam to ancillary equipment in or by means of which sterilisation is effected. Alternatively several forms of self-contained sterilisers are on the market.

Solid-fuel fired boilers are generally of a simple vertical type. The equivalent evaporative capacity of the majority is between 50 and 150 lb./hr. and working pressures of nil to 60 or 80 lb./sq. in. are used. Larger boilers may be used on some farms. Under good conditions a steaming efficiency of 50 to 60 per cent. could be expected but this is frequently—if not usually—seriously diminished for the reasons quoted above. Most serious of these factors is the short time of operation. The weight of fuel required to bring the boiler up from cold to working pressure is usually from one to two times the fuel burned during one hour's steaming. Thus in practice the overall efficiency is seldom better than 25 per cent. This cannot be avoided; the best that can happen is the development of a nice judgment in firing no more fuel than is necessary, that is completing the operation with the minimum of residual firebed and steam or water reserve.

Gas firing is very infrequent as few farms have a gas supply. Oil firing is however slowly increasing and special designs of boiler are now coming forward. Apart from the saving in labour, the overall efficiency should be higher than that of a solid-fuel fired boiler as there is no loss through residual fuel at completion of sterilisation.

Electric boilers may be of the immersion heater or floating electrode type. There are several designs of the former with loadings from 9 to 36 kW operating at 15 lb./sq. in. working pressure; the one design of the electrode type operates on 20 kW with a working pressure of 30 lb./sq. in. These boilers are generally insulated since their evaporative capacities are necessarily low; radiation losses must therefore be kept to a minimum. In practice an equivalent evaporation of 3 lb./kWh, can fairly easily be obtained—an efficiency of 85 per cent. The electrode boiler probably has the best overall thermal efficiency of all farm boilers since only a small part of the water capacity is left at high temperature.

The steam produced must be conveyed to the point or points of utilisation. Long runs of connecting piping result in high heat losses, and if of inadequate diameter, call for higher working pressures to give the required mass flow rate. It is essential therefore that this distance be short and  $\frac{3}{4}$ -in. or 1-in. tube be used. Electricity shows to advantage here since an electric boiler, unlike the oil or coal-fired boiler, can be placed in the same room as that in which the steam is used. This feature is emphasised in the self-contained electric sterilising chest in which a small steam generator is attached directly to the chest. The working pressure is practically atmospheric and a much lower evaporative

capacity can be used because transmission losses are avoided and the complete apparatus can be efficiently insulated. A longer time may be required to complete the sterilising operation but in spite of this opportunity for greater heat loss, the equipment is probably the most efficient thermally of all the types under review. The longer time does not normally involve additional labour, in fact less may be required if automatic switching is used. At least one self-contained steriliser using solid fuel is now on the market, being so designed that the chimney and fire door can be outside the sterilising room in which the equipment is placed. Here again residual heat losses are low.

Some efforts have been made to introduce the electrically-heated storage boiler. This has the advantage of a good load factor which is attractive to the supply undertaking but the thermal losses over 24 hours may be considerable and may exceed the losses of a boiler operated in a normal manner.

#### UTILISATION

It is usual to sterilise milking utensils and similar articles in the sterilising chest ; the small producer-retailer may also sterilise milk bottles by this method. The criterion for this operation is the maintenance of the chest and contents at a temperature of 210° F. for ten minutes for utensils and 15 minutes for bottles. Steam consumption for this operation varies widely and depends upon the size of chest, weight and character of contents and the conditions of installation insofar as they affect heat losses. Sterilisation may also be carried out by indirect application. In the case of churns, inversion over a steam jet for two minutes is usually adequate. Teat cup clusters are usually sterilised by passing steam through for two minutes after 210° F. is reached at the outlet. The rate of steam supply necessary in these cases is quite small under reasonable conditions—of the order of  $\frac{1}{3}$  lb. per minute. It is therefore extremely easy to waste steam on such an operation by a margin of several hundreds per cent. Non-detachable coolers are steamed *in situ* preferably by using metal covers which, while not pressure tight, confine the steam to parts to be sterilised. If a brine cooler, the brine should be drained for this operation or at least prevented from circulating. In direct expansion coolers, of course, provision must be made for the increase of internal pressure consequent on steaming.

Pipeline milking machine installations are also sterilised by direct application of steam. After thorough washing steam is passed into the system in order to heat all milk contact surfaces. A period of three minutes should elapse after the temperature of the issuing vapour reaches 210° F. at every outlet. It is usually possible to carry out this operation piecemeal if desired and thus quite small rates of steaming can be adequate if the additional time involved is allowed. However, in view of the comparatively large radiation losses from the piping and equipment and the extremely variable ambient conditions which may obtain, a steaming rate of not less than 1 lb. per minute for a three-unit plant should be allowed. Assuming the steam is fairly dry, the pressure at which it enters the systems in order to obtain this flow will be something less than the 1 lb./sq. in.

#### PROCESS EFFICIENCY

As a bactericidal process steam sterilisation of milking equipment on the farm is undoubtedly extremely efficient. As a thermal process however it is

usually the reverse. The summarised heat balance of a coal-fired installation such as has been described approximates to the following :—

<i>Losses</i> , including radiation, waste steam, flue gases, etc. . . . .	85 per cent.
<i>Residual heat</i> in boiler and equipment, usually lost as radiation . . . . .	14 " "
<i>Useful heat</i> applied to utensils to be sterilised . . . . .	1 " "
<i>Heat supplied</i> in total fuel consumed . . . . .	<u>100 per cent.</u>

A similar analysis for the self-contained electric sterilising chest might show :—

<i>Losses</i> , including radiation and waste steam . . . . .	68 per cent.
<i>Residual heat</i> in equipment, usually lost as radiation . . . . .	25 " "
<i>Useful heat</i> applied to utensils to be sterilised . . . . .	7 " "
<i>Heat supplied</i> as electrical energy . . . . .	<u>100 per cent.</u>

From the national point of view however this must be qualified by recognising the losses involved in producing electricity from coal and transmitting it to the farm. Expressed in terms of the heat of the coal burned to produce the electrical energy used, the figure of 7 per cent. is reduced to just over 1 per cent.

From the fuel economy point of view it is evident that this process is a difficult one. Certain losses are of course inevitable but much can be done to minimise these. Oil or electricity are probably better suited to farm conditions than a solid fuel because they eliminate the need for stoking skill. There is a growing realisation that good accommodation is necessary for the equipment. The value of insulation is not generally realised though this probably can make a bigger contribution to fuel economy than any other single factor. While due attention must be paid to the prospects of expansion, equipment which is unnecessarily large for the job is wasteful in every respect. Above all, the technique of utilisation is of the greatest importance and this requires not only a thorough understanding of the process but a strict attention to daily routine.

## 8. Electric Heat for Agriculture and Horticulture

By C. A. CAMERON-BROWN, B.SC., M.I.E.E., M.I.B.A.E.

The speaker pointed out that electricity is not generally used as a major source of heat in agriculture and horticulture, though there are possibilities in this direction in intensively-heated glasshouses. Its main contribution is to ease the manpower position by reducing labour and by improved amenities—this last being a substantial factor in retaining labour on the farm.

There would appear to be some 70,000 agricultural holdings in England and Wales having main electricity supplies. The average consumption including domestic usage is 4,000 kWh. It is anticipated that the consumption per holding may rise to double this figure and that within the first 10 or 15 years during which unfettered development is possible, a total 250,000 holdings

may receive a supply of electricity. This estimate suggests a total agricultural and horticultural consumption of electricity of 2,000 million kWh a year. The price visualised is  $1\frac{1}{2}d.$ , or possibly  $1\frac{1}{4}d.$  a kWh.

#### LINES OF DEVELOPMENT

The principal use for electricity is in milk production.

The average herd requirements for milk sterilisation will be met by self-contained steaming chests with built-in electrically-heated steaming units; these, with hot-water storage, will supply steam and hot-water requirements on a farm for about 8,000 kWh. a year. Central recorder milking plant, when in use, involves the same total quantity of steam for chest sterilisation with, in addition, sterilisation of the recorder equipment. A 3-unit recorder, regarded as fairly typical, using a 27 cu. ft. chest for utensil sterilisation, would require for sterilisation and hot-water requirements some 15,000 to 20,000 kWh a year, assuming two complete sterilisations a day. The foreseeable future drive towards higher standards of hygiene gives no cause to anticipate any reduction in these figures.

The importance of the load factor in electrical practice suggests the use of storage steam plant, operating during off-peak periods to build up a reserve of steam for the day's operations. Storage units loaded on a range of, say,  $1\frac{1}{2}$  kW, 3 kW, and 6 kW could between them cover the whole range of farm steaming requirements.

It will be highly important to educate the farm worker in the proper use of his equipment, and particularly to use steam only when necessary. Whilst farm workers can be trained, there is serious need for tackling the problem at the source at every agricultural college, teaching or training institution. The colleges should be equipped with all modern types of steam-raising and sterilising equipment and should learn what are modern steaming requirements.

It is likely, if conditions favour it, that milk will be pasteurised or heat-treated on the farm, though this development is not yet in sight.

Direct power requirements connected with milk production—for milking, cooling and water supply are under 5 h.p., with a consumption of 1,000 to 2,000 kWh a year.

#### THE FARMSTEAD

There can be a wide variation in the equipment and demands in the prosecution of the everyday round-the-farm-building tasks. These can vary, from nil in the pre-war days when all feeding stuffs were brought in ready-prepared, to a connected load of 50 or 60 h.p. where large hammer-mill grinding and threshing are done. If a self-contained farm-feeding-stuffs economy is maintained, and there may well be good reason to encourage this, nothing much can be done to reduce consumption, which in any case is not likely to be very substantial. Something can, however, be done to reduce the load demand for grinding by using the modern small (3 h.p.) automatic hammer mill used more or less continuously in place of the large mill taking anything up to 30 h.p. or more, used intermittently.

The other large power demand, threshing, is not so easily reduced, but much could be done to develop the idea of fully mechanised built-in threshing, using the modern small thresher. Power-driven mills are likely to increase in use, but their power demands are modest—rarely over 5 h.p.—and the total consumption small. Chaff-cutters and root-cutters are now far from general in use, and again the power and the consumption are small. Hoists and

elevators are essential, and will increase widely in installations, but their power demand is small as is the aggregate consumption.

#### GRAIN DRYING

The all-electric grain-dryer presents the largest single load in farming, but less than a dozen of these machines are as yet installed. Advantages lie in the direction of operating, convenience and precision of heat conditions, though the direct running cost is high. Since the tendency is for the plants to be operated at the period of winter peak load, they are not very attractive to supply companies. The electrical industry, therefore, watches with considerable interest the progress of two lines of development :—

- (1) Continuous automatic drying by small dryers at from 30 to 60 kW loading;
- (2) Long-period drying in bins by continuous blowing with air slightly warmed or, rather, de-humidified.

The in-bin method holds out the higher attraction and because of the long-period running and automatic control required the whole thing would only be practicable on an all-electric basis. It holds promise if only because several in-bin installations have been run successfully using cold air only. Askham Bryan rightly, however, draws attention to the dangers in cold air blowing only, and the additional safeguard of a slight warming should put the whole thing on a universally sound basis.

The main thing to recognise, however, is that with any simplification of drying on the lines indicated, and the introduction of smaller units, not only will there be a substantial change-over to all-electric drying, but a large number of smaller growers, who would not consider installing dryers of the present-day types, would then instal drying equipment. It would indeed, not be unreasonable to expect something of the order of 2,000 all-electric drying units, averaging, say, 150 tons of drying per annum and at average consumption of 50 kWh per ton aggregating 15,000,000 kWh.

#### GRASS DRYING

Electrical heating has not been applied to grass drying.

#### HAY-DRYING

Investigations are now in progress upon two methods :

- (1) The American batch system of blowing hay, secured and housed after one day's wilting and thereafter dried off by continuous blowing with no further loss of colour;
- (2) The Swedish (Edholm) method of "continuous" drying by feeding each daily cut of wilted hay into a blowing unit which it leaves in due course at the end of three days.

These methods would presumably be linked with some degree of humidity control, probably restricted to night-time. Being a summer load it would be off-peak. The solution of the hay-conditioning problem would appeal to every owner of a milk herd and if a successful method could be secured the author asks if a total demand of 2,500,000 kW and consumption of 1,000 million kWh would be a reasonable guess for the potential load.

#### GLASSHOUSE HEATING

The heating of large commercial glasshouses ranks with grassdrying as probably the most difficult field in which to make a case for electrical operation.

The operational advantages of electrical heating pre-dispose glasshouse owners to favour electricity, however, and in smaller houses, owner-operated,



where current costs about  $\frac{1}{2}d.$  a unit and temperature control is essential (i.e. propagating houses), electricity will continue to be applied. The better control secured by electrical heating often enables the "target" temperature to be reduced.

It is anticipated that in due course practically all amateurs' greenhouses will be electrically heated.

#### SOIL WARMING

Electricity is particularly suited to soil warming. The main lines of application are :

(1) Hot-beds—the gentle warming of soil in frames under lights to produce early spring salad crops. This has been taken further to provide propagating beds for the raising of plants;

(2) Pre-warming of glasshouse soil to produce the optimum soil condition for planting tomatoes;

(3) Warming glasshouse soil during growth of crops;

(4) Warming of soil under cloches in the open.

The first two have been developed in technique and economy to the stage of commercial application. The latter two have not yet been fully investigated to the stage of definite authoritative conclusions and recommendations being made.

(1) The soil-warmed hot-bed has been found to be a practicable and economic way of producing early salad crops. The specific loadings are low—not exceeding 5 W per sq. ft. and usually below  $3\frac{1}{2}$  W per sq. ft. or 150 kW per acre. Furthermore, these loadings permit off-peak running at night only, the consumption for the growing season—January to March—being of the order of 108,000 kWh per acre. It may well be that this is a more economic ultimate use of coal than raising lettuces in glasshouses with slight heat.

(2) The pre-warming of tomato-house soil for planting was developed not only to cut down the time required for this purpose, but, and mainly, to cut down the cost and coal consumption by the traditional means of running the ordinary glasshouse heating system for a period which, in many areas, may be as long as four weeks. For normal work a loading of the order of 5 W per sq. ft. is used and a continuous warming up of 24 or even 30 hours may be necessary. If off-peak running is insisted on, a higher specific loading might enable the warming to be done in one night or in two successive nights. The houses should not all be treated at the same time but one after another. This method will reduce the maximum demand and, where the low voltage system is used, enable a smaller transformer, which can be moved from house to house in rotation, to be employed.

(3) Direct warming of glasshouse soil enables the glasshouse temperature to be reduced and thus effects a total economy. Soil-warming of this kind can be done at from  $3\frac{1}{2}$  to 5 W per sq. ft. on night running only.

#### SOIL STERILISING

In the "electrode" method current is passed directly through the soil. In the "immersion" method insulated heaters are placed in the soil, which is warmed by conduction. The electrode method is rather unpredictable as to loading, since this depends on soil consistency and moisture content, but loading is of the order of 2 to 3 kW per cwt. The immersion method is still in the stage of experimental investigation in this country, but loadings of the

order of 2 to 3 kW per cwt. are probable. Consumption for both systems is of the order of 1.5 to 2 kWh per cwt.

#### IRRIGATION AND SPRAYING

The largest power uses in horticulture are for irrigation and for control-spraying of fruit. These call for units up to 50 h.p. and sometimes over, depending on type of plant and scale of operation.

Irrigation or field spraying is a continuous process over long periods and the consumptions are of the order of 60 to 80 kWh per acre per inch of "rain", although these consumptions can be substantially exceeded by certain types of plant and layout. Much of this application could be made at night since the actual deposit of the "rain" is controlled automatically.

Control spraying of orchards depends on manual control of the sprays and can therefore only be operated during normal daylight working hours. Part of the spray application takes place in winter and would coincide with normal peaks.

#### POULTRY FARMING

This industry will no doubt expand again, but no figures appear to be readily available upon which to base even a rough assessment of the probable loads and consumptions. In one department, however—the basic production of day-old chicks—it is doubtful whether there will be any appreciable increase over the pre-war installations which were capable of turning out vastly increased numbers. The bulk of this production is in large specialised units or "hatcheries", a substantial proportion of them being in the North. These units employ large cabinet or "mammoth" incubators operated electrically and with individual loadings up to 4.4 kW and in the larger installations in batteries of as many as ten cabinets.

Equipment of this kind working "all out" but allowing an annual overhaul period could account for an annual consumption of 27,000 kWh per cabinet.

The author estimates the annual possible use of electricity in poultry farming as follows :—

	<i>Annual current required kWh</i>
Hatching 570,000,000 head of table birds . . . . .	57,000,000
Rearing above day-old chicks to four weeks old in battery brooders . . . . .	19,000,000
	<hr/> 76,000,000 <hr/>

Egg production depends too much on Government import policy for a guess to be made of probable current consumption. It is likely, however, to be much less than in the case of table birds. Individual unit loads are not likely to exceed 1,500 W for incubating and 300-400 W for rearing with aggregate loadings in single installations probably not exceeding 7,500 W and 10 kW respectively.

The author considers that equipment for the production of pedigree stock may well become all-electric, but the loads and consumptions will be relatively small.

## 9. Glasshouse Heating, with Special Reference to Tomato Growing

By D. STEWART

In Scotland commercial growing of tomatoes is only possible under glass and with the application of heat over the whole growing period.

The houses are roughly 16-ft. wide, frequently up to 250-ft. long, 5-ft. to the eaves and 10-ft. to the ridges. Ventilation is by window openings along the ridges by manually-operated control gear at the ends of the houses. In large farms, the houses are divided into blocks containing 10 to 12 houses, without intervening partitions, while separate heating arrangements are usually arranged for each block.

Seed is sown in shallow boxes in December, and in January the young plants are picked and potted, to be placed in a forcing house. As they grow, they are dispersed to provide more space and light. In March they are planted in the ground throughout the farm, the soil having been previously warmed to 55°–60° F., 1 ft. below the surface. Apart from all the other attentions necessary, the temperature of the houses must be maintained from 65°–75° F. till the cropping is complete. Every effort is made to obtain tomatoes for the early markets, as the price obtained falls rapidly as supplies increase. The fruit is taken from late May to early October, after which the pipes are emptied against frost, and the work of preparing the ground for the following year is begun.

Sterilisation of the soil must be systematically carried out to ensure good crops and the general practice is to cover the whole area every year, although in the South it may be found satisfactory to sterilise less extensively. Steam is the most suitable soil-sterilising agent. The earth is removed to a depth of some 18-in. and a grid laid down covering 30–40 sq. ft., with jets downwards. The earth is filled in, covered by a tarpaulin and steam at 80 lb. pressure is maintained for 30–40 min., with the ground temperature raised to over 200° F. Approximately 25–30 tons of coal will be consumed in sterilising each acre of ground.

A vertical or portable boiler may serve the needs of a farm of, say, 50,000 sq. ft., but when the area increases appreciably, a Lancashire boiler becomes the more suitable installation and readily performs the double purpose of heating and sterilising.

The extent and contour of the ground very largely determine the principle of heating, the two common methods of maintaining glasshouse temperatures being these :—

(1) *Low-pressure hot-water boiler* with 4-in. flow and return pipes. A single boilerhouse may contain the boilers for the whole of a small farm, while in a large establishment, a boilerhouse may serve one or two blocks arranged for all systems to connect to larger common flows and returns. It is, of course, possible to make use of the sterilising boiler, where the heating boilers cannot cope with severe weather.

(2) *Steam to water systems*, where Lancashire boilers serve both heating and sterilising needs and where the 4-in. pipes are filled with water, and steam introduced to raise the temperature by means of jets or circulators.

Jets were common, where flow and return pipes existed, but circulators are more satisfactory if employed with closed circuits. The circulator consists of a cast-iron body, spigoted or fauceted to receive the pipes, containing three nozzles with a steam jet arranged to each, steam being individually adjustable, but controlled by a 1-in. supply valve. The nozzles vary in size—small, medium and large—and a circulator, according to capacity, may heat from 400 to 2,500 ft. of 4-in. pipe or 95,000 to 595,000 B.Th.U. an hour, by condensing 95 to 595 lb. of steam an hour. It is not good practice to alter the undulating nature of the ground within the houses, and the employment of circulators allows the pipes to follow the ground, open air venting being necessary only at the first highest point, the condensate being taken at the return side of the circulator.

The condensate should be returned to the boiler feed by pipe directly or, preferably, by an expansion tank on each block of houses, with a capacity suitable to the amount of piping. Initial planning of the houses should include the pipe flow. The control of the house temperature is sufficiently accurate by manual manipulation of a main control valve or valves, as the space temperature response is rapid in comparison to the low-pressure hot-water boiler. A stoker is always on duty and recording thermometers usually form part of the equipment.

For every 100 tons of tomatoes there will be a coal consumption in the region of 550 tons annually.

Other methods of heating have been tried, but for simplicity, efficiency and suitability for the type of labour employed, the 4-in. hot water pipe system would appear likely to find favour for some time to come.

Some ten years ago in the South-West of Scotland, eleven houses were fitted with very small unit heaters, specially designed for the experiment. The reasons for the try-out were to find if the plants would crop earlier and to ascertain the advantages of close thermostatic control, in addition to those of a clear ground area, free from pipes, for tillage. It was found that, as the plants grew in the vicinity of the heaters, they had to be trained away from the hot air discharged from the units; that the results obtained did not warrant departure from the hot water pipe systems; and that glasshouse labour favoured the simpler installation.

Some years before the war, thermostatically-controlled oil burners were also employed with low-pressure hot-water boilers, but the tomato prices then prevailing were not sufficient to cover oil costs.

Anthracite, because of its easy banking, clean and slow burning characteristics, is the favourite fuel for low-pressure hot-water boilers. The fires are banked overnight unless in very severe frosts, experience dictating the method of banking fires and fixing dampers.

Lancashire boilers consume poor qualities of dross and the following figures are careful 1934/35 comparisons, the feet referred to being the total length of all respective houses :—

11,000 ft. of glass, sectional boiler, 1,000 tons anthracite	£1,400
10,000 ft. of glass, Lancashire boiler, 1,028 tons dross	£720
10,000 ft. of glass, 598 tons oil	£2,500

A change from oil to anthracite approximated to the first cost. The steam to water heating by Lancashire boilers indicates substantial savings, after adequate allowance for additional wages and depreciation.

Although there is a close proportionality in the extent of glass and fuel consumptions, there is no connection between the figures already given, and those that follow ; the farms being in different areas and under different ownership.

Low-pressure hot-water boilers.

10,000 ft. of glass.

Fuel—Anthracite

1935/36.	862 tons, 14 cwt. ; price at pit, 28s. per ton	. £1,266 9s. 0d.
1938/39.	880 tons, 6 cwt. ; price at pit, 36s. per ton	. £1,465 2s. 2d.
1945/46.	807 tons, 14 cwt. ; price at pit, 54s. 4d. per ton	. £2,387 15s. 1d.

Lancashire boilers—Steam to water heating

(including sterilisation of  $7\frac{1}{2}$  acres)

11,000 ft. of glass.

Fuel—Dross.

1935/36.	1,065 tons 19 cwt. ; price at pit, 10s. per ton	. £866 0s. 9d.
1938/39.	1,271 tons 11 cwt. ; price at pit, 16s. per ton	. £1,091 13s. 10d.
1945/46.	1,494 tons 8 cwt. ; price at pit, 34s. 5d. per ton	. £2,770 15s. 3d.

The lesser consumption of anthracite in 1945/46 was due to shortage of supply, while the higher consumption of dross is due solely to the poor qualities which were supplied, and, at the same time, cost was almost three times that of 1935/36 and more than twice that of 1938/39. Difficulties in securing suitable and sufficient fuels during the war years have given many anxious moments to growers, as failure to maintain a suitable temperature continuously, may, within a day, ruin the entire crop. The use of Lancashire boilers, with their ability to consume inferior fuels, may offer a partial solution to the present fuel supply position, and it is possible that the future policy of the Ministry of Fuel may be to designate the fuels which will be made available for horticultural purposes at reasonable and controlled pit-head prices, according to thermal values.

## 10. Artificial Rain

By L. KINNELL

It might be thought that the average rainfall in Great Britain was adequate for the growth of all crops without the aid of artificial watering equipment, but the intensive home production now necessary requires adequate moisture to be available on demand.

The number of plants installed for the production of artificial rain over intensive market gardens and crops under glass is rapidly increasing, it being found that such plants are well worth their capital outlay, even if they are in operation for a few weeks only during the year. The main reasons for this are as follows :—

- (1) They provide insurance against drought occurring at a critical growing period.
- (2) Moisture applied at the right time and in a natural manner increases the tonnage yield per acre, the rate of growth and the quality of the crop.

(3) The system can be utilised as a vehicle for the application of fertilisers and nutrients.

(4) On certain "hot" soils, it is impossible to grow vegetable crops without heavy application of humus in the form of dung. Whilst it is not claimed that such manures can be entirely superseded, artificial rain plant forms a valuable auxiliary in these times of acute dung shortage.

This section of horticultural engineering is known as "overhead irrigation" and whilst the total power, or fuel, consumed in a given period may be small, compared with other farm requirements, the installed h.p. forms a large percentage of the total power requirements of the farm or nursery. Therefore, the correct design of these installations is important.

These notes deal with the problem in two sections, for outdoor crops and for crops under glass.

#### IRRIGATION OF OUTDOOR CROPS

A typical overhead irrigation plant can be divided, for the purpose of description, into three parts :—

- (1) Rotary sprinklers or spray-lines, portable or fixed, for delivering water over the land in the form of spray.
- (2) A system of distribution mains, standpipes and valves.
- (3) A source of water, and pumping plant.

#### SPRAY-LINES

Spray-lines are manufactured in 16-ft. lengths, fitted with instantaneous couplings and nozzles, and are either rotated by hand at intervals or automatically by means of an oscillating water motor. For salad and root crops the spray-lines are set up in runs up to 600-ft. long and 40 to 50-ft. apart, the nozzle arrangement being designed to give rates of rainfall from 1-in. to 1½-in. in eight hours, according to crop and the soil absorption rate.

#### DISTRIBUTION SYSTEM

The water is conveyed to the spray-lines inlet through a system of trunk and distribution mains, standpipes and valves. In certain cases it is convenient to use portable mains such as the Victaulic.

#### POWER REQUIREMENTS

Each plant must be designed to suit the type of crops to be grown, the area to be irrigated, the type of soil and the water supply available. Therefore, it is impossible to give figures of power consumption except between wide limits, as the consumption will vary very widely according to the conditions mentioned. Generally, the schemes are designed so that the whole of the crop areas receive 1-in. of rain in ten days.

A farm of 50 acres, devoted to the intensive production of salad crops, would require a plant capable of covering 5 acres a day. Assuming the working day of the plant in spring or summer is 16 hours, sufficient quantity of spray equipment to cover 2½ acres at one time must be provided.

For spray-lines, this capacity requires a pumping plant and water supply of 7,500 gallons an hour at a pressure sufficient to maintain initial pressure at the spray-lines of 50-70 lb. per sq. in.

Previous reference has already been made to the wide variation of power required per acre. Referring to the 50-acre farm again, assuming that there

is a stream running through it and that the land is level, the power required would be 15 b.h.p. made up as follows :—

Pressure . . . . .	8·0 h.p.
Suction and distribution loss . . . . .	4·6 h.p.
Power reserve . . . . .	2·4 h.p.

Alternatively, if the only available source of water is a borehole  $\frac{1}{4}$  mile away, with a standing water level of 100 ft. from the surface, then the installed b.h.p. will have to be increased to 25 h.p. made up of :—

Pressure . . . . .	8·0 h.p.
Lifting head . . . . .	6·2 h.p.
Distribution loss . . . . .	6·5 h.p.
Power reserve . . . . .	4·3 h.p.

It will be seen that it is necessary for each installation to be carefully designed with correct main sizes to avoid excessive power loss through friction and that the pump and power unit, Diesel, petrol, or electric, be carefully selected for this duty.

#### WATER CONDITIONING

The foregoing is a description of a simple plant, but much development has taken place in the utilisation of overhead irrigation as a means of distributing small quantities of trace elements and fertilisers. Saturated solutions of these nutrients are injected either by means of parallel feeders or hydraulically-operated dosage pumps fitted to the oscillators on individual spray-lines or installed at the central pumping station. The amount of power absorbed is so small that it can be neglected.

It is not generally necessary to warm the water as it is tempered by passing through the main ; on being thrown into the air in the form of fine spray, it quickly reaches atmospheric temperature. Where deep-well water is used on delicate crops in the early months of the year, plant for warming the water is installed, consisting of low-pressure hot-water boilers connected to an intermediate reservoir or instantaneous heater. As the units are used only occasionally in the early part of the year, the total fuel consumption per annum is comparatively small, but care should be taken to see that adequate boiler power is installed and that radiation losses are reduced to a minimum.

Another power requirement is aeration equipment used to increase the oxygen content of the water, consisting of a compressor delivering air direct into the pressure side of the pump, but here again the H.P. required is fractional and it can be neglected.

#### CROPS UNDER GLASS

The general method of watering crops under glass is by hoses fed from standpipes, supplied by water at a low pressure from a storage tank on a tower which is a feature of the glasshouse areas, such as the Lea Valley. Where the water is pumped from the wells or streams, the same precautions in the design of the system must be used as in outdoor irrigation, otherwise there will be excessive power wastage through friction.

A recent development, for tomato crops in particular, is the use of the overhead spray system under glass, consisting of spray-lines carried at the ridge or on purlins with fine spray nozzles giving rates of watering up to  $1\frac{1}{2}$ -in. an hour, producing also a mist or fog which, it is claimed, assists the setting of the fruit blossom.

## WATER CONDITIONING

As both these systems are used during the cold months, warming of the water is important and in more general use than for outside watering. The method employed is to have a separate low-pressure hot-water boiler beneath the tank and tower, heating it either directly by a flow and return or indirectly by means of a coil in the tank. Although the maximum temperature required may only be 105° F. in the tank, in cold weather the radiation losses are considerable.

Owing to the size of the tank normally employed, lagging is difficult and costly and it is impossible to prevent heat loss from the surface of the water.

An alternative method is to run the supply pipe from the tank through the main heating pipe. Where steam boilers are employed for heating services, the problem is simplified as a calorifier can be used to act as an instantaneous heater.

Future practice will depend upon the development of the main glasshouse heating installations, but much can be done with the existing installations to obtain a fuel saving by the proper appreciation of radiation losses and of the necessity of efficient stoking and maintenance of the plant.

*Discussion*

**Mr. F. E. Rowland:** I would like to speak from the standpoint of an electrical engineer interested in the design and manufacture of agricultural equipment.

Mr. Cameron Brown referred to the advantages of electric heating for grain drying and the inevitable higher running cost. It is interesting to note that for a moisture removal of 1–2 per cent., in southern England the cost of electric heating is only 0·5–1·0 per cent. of the value of the finished product. This is small compared with the acknowledged consistency of quality. In northern England for a moisture removal of 6 per cent. the percentage cost is increased to 1·5–3·0 per cent. These figures are for the cost of heating at approximately 1d. per unit, and exclude the saving of one man's time at a period when labour is short.

For herb drying the absence of fumes with electric heating is particularly advantageous.

A large proportion of dairy sterilising plant is now electrically heated and positive and economical results are obtained. There is some misconception as to the cost at which electricity is economical. Some time ago I heard of an angry protest from a farmer who was asked to pay 1·8d. per unit for a 19 cu. ft. 4 kW sterilising chest. A comparison was made with coal firing and it was found that whilst the cost for electricity was 7·2d. per operation, with coal at 4s. a cwt. the cost per operation was about 8d. Consequently even at this comparatively high figure for electricity, a saving of 1s. 6d. per week was shown, without taking into account the convenience of electricity and the saving in labour, which can account for several shillings a week.

In another instance, a farmer who acknowledged the benefits which would accrue by installing an electric steam raiser in place of fuel-fired equipment for a recording milking plant stated that a running cost of £45 a year was out of the question. On investigating his fuel costs it was found that it exceeded that for electricity by £5 a year.

In dairy sterilising recording plant, constant evaporation with electric steam raisers eliminates the necessity for using high pressures. Consequently



rubbers last longer and the steam condenses before escaping to atmosphere, thus giving up its heat in the plant. More precise methods of sterilising are desirable and no doubt in the course of time thermometers will be fitted at vital points such as teat cups and glass jars.

Low-voltage soil warming with transformers and bare conductors is likely to be widely used and it is opportune to sound a warning of the necessity to use properly designed transformers, to eliminate the risk of live parts at mains voltage being exposed by users. Knowledge and experience is required regarding the length, gauge and type of conductors which are required. There is a risk of misleading results being obtained through the use of unsuitable equipment.

Colonel Waley Cohen stated that 100,000 tons of coal could be saved each year in the dairy industry by adopting the recommendations of Report No. 1 of the Agricultural Overseas Committee. This saving could be effected by chemical sterilisation which he had himself carried out with complete success for over three years. For complete success steaming once a week was desirable.

Another speaker emphasised the appalling quality of the fuel being delivered for use on grass dryers. He did not think that grass drying could be effective on aerodromes and the like due to difficulties in transporting grass with 70 per cent. moisture long distances to the dryer. He would prefer to see the grass converted to silage in such cases.

Attention was drawn to the use of electric heating as an adjunct to hot water in glasshouses.

Mr. Lowe asked why double glazing had not found wider application in glasshouse building, particularly since hermetically-sealed double glass was now available.

Mr. Gamble replied that due to the increased weight, the structural work was increased with a consequent reduction of light.

Mr. Jackson enquired as to the application of conditioned air heating.

Mr. Gamble stated that this had been tried with small experimental houses in the U.S.A. One of the difficulties was that the houses must be air-tight but there were numerous advantages to be obtained—notably better pest control.

Mr. Church suggested the superimposition of electric heating in houses with particular reference to propagating houses. He stressed the value of blowing warm air across the chrysanthemum blooms and thus preventing rotting in the heads of the flowers.

Mr. Gamble replied that in considering the use of electricity, one should not lose sight of the overall national economy in fuel, bearing in mind the low thermal efficiency when using coal at the power station. He again stressed that heating systems must be capable of wide flexibility and top heat is often necessary.

Mr. Baxter enquired as to the relative merits of the Lancashire boiler and the Economic boiler.

Mr. Gamble replied that the choice of boiler depended very much on the labour available. If the boiler was required to withstand rough usage then a Lancashire boiler would probably be more suitable. The Economic boiler, although having many advantages, was more essentially a machine and should, therefore, be treated as such.

**Mr. C. Ellwood Holmes** wrote : The value of roof insulation is well established for industrial heating ; why ignore it in glasshouses ? Single glass roofs used in glasshouses pass 1·16 B.Th.U./sq. ft./hr./° F. temperature difference, whilst the side lights lose 1·07 B.Th.U. If double glazing were used the loss would be 0·62 and 0·60 B.Th.U. respectively—an average reduction of, say, 40 per cent. One of the objections put forward against double glazing is that the space between the glasses would be a dirt trap and provide a breeding ground for parasites. A new type of double glass is available which is hermetically sealed ; this objection is thus no longer valid.

It is not suggested that double glass could be economically applied to existing houses, but it would appear to be a sound proposition in new construction where the supporting members could be designed to carry the double weight. Double glass adds to the initial outlay, of course, but if the fuel consumption for single-glazed houses is taken as 180 tons an acre a year, at £3 a ton, the annual saving would be £216. Capitalising this at 5 per cent. to cover depreciation gives £4,330, so that any amount by which the increased capital cost falls short of this figure is dividend-earning, not to mention that 72 tons of fuel a year would be released for other purposes from every acre. Are there any insurmountable reasons why this method should not be more widely adopted ?

In dismissing the possibility of automatic firing because of the impossibility of obtaining supplies of washed smalls for underfeed stokers, Mr. Gamble referred to magazine boilers burning coke, but did not mention semi-producer stokers and boilers which also use coke or anthracite, and which are claimed to have a higher combustion efficiency than the magazine type and to be more flexible and responsive to thermostatic control.

If the temperature of a glasshouse can be maintained at the optimum figure day and night, the crop yield is increased by 20 per cent. Technical reasons make it virtually impossible to maintain adequate temperatures all through the night when using hand-fired boilers that are unattended at night. Unless the firebed is of the right depth combustion efficiency falls ; the proper methods of firing as advocated by the Ministry are seldom realised on hand-fired boilers during the daytime in glasshouses and never throughout the unattended hours at night. The higher efficiency of the magazine and semi-producer boilers and stokers are due in part to the maintenance of a constant depth of fire-bed throughout the firing cycle. It is claimed that the semi-producer furnace, having no fire-bars, deals with the ash better than other types and operates for 12 hours without attention.

To obtain constant temperature, thermostatic control is necessary and can be most easily applied to the semi-producer and underfeed stokers. It is useless to control the water temperature because this introduces the human element to set the thermostat to give a water temperature in keeping with the outside conditions which may change quickly. A better arrangement is to use a room thermostat because this instrument will maintain any pre-determined internal temperature without human attention and regardless of changes in weather conditions ; it also takes into account the greater losses caused by wind and rain. Sunshine has a great effect on glasshouse temperatures, however, and by the time the thermostat reacts to the rapidly rising temperatures due to this cause, the impetus causes a big rise above the pre-determined setting. In my opinion, the best automatic temperature control is the Pilot Compensator because it is anticipatory in action.

Auto-firing devices which are mechanical and dependent on electric supply are prone to breakdown ; magazine and semi-producer systems are non-mechanical. It must be admitted that the possible loss of a crop due to failure of heating must be guarded against at all costs and for this reason I would not advocate auto-firing in situations where attendants live at a distance from the glasshouse. Where they live on the spot it is easy to provide an alarm to give ample warning of breakdown of electricity, or falling temperature, or of both. The potentialities of gain through automatic firing are so great that it merits serious consideration ; it enables the grower to secure a 20 per cent. increase in crop with a minimum saving in fuel of 20 per cent. due to the higher combustion efficiency. Where large anthracite is now used for hand firing, there is a further financial saving due to the lower cost of the small fuel used for auto-firing.

Mr. W. A. Hubbard wrote suggesting that farmers and horticulturists having heating and ventilating problems could be put in touch with suitable consultants and contractors through The Institution of Heating and Ventilating Engineers, 72/74, Victoria Street, London, S.W.1.

The standard grain dryer used in conjunction with the combine harvester when operated by unskilled labour was subject to wide fluctuations of inlet air temperature. When converting these plants to oil firing, it was common practice to insist on automatic control and to include a recording thermometer so that grain buyers may be assured that the proper drying temperatures had not been exceeded.

In the controversy : individual dryers *v.* central drying plants, the capital cost of the individual dryer and of subsequent improvements must be considered. For example, there were some hundreds of oil-fired dryers now in operation where the automatic controls were designed to regulate the oil supply only, on the high and low control principle, which meant that at low flame the oil burners were operating with a considerable excess of air and consequently at a lower efficiency, whereas on the central dryers, where the capital cost of the apparatus was not such a vital factor, oil-firing plants had been installed which automatically regulated the oil and air supplies in proportion, thus maintaining a practically constant efficiency whether the plants were working under maximum or minimum load conditions. Conversion to oil of many pot furnaces burning solid fuel had been successfully accomplished but if the furnaces had originally been designed to burn liquid fuel their efficiency would generally have been higher. While the capital cost of conversion of individual dryers given by Mr. Chartres was fairly accurate, the cost of conversion of a central drying plant on sound technical lines would be considerably greater.

While lagging and air recirculation had not been seriously applied to ordinary grain-drying plants, they had been applied to plants for drying and curing malt, where any extra capital cost involved in efficient heat insulation and recirculation of the gases had been fully justified by the resultant fuel economy. Whereas an average of 5 gallons of oil was required to dry and cure a quarter of malt on a standard type kiln, figures of less than 4 gallons per quarter had been obtained on kilns which incorporate recirculation. As practically all the oil-fired dryers where the products of combustion pass through the charge were using Pool gas or Diesel oil, the calorific value figure of 18,000 B.Th.U./lb. given by Mr. Chartres was, of course, low, this particular grade of oil having a calorific value between 19,250 and 19,500 B.Th.U./lb.

The average farmer would be pleased to learn where he could obtain coal at 49s. per ton having a calorific value of 14,200 B.Th.U./lb. Some adjustment was therefore called for in the figures given in Mr. Chartres's paper.

Mr. Ellwood Holmes in a later communication gave further information obtained from Messrs. Pilkington Bros., Ltd., on the present position regarding the manufacture and use of double glazing for glasshouses. Mr. P. M. Davidson, of Messrs. Pilkington Bros., Ltd., wrote :—It is true that there have been considerable developments in connection with the production of hermetically-sealed double glazings. We ourselves were engaged upon this work prior to the war, but had to discontinue our experimental work soon after the outbreak of hostilities. Development work, however, continued in America and two types of hermetically-sealed double glazings are now on the market in that country.

The first is one made by the Libbey-Owens Ford Co., sold under the name of Thermopane, and consists of two sheets of glass with a metal spacer piece of lead soldered on to marginal strips of copper deposited on the glass at high temperature.

The second is made by Pittsburgh Plate Glass Co. and is sold under the name of Twindow. This consists of a square-section metal tube, which acts as spacer between the two sheets of glass, the latter being secured to the tube with a plastic compound. The whole unit is then held together and protected by a U-section channel of stainless steel which covers the whole of the edge of the unit and extends up the face of the glass sheets a distance of about  $\frac{3}{8}$  in.

About six months ago we resumed our work on the development of such glasses and, although very good progress has been made, we have not yet reached the stage of being able to put on the market a competitive article. We might mention that our experiments are along quite independent lines, not connected with either of the American products. Both the American products are relatively costly, and of course all hermetically-sealed units have the disadvantage that they must be factory-produced to the required size, and cannot, as in the case of ordinary glass, be cut on site from stock sheets.

Another line of approach to this problem is by the production of double-glazed assemblies, where the interspace is not hermetically sealed but is deliberately vented by a small aperture to the outside air.

It must be appreciated that the efficiency of the double glazing as an insulator against the passage of conducted heat is equally great under similar conditions, whether the unit is sealed or unsealed, provided the air in the interspace is stationary. To reduce the incidence of condensation the vent should be to outside atmosphere.

From the point of view of the application of double glazing to glasshouse work there is no doubt that the only economic approach under present conditions, is by the use of the unsealed type, but as a result of current experiments, a sealed double glass may be available at a future date, at an economic price.

Regarding the heat insulation value of double glazing, the heat conductivity in B.Th.U. per sq. ft. per hour per ° F. temperature difference is approximately 1.1. (This is based on average values for the surface resistance, as of course the transference of the heat from the air to the glass surface produces the majority of the resistance to the transmission of heat.) In parallel conditions, using two sheets of the same type of glass, spaced 0.75 in. apart, and similar surface resistance values, the heat conduction figure is 0.54 B.Th.U. Even if the still-air space is reduced to 0.25 in., we still obtain 90 per cent. of this

effectiveness. It will be seen thus that there is a very material saving in the reduction of heat loss by conduction.

Regarding the point which you raise that double glazing reduces the beneficial effect of the sun's rays, it is correct to say that two sheets of glass will filter out more than does a single sheet. On the other hand, that part of the sun's infra-red and visible radiations which reach the earth's surface having penetrated the atmosphere is not, to any great extent, altered by passage through glass of the thickness normally used in horticultural work and indeed the scum of dirt which forms on the outside of the glass has a greater effect than has the actual glass itself. Prior to the war there was considerable controversy regarding the efficiency of "Vita" glass, which is a glass of special composition designed to transmit a high proportion of the ultra-violet rays of natural sunlight, and very conflicting evidence was produced for and against its use in horticultural work. It is an undoubted fact that a greater proportion of the ultra-violet rays pass through the glass, but the general feeling was that this additional ultra-violet light, although beneficial to the plants was equally beneficial to their enemies, so that the net effect was to a large extent dependent on the particular conditions of the experiment.

Double glazing has been suggested for horticultural work on many occasions, and indeed a patent has been taken out for a specially shaped wooden glazing bar to permit the introduction of a supplementary sheet of glass below the permanent one, when conditions necessitated the extra insulation. This pane of glass was merely let in and could be taken out at will.

The Chairman of the Section, Mr. W. L. Boon, summed up the major conclusions from the discussions of this section as follows: The deliberations of this section were most informative and the papers presented covered a very large phase of drying, conditioning and storing. It is not generally realised that a very large quantity of fuel is used for these purposes. Practically every commodity which enters into our daily life has undergone a drying or conditioning process of one kind or another, and has, therefore, used fuel.

It is evident that a great deal of new design has, in recent years, gone into the production of drying and conditioning equipment. All large manufacturers are very conscious of the need for obtaining the highest maximum efficiency from their plants. As a member of the Fuel Efficiency Committee I was very pleased to see that demonstrated in the papers.

It is pleasing, too, to note that many of them are well versed in the use of waste heat and work to the general rule that all drying and conditioning should be carried out by low-grade heat. The great bulk of drying and conditioning is, however, carried out in old types of plant, and it would appear that there is considerable scope for economy in this direction. There seems no doubt that low-temperature radiant heating or drying, particularly of paint or painted products, has reduced fuel consumption enormously, due to the shorter time taken in the process. It is plain, however, that the modern direct-fired air circulation conveyor and convector ovens are also under the same conditions of operation, equally, if not more, efficient.

Considerable stress is laid on the fact that the greatest single economy which can be achieved in drying and conditioning would generally lie in the mechanical extraction of moisture prior to the thermal process. There is room, therefore, for a good deal of work to be done in this direction.

In Session II, which dealt with "Factory Heating and Air Conditioning", a very wide subject, we also had a very successful meeting from the point of view of the number of very constructive suggestions which were made for recovery. Generally it has been shown that heat loss arises very largely from conduction through walls and roofs of buildings and through ineffective use of warm air and through faulty boiler practice. It was stressed that corrugated or other lightly constructed buildings are highly susceptible to loss of heat by conduction and through the incursion of cold air, and that these faults are curable only by the provision of insulation. The whole question of structural insulation has come very prominently before this session, and it would appear that there is no other single factor which is so important in the saving of fuel in regard to space heating as that of structural insulation.

Other important points made were concerning the correct position of heating appliances, radiators and so forth, losses due to temperature variations between floor and roof, to leaving doors and windows open and allowing cold air to enter and hot air to escape, and so on. It was suggested that if it were possible to reduce the temperature of factories by only 2° F. considerable savings of fuel would be realised.

In Session III—"Heat for Agriculture and Horticulture"—statements suggest that the use of heat in agricultural processes has apparently resulted largely from mechanisation. Therefore, it is evident that this industry will continuously expand in its requirements of fuel, so that in this case it will require more fuel and not less.

It is claimed that a large proportion of our crops has been saved in this year's harvest by the use of combine harvesters and grain and grass dryers, involving the use of additional fuel. It was clearly brought out that the artificial drying of grass has produced a winter feeding-stuff for cattle which has double the food value of ordinary hay, and can replace imported concentrates. This, again, has required extra fuel, but it has been most worth while.

The sterilisation of milk and the drying of herbs and vegetables is also an increasing requirement which, again, is dependent upon more fuel.

In regard to glasshouse heating, it is stated that this country aims at becoming self-supporting in the production of horticultural products. Glasshouse heating now takes 750,000 tons of coal per annum, or more than half of the total fuel used in agriculture. The view is that this industry must expand and that again there will be a demand for more fuel, but that fuel, I hope, will be used efficiently.

Agriculture for all purposes now requires 280 million kWh per annum, and the demand for electricity for both domestic and farm use is growing at such a rapid rate that it may well amount to 2,000 million kWh per annum within ten years. The quantity of fuel used for heating glasshouses, chiefly for tomato growing, varies from 100 tons to 400 tons per acre, but the maximum target figure should not exceed 180 tons.

Various means of effecting economies were clearly demonstrated. It is agreed that the farmer generally is not fuel-conscious, nor has he available within his own industry any advisory body through which information can be given to him on appliances and their use. He has to rely, therefore, upon his own resources. It is suggested that in view of the importance of the industry and the largely increased demand for fuel which is likely to arise from it, some advisory service should be provided for this purpose.

## APPENDIX TO VOLUME I

*(Publications referred to during the Conference, not reprinted in full.)*

<i>Title</i>	<i>Obtainable from</i>
(1) Bulletin MC/131 of the Boiler Availability Committee, "Methods of Cleaning Modern Stoker-fired Boiler Plant".	The Boiler Availability Committee, 14, Old Square, Lincoln's Inn, London, W.C.2.
(2) Beer and Coal . . . . .	Ministry of Fuel and Power.
(3) Laundering and Coal . . . . .	Ministry of Fuel and Power.
(4) Report to the Board of Trade Wool Working Party.	H.M.S.O. 3s. 6d. net (by post 3s. 10d.).
(5) Air Conditioning in Cotton Mills, by A. Leslie Longworth.	Ministry of Fuel and Power.
(6) Educational Syllabus on Steam Utilisation.	Ministry of Fuel and Power.
(7) Syllabus of Institute of Fuel Examination.	Institute of Fuel, 18, Devonshire St., London, W.1.

*End of Volume I*

OFFICIAL



PUBLICATIONS

---

### THE EFFICIENT USE OF FUEL

A text-book on fuels and their efficient utilisation for the use of students and technical men in industry.

*Royal 8vo.* · 815 pages · *Price 12s. 6d.*  
*Cloth* · 303 illustrations · *By post 13s. 2d.*

### THE EFFICIENT USE OF STEAM

*A companion volume to "The Efficient Use of Fuel."*

The contents cover most aspects of the heating and power properties of steam, and several chapters are devoted to guidance on lagging, instruments, traps, condensate, flash, peak loads, etc. Individual chapters also deal with multiple effect evaporation, automatic controls, Heat balances, costing and regression. Other sections are concerned with the practical aspects of steam and power saving.

*Royal 8vo.* · 912 pages · *Price 15s.*  
*Cloth* · 438 illustrations · *By post 15s. 9d.*

### FUEL ABSTRACTS

A monthly summary compiled by the Fuel Research Station (D.S.I.R.) comprising over 500 abstracts per month of the world literature on all technical and scientific aspects of fuel and power.

*Annual Subscription*  
*£2 10s. 0d. post free*

*(Single issues are not sold separately)*

---

OBTAINABLE FROM

**H.M. STATIONERY OFFICE**

AT THE ADDRESSES OVERLEAF  
OR THROUGH ANY BOOKSELLER



*Crown Copyright Reserved*

LONDON  
**PRINTED AND PUBLISHED BY HIS MAJESTY'S STATIONERY OFFICE**  
To be purchased directly from H.M. Stationery Office at the following addresses:  
York House, Kingsway, London, W.C.2; 13a Castle Street, Edinburgh, 2,  
39-41 King Street, Manchester, 2; 1 St. Andrew's Crescent, Cardiff;  
Tower Lane, Bristol, 1; 60 Chichester Street, Belfast  
OR THROUGH ANY BOOKSELLER  
1948  
Price 6s. 0d. net

S.O. Code No. 41-