

**STUDIES  
IN  
COAL WASHABILITY**



COUNCIL OF SCIENTIFIC & INDUSTRIAL RESEARCH

STUDIES  
IN  
COAL WASHABILITY  
( STUDIES 4, 5 & 6 )

BY

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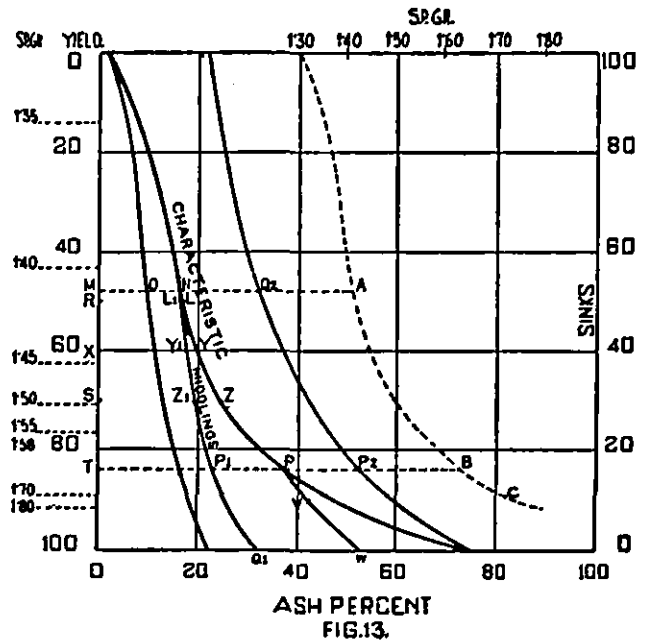
# STUDY 4

## THE MIDDINGS CURVE

As explained in Studies 1 and 3 the characteristic curve is best regarded as the parent curve from which the other curves, required to study the cleaning possibilities, may be derived; and the yield of middlings of a stipulated ash content can easily be obtained direct from it. However, if middlings recovery is an important factor, a separate middlings curve should be drawn to show the amount of ash and yield of the middlings themselves at different density cuts. The purest or primary product is first removed at a definite cut dependent upon the requisite purity. Thus, in India, coal for coking may have ash percentages not exceeding 15 to 17, the exact value depending on the yield of volatile matter in the pure product. Once this fraction has been removed, the rest of the coal can be considered as devoid of low ash constituents. If now we desire to recover some portion or middlings of stipulated ash (the remainder being rejected as refuse), the floats curve for this secondary separation can easily be drawn, showing the floats recovery *per 100 parts of the original coal*. These secondary floats are the middlings, and the curve may be drawn on the principles of area integration explained for the total floats curve of the original coal (STUDY 1).

Thus, in Fig. 13, if a primary product with 10 per cent ash is desired, the coal is cut at O, which means at a specific gravity of 1.41, given by (A) on the yield gravity curve: the yield will be 47.0 per cent (point M). Through this point the straight line MON cuts the characteristic curve at N, and the sinks curve at Q<sub>2</sub>. Proceeding as usual, the area enclosed by MNYX, when divided by XM, gives the length XY<sub>1</sub>, and thus point Y<sub>1</sub>; and the area MNZS divided by MS gives the length SZ<sub>1</sub> and thus the point Z<sub>1</sub>. Observe

that if this area is small, e.g. MNLR, the area divided by MR gives RL<sub>1</sub>, which approximates in length to MN. The floats ash curve for the middlings thus begins at N, which lies on the original characteristic. Similarly, other points are obtained, and eventually Q<sub>1</sub> against 100 per cent yield, i.e. where all the product is removed. Q<sub>1</sub> corresponds exactly to Q<sub>2</sub> on the total sinks curve, as the per cent ash for Q<sub>1</sub> must be identical with that for Q<sub>2</sub>. The curve NL<sub>1</sub>Y<sub>1</sub>Z<sub>1</sub>Q<sub>1</sub> is evidently the middlings floats/ash curve, and from it the yield of middlings of any desired ash may be read off. Thus, if we want middlings having 23 per cent ash, P<sub>1</sub> is located on this curve over the 23 per cent ash value. MT gives the amount of such product. It is 84 - 47.0 = 37.0 per cent of the original coal. The rest, 16 per



cent, has 52 per cent of ash ( $P_2$ ) and may be rejected. Observe that in order to produce this middlings fraction of 23 per cent ash, we cut at a specific gravity of 1.635, given by point B on the gravity curve.

The great value of the middlings curve is that from it we can see at once what will be the yields of middlings of various stipulated ash values. This is important, since the quality of the middlings may have to be adjusted from time to time in the light of the fluctuating demands of the market.

It remains to say that if two or more middlings fractions are practicable and desired, the above procedure is repeated on the "rejects" of the first middlings. Thus the curve PW may be drawn for the rejects and utilized as above.

### THE ASH UNITS CURVE & MIDLINGS

A method has already been suggested whereby we can assess the middlings from the ash units curve (see STUDY 2). The method outlined in Study 2, however, is not capable of ready utilization, and can be improved.

The ash units curve may be employed to great advantage in dealing with middlings if we are prepared to distort the diagram and enlarge the ash units scale as in Fig. 13U. F. W. Mayer\* ("Erweiterung des Verwachsungs Kurvenbildes durch eine Mittelgutkurve", *Glückauf*, 79, 1943) employed a similar curve which he termed an M curve. This is an ash units curve using summation

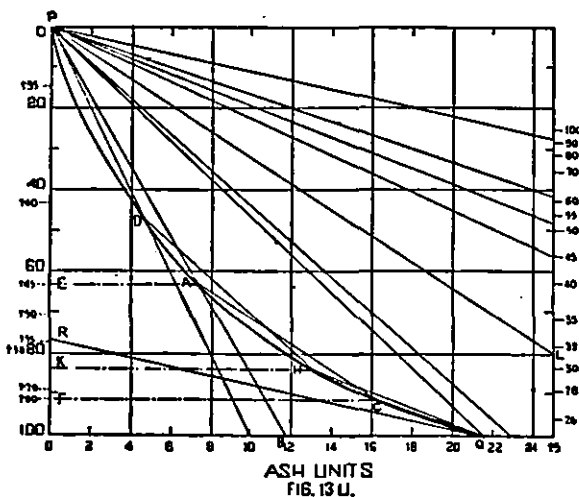
values. Mayer's procedure, modified to ash units, is as follows:

The values for the coal displayed in Fig. 13 are plotted on an ash units basis, in Fig. 13U, the ash units being derived as explained in Study 2, i.e. by multiplying the percentage yield at each stage by the percentage ash in that yield and dividing by 100. The curve is easily derived from the normal total floats/ash curve (Part 2, of STUDIES 1, 2 and 3). In order to make a diagram of convenient and useful size, the values for ash units are continued on the right-hand vertical axis, as recommended by Mayer. The numbering on this vertical axis shows the values which would have been obtained by drawing straight lines from the upper origin P to the horizontal axis OQ, produced for the ash values numbered. The divisions are easily obtained by simple geometry.

The ash units curve is now employed in the following way. Consider first a cut at a specific gravity 1.45. This will give a yield 62.8 per cent of cleaned coal as shown. Join P and A and produce to cut the ash axis at B. B gives the percentage ash because  $EA/PE = OB/100$ . If a middlings cut is now desired up to a specific gravity of 1.8, draw FC; join AC, and through P draw a line parallel to AC, to cut the ash units axis at L. This gives an ash value of 31 per cent. The residue CQ has an ash value which may be found similarly by drawing a line parallel to the straight chord CQ through P. It cuts the ash axis at 61 showing the ash of the rejects to be 61 per cent.

If now we desire to operate in a different manner, and to take off first 10 per cent ash coal and then a middling of 23 per cent ash, the procedure is as follows. Join P with point 10 on the ash units axis. It cuts the curve at D showing a yield of 47 per cent. Join P with 23 on the ash units axis and draw a parallel DH through D to cut the curve in H. H is found to correspond to a yield axis value of 84. The yield of middlings is  $84 - 47 = 37$  per cent. The ash of the residue may be found by drawing the parallel to the straight chord HQ through P. It cuts the ash axis at 52 showing this percentage of ash in the residue.

The ash units curve thus gives all the values we require, for the yields of primary washed coal and of middlings and of rejects with the ash in each case. If a second middlings be required after DH, containing say 45 per cent of ash, we join P with the 45 value on the ash units scale and draw



\*We are indebted to Dr. Jagat Ram of the Tata Iron & Steel Co. Ltd. for drawing our attention to Mayer's article.

through H a line parallel ( *dotted* in FIG. 13U ). It will cut the curve at C. The yield of such a fraction will be about 7 per cent ( KF ).

#### TANGENTS TO THE ASH UNITS CURVE

As the scales have now been distorted, angular measurements in radians or degrees are out of place. We may, however, draw tangents as before if we utilize the scales chosen. Thus for the coal in question ( FIG. 13U ) we can draw the limit line from ash value of 21.6 per cent by stepping off (  $21.6 + 2.16 = 23.76$  ) units upwards from O, which will be at the (  $100 - 23.76 = 76.24$  ) value of yield, as shown by the point R. The line QR is parallel ( of necessity ) to the line joining P with the 91 ash value. As explained in Study 2, the washability of the coal would be ideal if the units curve were to follow this line upwards from the total ash value (21.6) to the yield axis, and then proceed vertically from R up the yield axis to point P — in other words, if the “ curve ” were QRP. The larger the area lying between the units curve and the composite ideal “ curve ” QRP, the more difficult is the coal to wash ; and in the limit, if the ash units curve follows the straight line or chord PQ, the coal is absolutely unwashable, as the ash per cent of each fraction is the same. The limit line near the ash axis is nearly tangential to the units curve, and if the two paths run together ( upwards from Q ) for any appreciable distance, the indication is that there is much shale ( unadulterated ) present.

It is clear that this shale should be rejected and the amount of rejects can be gauged and assessed from the proximity of the 2 curves in these lower reaches, especially as the combustible matter in the rejects is measured directly by the vertical distance between the curve and QR at any point, as explained in the earlier studies.

There is another use of the units curve to which Mayer has drawn attention. If we wish to find the ash of the heaviest particle

of the floats above any particular point of cut, we draw a *tangent* to the curve at this point, and a parallel to this tangent through P to meet the ash axis. The value shown on the ash axis at the point of intersection gives the ash percentage required. If we regard the tangent as the limit of the chord, the explanation is clear. We are simply finding the ash of a minute middlings fraction at a point. The characteristic curve, of course, gives this value directly ( STUDY 1 ).

#### SUMMARY

The advantages of the standard washability curves, i.e. the characteristic and its derivatives, are that, if drawn to standard scales, they demonstrate visually the type of the coal and the washability potentialities at first inspection. The bends of the characteristic and its location stand out clearly and the significance is easy to appreciate. Moreover, the middlings float curves, derived as explained for Fig. 13, are of ready utilization. There is, however, the need for the 3 curves, and for the calculations ( which are considerable ) in order to obtain reliable graphs.

The advantages of the ash units curve and its uses as explained earlier and including Mayer's procedure are, that only one curve is needed, and that by simple geometrical constructions all requisite values are obtainable from it. The disadvantage is that the washability characteristics do not stand out quite so clearly at a glance, nor is it immediately obvious where cuts may be made with advantage, as all such curves have the same general trend. However, if standard diagrams be employed having, say 25 ash units horizontally equal in length to 100 yield units vertically, comparisons are facilitated. And in any case the limit line QR ( FIG. 13U ) should be drawn, as it is a most useful guide for normal ash types. If carbonates are present in quantity, special considerations arise, however.

## STUDY 5

### WASHING BEFORE & AFTER HAND-PICKING

HAND-PICKING is, to some degree, an alternative to washing. At mines where machine mining is not practised and where the seam contains thick bands of dirt, hand-picking virtually starts from the working face. The degree of "perfection" attained depends upon the experience, skill and goodwill of the miners, and also on the underground lighting, especially at the face. The hand-picking with which we are concerned here, however, is that done at the surface by special personnel engaged for the purpose and stationed near the screening plant and/or the picking belts. Whether it is better to hand-pick before washing than to wash direct without hand-picking requires consideration.

First, in the cost of labour for manual picking allowance must be made not only for the wages of the pickers but also for the provision of several amenities now common for all mine labour. Secondly, in days of labour shortage and labour unrest (and especially with relaxed supervision) it is not easy to prevent the loading of dirt in the mine along with the coal. During surface-picking, also, unless there is vigilance and close supervision, much material escapes rejection, or is *unnecessarily rejected*. Finally, in Indian (drift) coals, pieces may seem to be of inferior quality, which, on test, are found to be of good quality with low ash, and *vice versa*. Indeed, there is often genuine excuse for inefficient hand-picking, especially when the coal is wet.

The arguments against washing without any prior hand-picking are obvious. The accumulated rubbish in a washery treating unpicked coal increases the handling and washing costs, and the washery water becomes contaminated, necessitating more purification and more changes. Moreover, when picked coal only is washed, the washery

"rejects" for the majority of Indian coals will be fairly rich in combustible matter, and can thus be used as pulverized fuel, or as fuel for brick-burning or, in some cases, for cement manufacture: these rejects also often permit of the recovery of a middlings product. By contrast, if unpicked coal is fed to the washer, it will carry a large amount of extraneous material (which may or may not be pure shale), and this material may so increase the ash of the rejects as to render them practically useless, even as low grade fuel. In such cases, however, the washery problem can probably be solved by making a middlings cut, and rejecting only the heaviest 10 or 20 per cent as refuse.

In order to judge the merits and demerits of hand-picking before washing, in so far as washability is concerned, float and sink tests have been carried on two samples from the same seam and mine, one having been picked at the mine (surface) and the other unpicked. The results are shown in Figs. 14 and 15. Fig. 14 refers to the picked coal: Fig. 15 to the unpicked, i.e. run-of-mine coal.

In comparing the cleaning possibilities of the overall samples (Figs. 14H and 15H), we notice first that the overall ash percentage is only 18.9 for the picked sample, but 29.0 for the unpicked sample; while for 16 per cent ash coal, the percentage yield of clean coal is 94 in the former case, as against 74 in the latter. Thus, the percentage of rejects will be 6 and 26 respectively, the corresponding ash percentages in the rejects being 65 and 66. The foreign matter in each case will be about 10 per cent greater, i.e. 72 and 73 per cent, showing that the rejects in both cases are associated with 27 to 28 per cent of combustible matter.

Now the 74 per cent yield of clean coal from the unpicked sample (though compar-

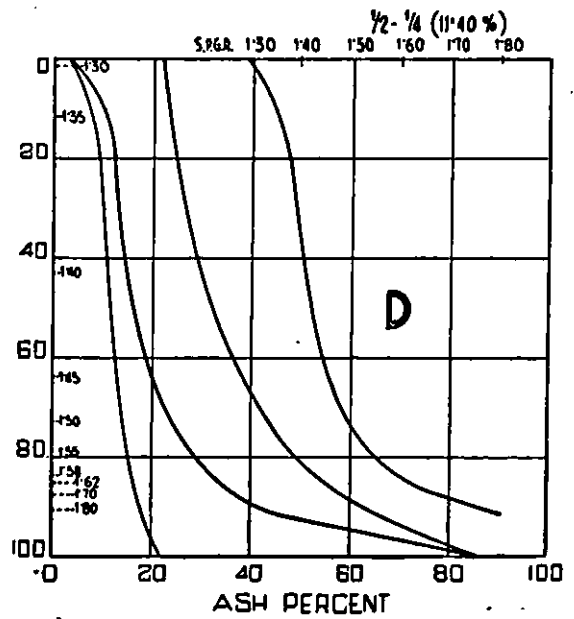
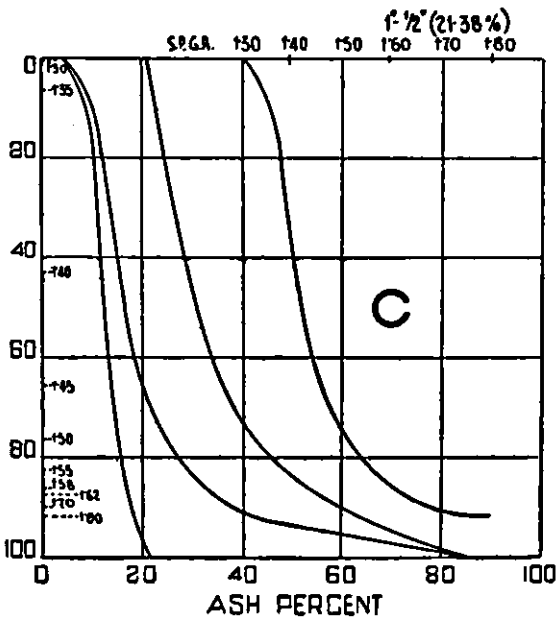
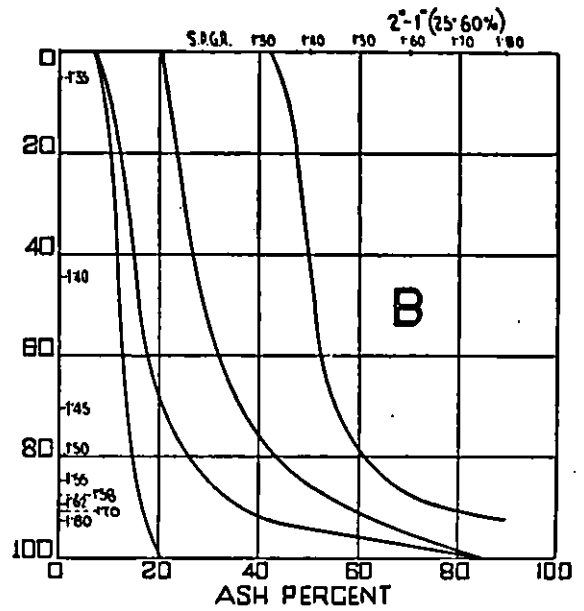
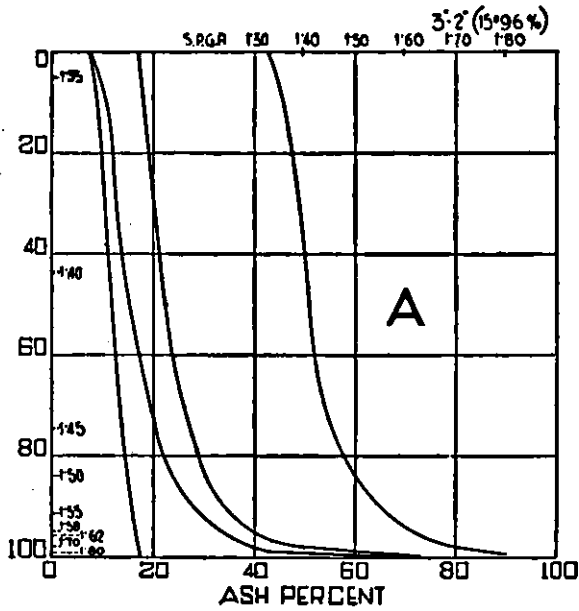


FIG.14(A,B,C & D)  
HAND-PICKED

ing poorly with the 94 per cent yield from the picked sample) is none the less a high value, and the washing characteristic and other curves show clearly that the coal can be easily cleaned. Consequently, hand-picking is *by no means necessary*. Moreover, if machine mining were later adopted for this coal, no great difficulties in washing need be anticipated, whether hand-picking were resorted to or not.

It is useful to examine the curves of Figs. 14 and 15 in order to compare the distribution of refuse in the various size fractions. Consider first the ash values of the picked sample for a 100 per cent yield in each size (values tabulated in the column 2 of TABLE 10). We find from the curves of Fig. 15, the yields of unpicked sample corresponding with the ash values given by the picked sample. These yields are shown in

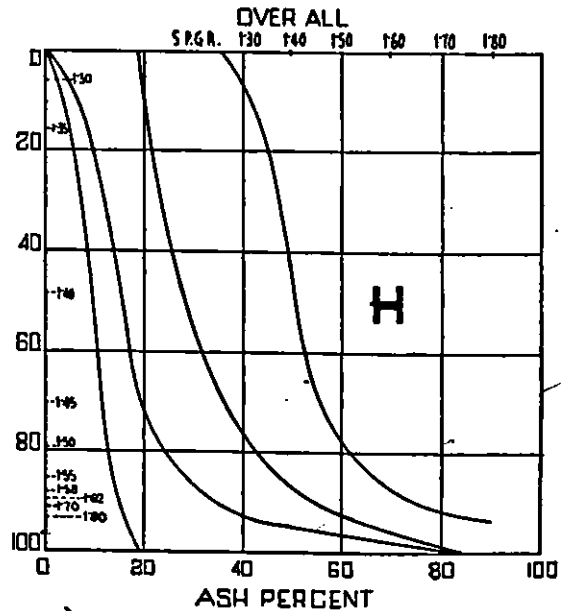
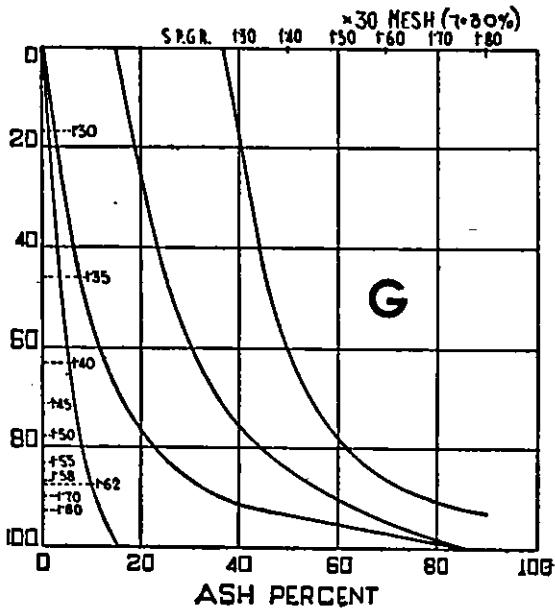
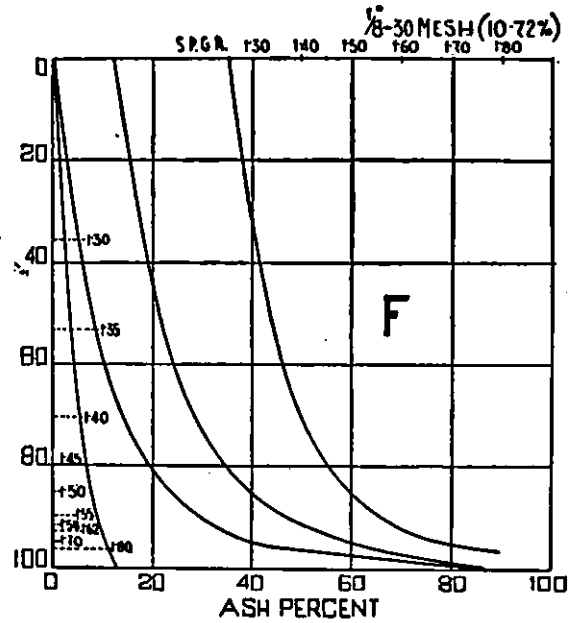
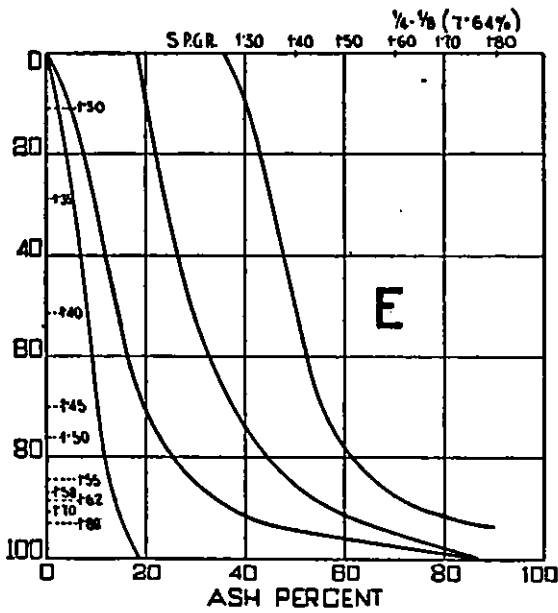


FIG.14 (E,F,G &H)  
HAND - PICKED

column 3 of Table 10. Column 4 of the same table is completed by subtracting from 100, the values of column 3, and it thus shows the proportion of rejects which have been picked out by hand (before breaking, be it noted).

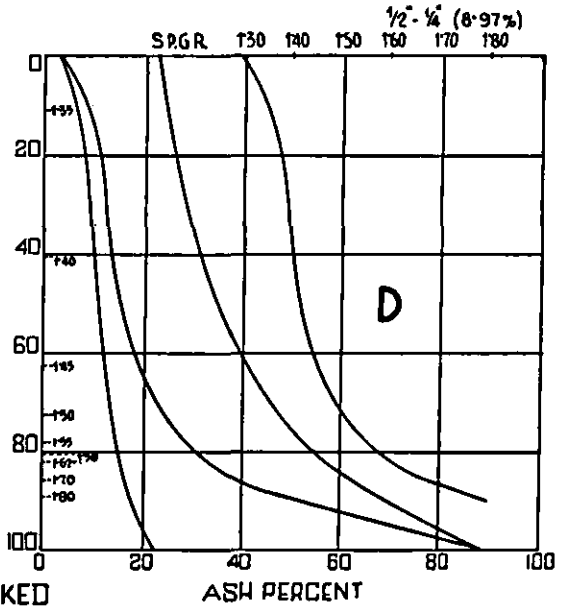
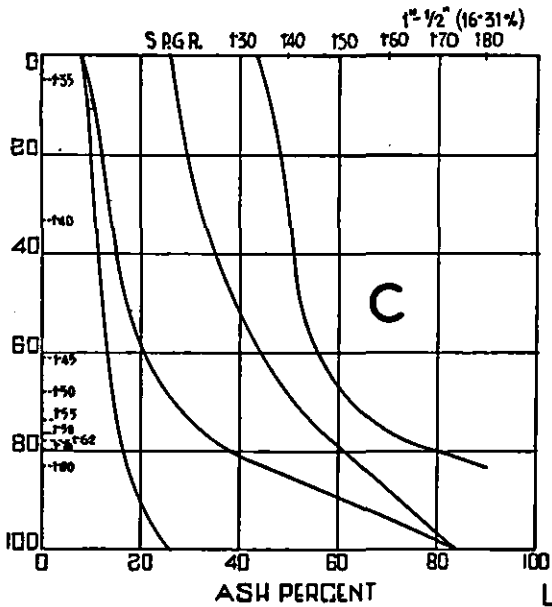
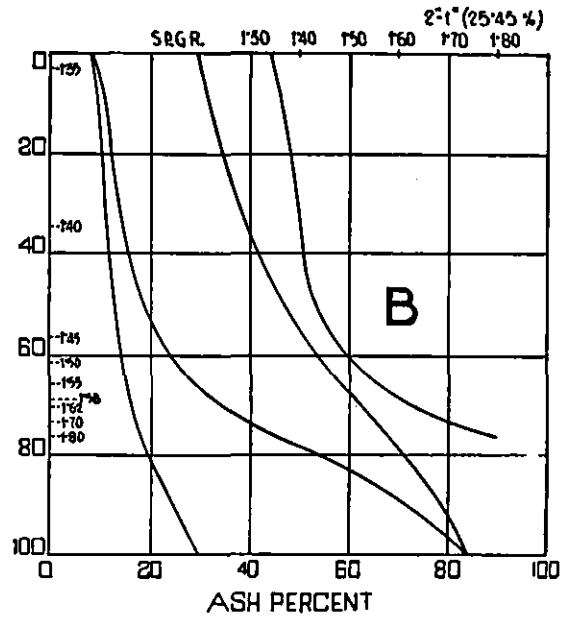
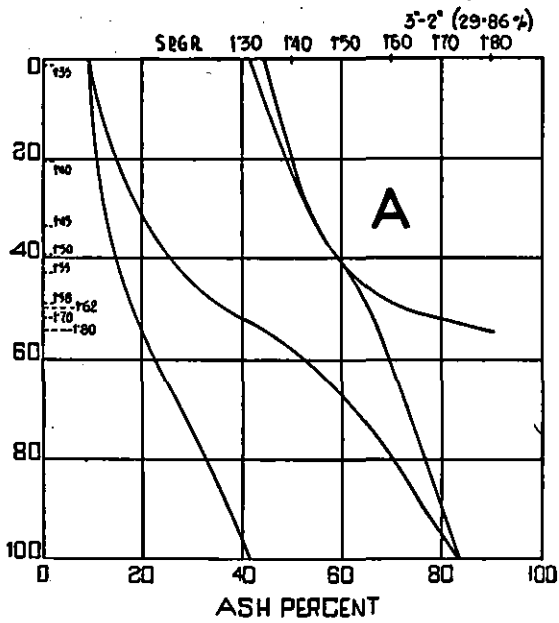
In the final column of Table 10 are shown the ash percentages of each such rejection. These rejections were, of course, removed mainly in the form of large pieces before the

sample was broken down to 3 in. for the washability tests.

It will be seen that

- (a) the ash of each fraction of the unpicked coal is greater than the ash of the corresponding size fraction of the picked coal ;
- (b) for the larger sizes, the above difference is considerable. Thus, for the 3 to 2 in., it amounts to  $41.4 - 17.4 = 24$  per





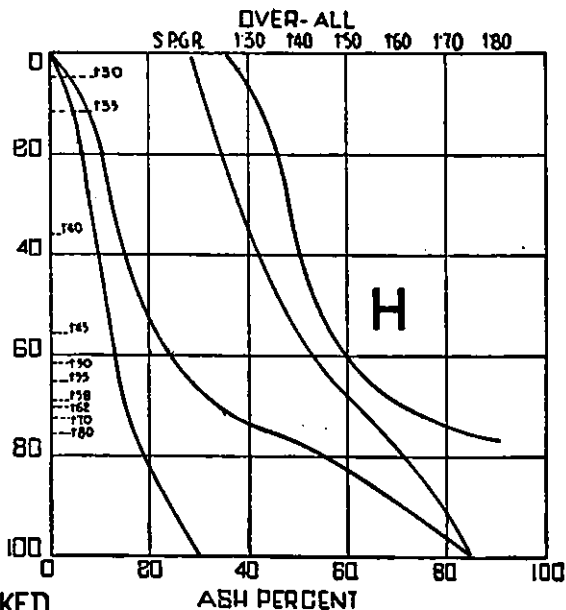
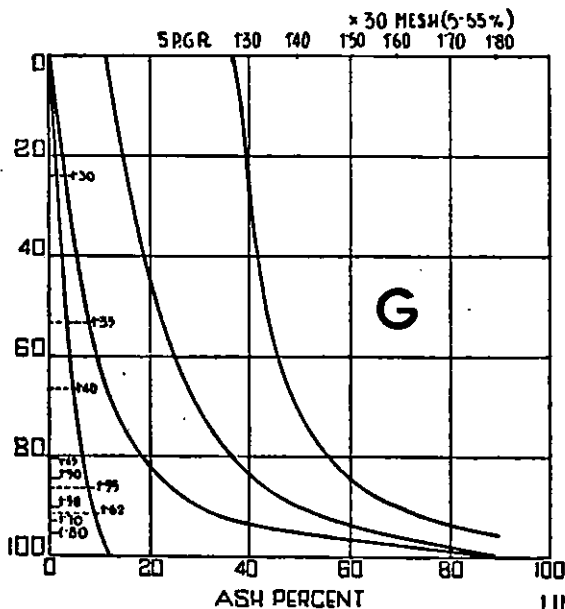
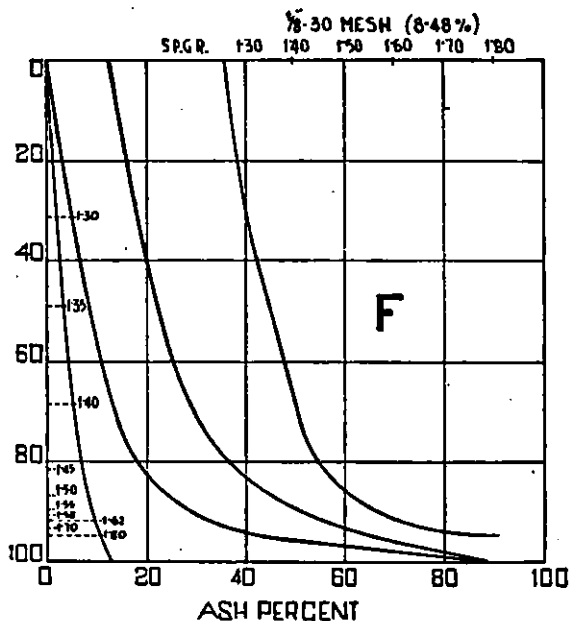
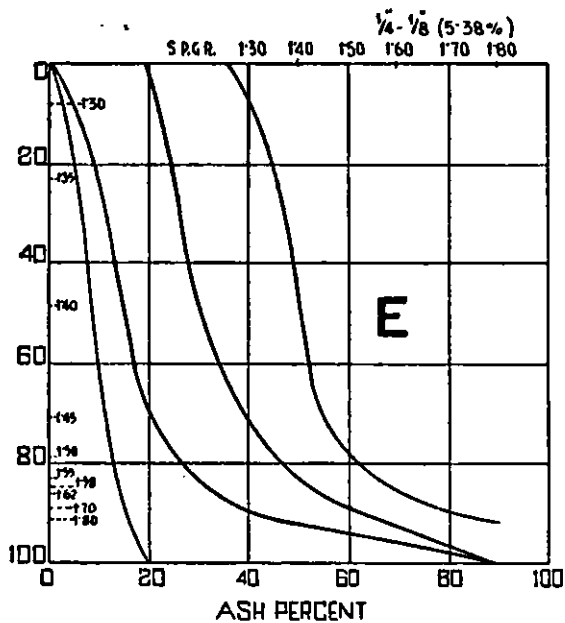
UNPICKED  
FIG. 15 (A, B, C & D)

cent. For the 2 to 1 in. size, it amounts to  $29.9 - 20.5 = 9.4$  per cent. For the smaller sizes, the difference is less. Thus for the  $\frac{1}{4}$  to  $\frac{1}{2}$  in., it is  $19.5 - 18.1 = 1.4$  per cent ;

- (c) the ash per cent of the rejections is large in each case, and it is particularly large for the smallest sizes. But even for the largest size (3 to 2 in.), it amounts to 64.5 per cent. It is clear that the hand-picking was fairly satis-

factory as regards the removal of dirt. Whether at the same time any good coal was removed is not shown up by these results. This is discussed below.

It is also apparent from Figs. 14 and 15 that in the picked and in the unpicked sample the fines through  $\frac{1}{8}$  in. mesh may be screened beforehand and, as their ash percentage is already below 16, they may be later mixed with the clean product without detriment



UNPICKED.  
FIG.15 (E, F, G & H)

for many purposes. On the other hand, it may be advisable to clean them (see STUDY 6).

It has been shown that most of the dirt bands present in the unpicked sample were removed by hand-picking. This was, no doubt, due to close supervision and thoroughness with which the work was carried out. We do not know, however, whether any material was unnecessarily rejected. The

assessment of such losses may be determined by weighing the consignment before and after hand-picking.

If the total weight of coal taken were 9.95 tons, and the weight of material rejected by hand-picking were 2.09 tons, then per cent rejected

$$= \frac{2.09}{9.95} \times 100 = 21.0.$$

TABLE 10

| Size,<br>inches                | ASH<br>PER CENT<br>OF PICKED<br>SAMPLE | YIELD PER CENT<br>OF UNPICKED<br>SAMPLE AT ASH<br>PER CENT<br>EQUIVALENT TO<br>PICKED SAMPLE | REJECTIONS<br>FROM<br>UNPICKED<br>SAMPLE | ASH<br>PER CENT OF<br>REJECTION |
|--------------------------------|--|--|--|---------------------------------|
| 3 to 2                         | 17.41                                  | 50.0   | 50.0                                     | 64.5                            |
| 2 to 1                         | 20.45                                  | 82.0   | 18.0                                     | 72.0                            |
| 1 to $\frac{1}{2}$             | 21.36                                  | 92.0   | 8.0                                      | 74.5                            |
| $\frac{1}{2}$ to $\frac{1}{4}$ | 21.74                                  | 98.0   | 2.0                                      | 84.0                            |
| $\frac{1}{4}$ to $\frac{1}{8}$ | 18.14                                  | 98.0   | 2.0                                      | 85.0                            |
| $\frac{1}{8}$ to 30 mesh       | 12.28                                  | 99.0   | 1.0                                      | 86.0                            |
| $\times 30$ mesh*              | 15.00                                  | 100.0  | ...                                      | ...                             |
| Overall                        | 18.86                                  | 80.5   | 19.5                                     | 71.0                            |

\* Low ash of the  $\times 30$  mesh material of the unpicked sample (Fig. 15G) may be due to veins of vitrain in the carbonaceous shale, removed by hand-picking.

The ash of hand-picked coal was 18.9 per cent.

From the graph the weight of material, which, when broken, will be rejected by washing the unpicked sample (if an ash of 18.9 per cent be desired in the clean coal), should be 19.5 per cent. It is clear, therefore, that from results as above there would be loss of 1.5 per cent (21 - 19.5) due to

hand-picking of the unbroken coal. In other words, useful coal with an average ash of 19 per cent has been thrown away to the extent of 1.5 tons in every 100 tons of run-of-mine coal. In such cases it is desirable to install coal-washing plant as much on the score of saving good material from being rejected by hand-picking as to obtain low ash coal in the clean product.

## STUDY 6

### VARIATION IN THE ASH OF A WASHED COAL

ONE of the major claims for washing is that it produces coal of uniform ash. Frequently, the percentage ash of the washed coal, as a whole, is all that we need to consider. This is given by the floats/ash curve for different yields. Yet, for any particular coal, a careful comparison of a series of curves for the different size fractions, e.g. Fig. 14, shows that the ash percentage of each size fraction is not the same, although the coal is cut at one definite specific gravity. Thus, for the 3 to 2 in. size, if a cut at specific gravity 1.5 is chosen, the ash may be 15 per cent; whereas for the  $\frac{1}{4}$  to  $\frac{1}{8}$  in. size the ash is only 11 per cent, and for the finer sizes still less. This means that if we wash the seam as a whole, then, although the ash content of the floats or clean coal will be of constant *average or overall* value, the ash percentage of the individual particles in the clean coal *will vary with their size*. This variation is the more marked in the smaller sizes below  $\frac{1}{2}$  in. Usually the proportions of each size fraction

which float are also different. Thus, we may obtain at a specific gravity of 1.5, floats for the 2 to 1 in. size amounting to 79 per cent and having an ash of say 14.5 per cent, while for the same coal the floats of the fines of  $\frac{1}{4}$  in. to 30 mesh at this same specific gravity (1.5) may be as much as 85 per cent, and the ash yield be as low as 7.5 per cent. These figures require consideration.

Now, if clean coal (overall) with 10 per cent ash is desired, the yield as read off from the floats/ash curve is 52.0 per cent, and the gravity of separation is 1.405. On the other hand, if the overall sample is screened beforehand and the individual fractions treated separately, the specific gravity of separation being maintained at 1.405, the yields, their percentage ash, and their respective contributions to the overall values are distributed as in Table 11.

Thus, the yield per cent (51.6) of the overall calculated from the different size fraction curves at self-same gravity agrees well with

**TABLE 11 — VALUES AT A DEFINITE SPECIFIC GRAVITY (1.405)**

( See Coal Washability Curves of Fig. 14 )

| Size,<br>inches                   | PER CENT<br>OF THE<br>TOTAL | YIELD<br>PER CENT<br>AT SP. GR.<br>1.405 | ASH<br>PER CENT<br>IN EACH<br>SIZE | CONTRIBUTION<br>TO OVERALL<br>YIELD OF<br>WASHED COAL | CONTRIBUTION<br>TO OVERALL<br>ASH<br>$\frac{d \times e}{100}$ |
|-----------------------------------|-----------------------------|--|------------------------------------|---|---|
| (a)                               | (b)                         | (c)                                      | (d)                                | (e)   | (f)   |
| 3 to 2                            | 15.96                       | 48.0                                     | 11.6                               | 7.7   | 0.89  |
| 2 to 1                            | 25.60                       | 49.0                                     | 12.0                               | 12.5  | 1.50  |
| 1 to $\frac{1}{2}$                | 21.38                       | 46.5                                     | 11.9                               | 9.9   | 1.18  |
| $\frac{1}{2}$ to $\frac{1}{4}$    | 11.40                       | 45.0                                     | 11.1                               | 5.1   | 0.57  |
| $\frac{1}{4}$ to $\frac{1}{8}$    | 7.64                        | 53.0                                     | 8.4                                | 4.0   | 0.34  |
| $\frac{1}{8}$ to 30 mesh          | 10.72                       | 71.5                                     | 5.5                                | 7.7   | 0.42  |
| $\times$ 30 mesh                  | 7.30                        | 64.0                                     | 5.5                                | 4.7   | 0.26  |
| Overall calculated                | 100.00                      | 51.6                                     | 10.0                               | 51.6  | 5.16  |
| Overall observed from<br>Fig. 14H | 100.00                      | 52.0                                     | 10.0                               | ...   | ...   |

the yield per cent (52.0) observed from the overall curve. In fact, it is on this basis that the overall curve is often constructed. It is seen, however, from Table 11 that the yield per cent varies from 45 to 71.5 for the different fractions at the self-same gravity, while the per cent ash ranges from 12.0 to 5.5, being least in the smallest sizes.

Now, if this 52 per cent of clean coal having 10 per cent ash (obtained at a gravity 1.405) be screened after washing, then each of the different size fractions instead of having 10 per cent ash will have the percentages of ash indicated in column (d) of Table 11. Thus, strictly speaking, uniformity in ash per cent is by no means obtained; and, if any size

fraction of stipulated ash be required, screening after washing certainly will not give the desired result.

#### YIELD AT SELF-SAME ASH PER CENT

To get the same percentage ash in different size fractions, we can screen the coal first and wash the different fractions at the appropriate gravities (which differ for each size) to give 10 per cent ash. The yield per cent and specific gravities are read off from floats/ash and gravity curves respectively. The values obtained from the curves for different fractions are shown in Table 12, column (c). These are the values which we

TABLE 12 — VALUES AT CONSTANT ASH ( 10 PER CENT )

( See Coal Washability Curves of Fig. 14 )

| Size, inches                   | PER CENT YIELD OF THE TOTAL | PER CENT YIELD WITH 10 PER CENT ASH | SPECIFIC GRAVITY OF CUT | CONTRIBUTION TO OVERALL YIELD $\frac{(b \times c)}{100}$ | CONTRIBUTION TO OVERALL ASH |
|--------------------------------|-----------------------------|-------------------------------------|-------------------------|--|-----------------------------|
| (a)                            | (b)                         | (c)                                 | (d)                     | (e)  | (f)                         |
| 3 to 2                         | 15.96                       | 20.0                                | 1.360                   | 3.2  | 0.32                        |
| 2 to 1                         | 25.60                       | 21.0                                | 1.370                   | 5.4  | 0.54                        |
| 1 to $\frac{1}{2}$             | 21.38                       | 18.0                                | 1.377                   | 3.8  | 0.38                        |
| $\frac{1}{2}$ to $\frac{1}{4}$ | 11.40                       | 30.0                                | 1.388                   | 3.4  | 0.34                        |
| $\frac{1}{4}$ to $\frac{1}{8}$ | 7.64                        | 68.0                                | 1.443                   | 5.2  | 0.52                        |
| $\frac{1}{8}$ to 30 mesh       | 10.72                       | 95.0                                | 1.698                   | 10.2   | 1.02                        |
| × 30 mesh                      | 7.30                        | 90.0                                | 1.700                   | 6.6  | 0.66                        |
| Overall calculated             | 100.00                      | 37.8                                | ...                     | 37.8   | 3.78                        |
| Overall observed from Fig. 14H | 100.00                      | 52.0                                | 1.405                   | ...  | ...                         |

TABLE 13 — VALUES AT CONSTANT ASH ( 10 PER CENT )

( See Coal Washability Curves of Fig. 16 )

| Size, inches                   | PER CENT OF THE TOTAL | YIELD PER CENT WITH 10 PER CENT ASH ( FROM CURVES ) | SPECIFIC GRAVITY OF CUT | CONTRIBUTION TO OVERALL YIELD | CONTRIBUTION TO OVERALL ASH |
|--------------------------------|-----------------------|---|-------------------------|-------------------------------|-----------------------------|
| (a)                            | (b)                   | (c)   | (d)                     | (e)                           | (f)                         |
| 3 to 2                         | 28.85                 | 10.7  | 1.364                   | 3.09                          | 0.31                        |
| 2 to 1                         | 25.65                 | 21.0  | 1.378                   | 5.39                          | 0.54                        |
| 1 to $\frac{1}{2}$             | 17.42                 | 32.8  | 1.390                   | 5.71                          | 0.57                        |
| $\frac{1}{2}$ to $\frac{1}{4}$ | 7.90                  | 35.0  | 1.380                   | 2.77                          | 0.28                        |
| $\frac{1}{4}$ to $\frac{1}{8}$ | 7.13                  | 72.3  | 1.458                   | 5.15                          | 0.51                        |
| $\frac{1}{8}$ to 30 mesh       | 8.36                  | 95.6  | 1.685                   | 7.99                          | 0.80                        |
| × 30 mesh                      | 4.69                  | 94.3  | 1.810                   | 4.42                          | 0.44                        |
| Overall calculated             | 100.00                | 34.5  | ...                     | 34.52                         | 3.45                        |
| Overall observed from Fig. 16H | 100.00                | 47.8  | 1.407                   | ...                           | ...                         |

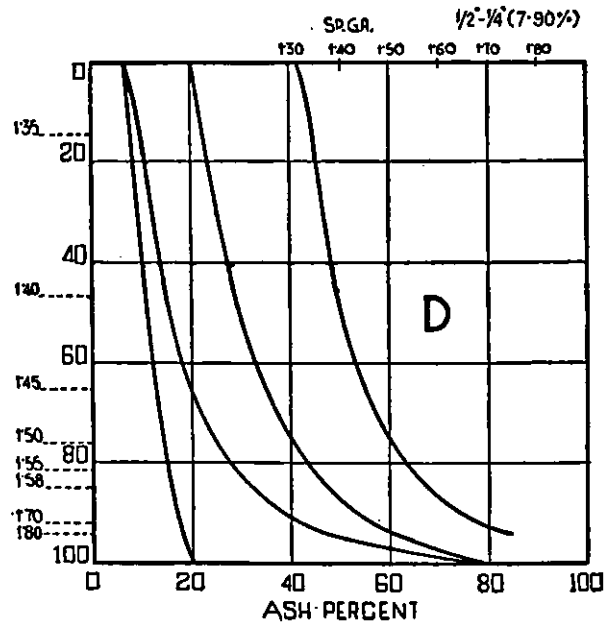
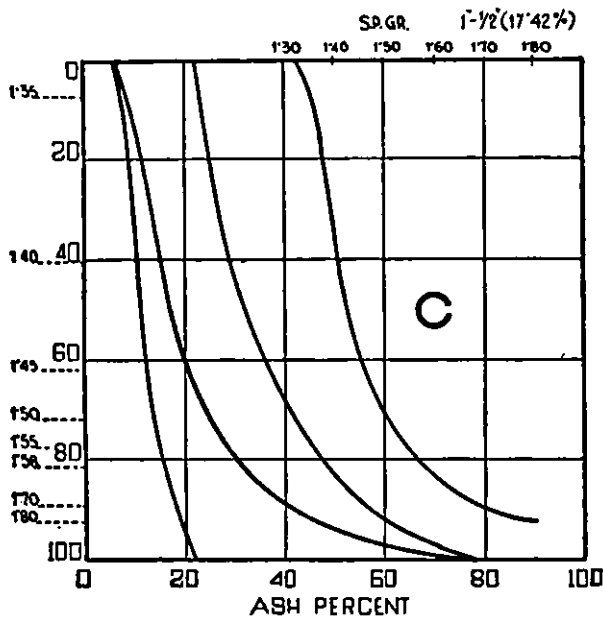
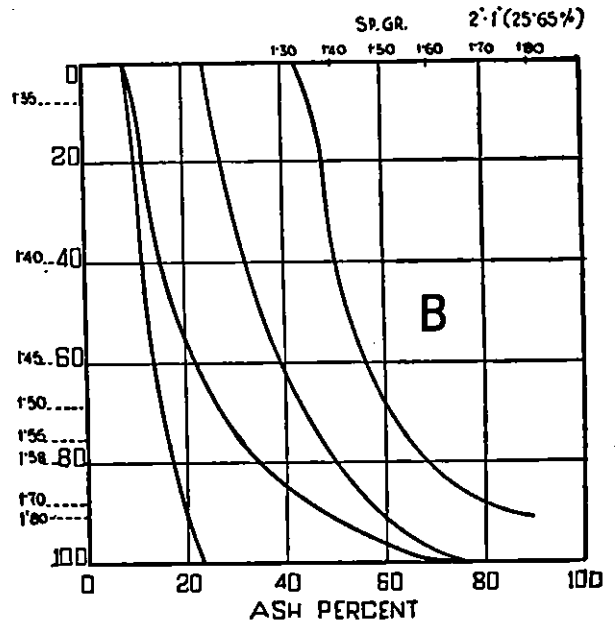
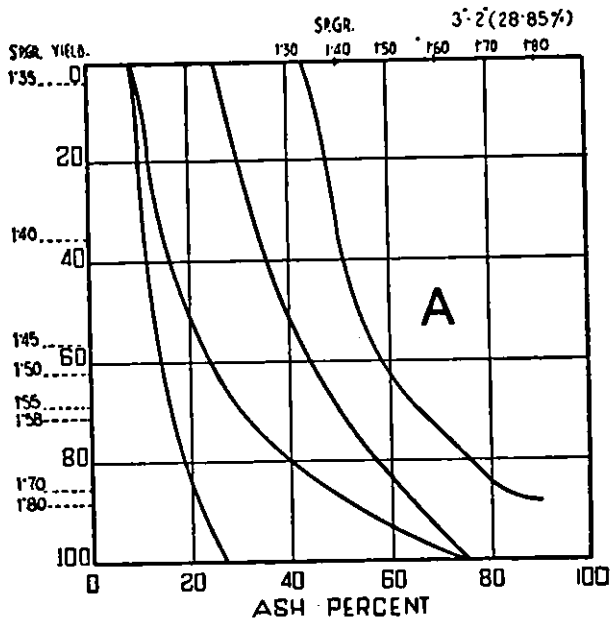


FIG. 16 (A, B, C, D)

should get if we were first to screen the coal to the said sizes, and then wash each size so that it gives its maximum yield of 10 per cent ash coal.

If now we calculate on the whole coal the yields for each size (see column e) and add them together, we find the overall yield of such 10 per cent ash coal is only 37.8 per cent, against 52.0 previously obtained for 10 per cent ash coal for the coal cut at a

gravity of 1.405 for all the sizes. *This difference is remarkable.* (It amounts to 52.0—37.8, i.e. 14.2 per cent of the original coal.) Nor is it easy at first sight to account for it.

In order to verify the figures, it was decided to take another large hand-picked sample (2,500 lb.), crush it to 3 in., and divide into four equal parts. Part (1) was screened and each size tested for washability in the

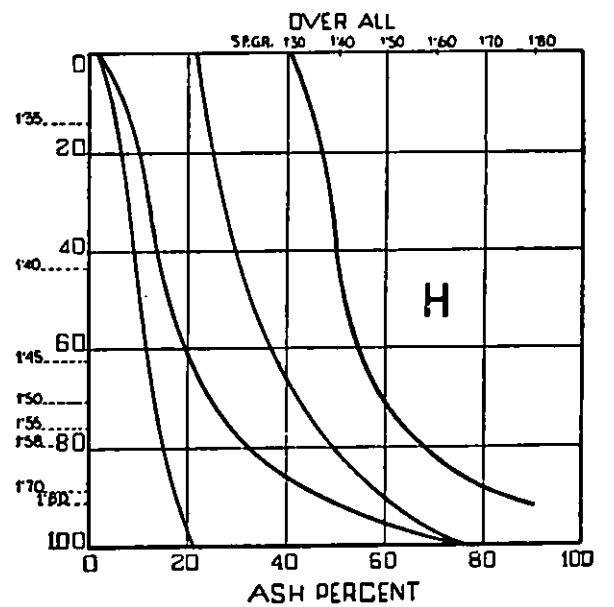
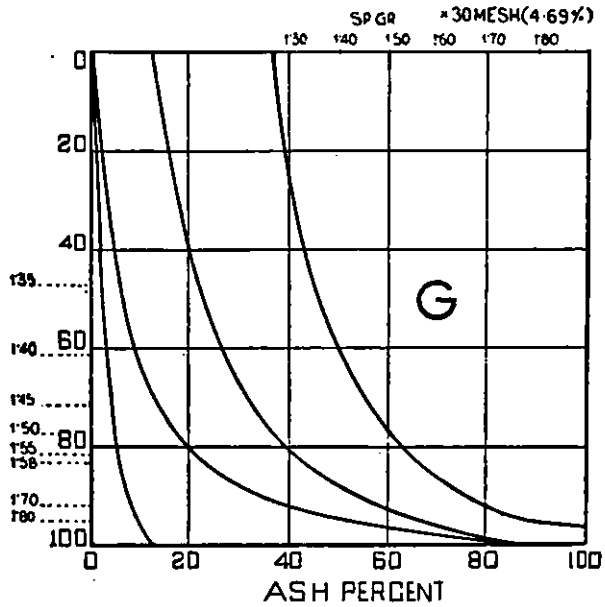
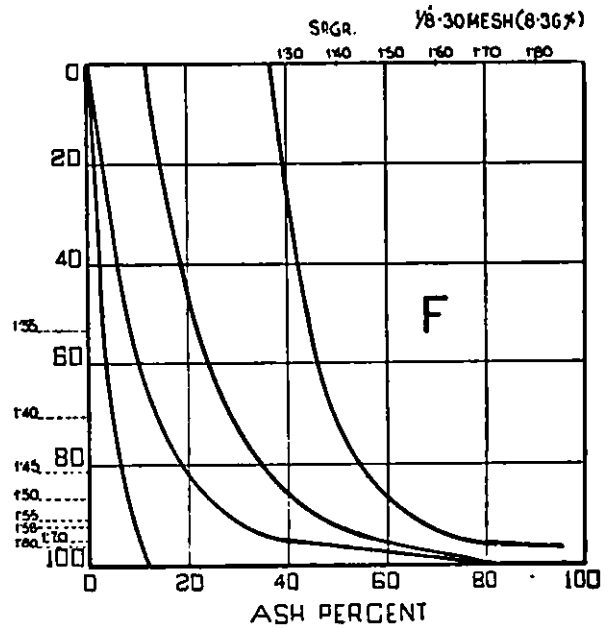
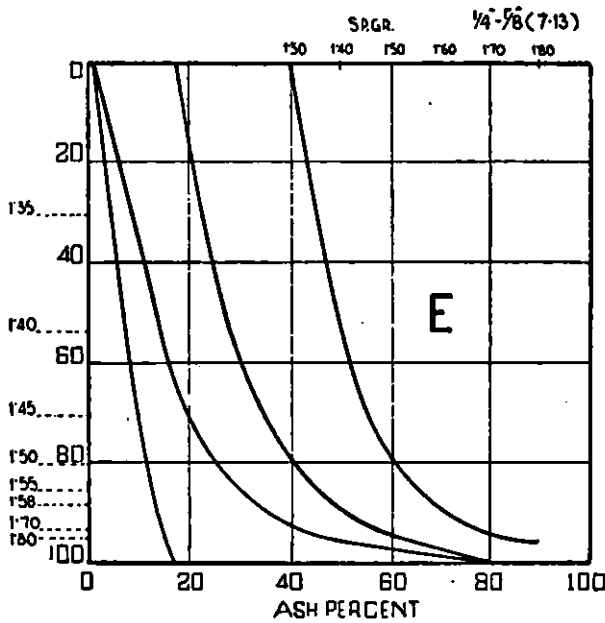
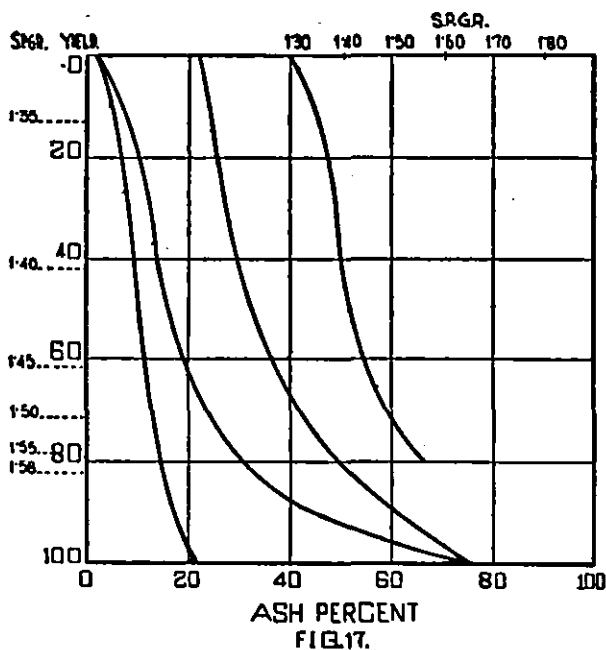


FIG.16 (E,F,G & H)

ordinary way. Part (2) was not screened, but tested for washability direct. Part (3) was screened, and treated at the indicated specific gravities (see above) to get 10 per cent ash coal for each fraction. Part (4) was kept in reserve. The overall ash for the sample was 21.5 per cent. The results for washability tests on part (1) are shown in Figs. 16A to H: the tests on part 2 are shown in Fig. 17. Fig. 16H gives the over-

all values, and should thus be identical with Fig. 17, neglecting experimental errors.

Table 13 shows the results for part (1) on the lines of Table 12. The yield of 10 per cent ash coal, when cut at the appropriate specific gravity, is (from the curves of each size) 34.5 per cent; while if the coal as a whole, Fig. 16H, is cut at a specific gravity of 1.407, the yield of 10 per cent ash coal is 47.8, a difference of 13.3 per cent.



From Fig. 17 this was checked. The same yield, namely 47.8 per cent, is obtained for 10 per cent ash coal from the unscreened sample. The proper specific gravity for each fraction to give 10 per cent ash coal was read from each of the curves of Fig. 16. The values are shown in column (d) of Table 13. These specific gravity values were used in testing sample 3, each size being floated at the specific gravity necessary to give 10 per cent ash coal.

The results of Table 14 show ash figures approaching closely to 10 per cent in most cases, though the experimental error is not small. This is probably due to attempts to effect a cut at a specific gravity which corresponds with a highly inclined part of the

characteristic. In the main, however, the results verify the previous tests and argument.

Table 14, column (e), also shows the contribution of each fraction to the overall ash. The amount of ash contributed from the  $\frac{1}{2}$  in. to 30 mesh fraction is comparatively large.

An examination of Tables 13 and 14 shows that the discrepancy between the total yields of the sized coal washed to give 10 per cent ash on the one hand and of the washed overall coal floated at 1.407 sp. gr. on the other (a discrepancy of 13.3 per cent) arises from the fact that in washing at 1.407 we actually take less quantities of the smaller sized material (whose ash percentage is then very low) and we mix with these quantities *greater* amounts of the larger sized material whose ash percentage is only a little higher than 10.0. In order to understand how these differences arise, the characteristics of Fig. 16 should be examined. Note particularly that the characteristics for the larger sized coal are more nearly vertical than are those for the finer sizes. This means that the density yield curves also slope more steeply for the larger coal (*see* STUDY 1). Consequently, a slight change in density or in ash percentage (horizontal) creates a greater change in yield (vertical) values with the larger sizes than it does with the smaller. Alternatively, for a fixed change in yield, the change in density and in ash will be *less* for the larger sizes than for the smaller.

As stated earlier, in order to elucidate the matter a further part of the sample was taken and sized, and each size floated at its right specific gravity to give 10 per cent ash coal in the floats. The yield of each size was found, and its ash determined (*see* TABLE 14). The *sinks* obtained from each

TABLE 14 — EXPERIMENTAL VALUES OF PART (3) FOR CONSTANT ASH (10 PER CENT)

| SIZE, inches                   | SPECIFIC GRAVITY OF CUT | YIELD PER CENT OF TOTAL | ASH PER CENT | CONTRIBUTION TO OVERALL ASH |
|--------------------------------|-------------------------|-------------------------|--------------|-----------------------------|
| (a)                            | (b)                     | (c)                     | (d)          | (e)                         |
| 3 to 2                         | 1.364                   | 2.78                    | 9.8          | 0.27                        |
| 2 to 1                         | 1.378                   | 5.80                    | 10.4         | 0.60                        |
| 1 to $\frac{1}{2}$             | 1.390                   | 5.75                    | 10.5         | 0.60                        |
| $\frac{1}{2}$ to $\frac{1}{4}$ | 1.380                   | 2.73                    | 10.0         | 0.27                        |
| $\frac{1}{4}$ to $\frac{1}{8}$ | 1.458                   | 5.21                    | 9.8          | 0.51                        |
| $\frac{1}{8}$ to 30 mesh       | 1.685                   | 7.87                    | 9.9          | 0.78                        |
| x 30 mesh                      | 1.810                   | 4.39                    | 9.3          | 0.41                        |
| Overall (calculated)           | ...                     | 34.53                   | 10.0         | 3.44                        |



TABLE 15

| SIZE, inches             | AMOUNT IN EACH SIZE | SP. GR. OF CUT | YIELD PER CENT OF THE TOTAL | ASH PER CENT | WT. OF ASH | SP. GR. RANGE | YIELD PER CENT OF THE TOTAL | ASH PER CENT | WT. OF ASH | CUMULATIVE AT SP. GR. 1.407 |      |      |       | CUMULATIVE FOR 10 PER CENT ASH AT PROPER SP. GR. OF CUT |      |      |     |
|--------------------------|---------------------|----------------|-----------------------------|--------------|------------|---------------|-----------------------------|--------------|------------|-----------------------------|------|------|-------|---|------|------|-----|
|                          |                     |                |                             |              |            |               |                             |              |            | (a)                         | (b)  | (c)  | (d)   | (e)   | (f)  | (g)  | (h) |
| 3 to 2                   | 28.85               | 1.364          | 2.78                        | 9.8          | 0.27       | 1.364-1.407   | 8.86                        | 13.0         | 1.15       | 11.04                       | 12.2 | 1.42 | 1.364 | 2.78  | 9.8  | 0.27 |     |
| 2 to 1                   | 25.65               | 1.378          | 5.80                        | 10.4         | 0.60       | 1.378-1.407   | 4.76                        | 13.3         | 0.63       | 10.55                       | 11.7 | 1.23 | 1.378 | 5.80  | 10.4 | 0.60 |     |
| 1 to 1/2                 | 17.42               | 1.390          | 5.75                        | 10.5         | 0.60       | 1.390-1.407   | 1.06                        | 14.1         | 0.23       | 7.41                        | 11.2 | 0.63 | 1.390 | 5.75  | 10.5 | 0.60 |     |
| 1/2 to 1/4               | 7.90                | 1.390          | 2.78                        | 10.0         | 0.27       | 1.390-1.407   | 1.12                        | 13.5         | 0.15       | 3.85                        | 10.9 | 0.42 | 1.390 | 2.78  | 10.0 | 0.27 |     |
| Total of upper fractions | ...                 | ...            | ...                         | ...          | ...        | ...           | +16.39                      | 13.2         | +2.16      | 33.45                       | 11.7 | 3.90 | ...   | 17.06   | 10.2 | 1.74 |     |
| 1/4 to 30 mesh           | 7.13                | 1.407          | 4.12                        | 7.9          | 0.32       | 1.407-1.458   | 1.09                        | 17.0         | 0.19       | 4.12                        | 7.9  | 0.32 | 1.458 | 5.21  | 9.8  | 0.51 |     |
| 30 to 30 mesh            | 8.36                | 1.407          | 5.98                        | 5.2          | 0.31       | 1.407-1.685   | 1.89                        | 24.9         | 0.47       | 5.98                        | 5.2  | 0.31 | 1.685 | 7.87  | 9.9  | 0.78 |     |
| 30 to 30 mesh            | 4.69                | 1.407          | 3.05                        | 4.1          | 0.12       | 1.407-1.810   | 1.34                        | 21.6         | 0.29       | 3.05                        | 4.1  | 0.12 | 1.810 | 4.39  | 9.3  | 0.41 |     |
| Total of lower fractions | ...                 | ...            | ...                         | ...          | ...        | ...           | -4.32                       | 22.0         | -0.95      | 13.15                       | 5.7  | 0.75 | ...   | 17.47   | 9.7  | 1.70 |     |
| Total of whole coal      | 100.0               | ...            | ...                         | ...          | ...        | ...           | 12.07                       | 10.0         | ...        | 46.60                       | 10.0 | 4.65 | ...   | 34.53   | 10.0 | 3.44 |     |

[Nett gain

size (above 1/4 in.) were then tested in a liquid of specific gravity of 1.407, and the floats of the sizes below 1/4 in. were tested at the same specific gravity. The smaller sizes require a higher gravity than 1.407 to give 10 per cent ash coal. See column (n) of Table 15.

In Table 15 the different size fractions of part 3 of the sample are given in column (b) as percentages of the whole coal. Columns (c) to (f) show the yields, etc., using the specific gravity of cut stated. Observe that for the finer sizes the specific gravity is 1.407. Columns (g) to (j) show the yields, etc., for the specific gravity ranges stated under (g). As the specific gravities in (c) were below 1.407 for the larger sizes (i.e. above 1/4 in.), columns (h), (i) and (j) show the additional yields, etc., in these sizes which float at 1.407; while for the smaller sizes (below 1/4 in.) the values are those for coal which sinks at 1.407 but which floats at the specific gravity necessary for 10 per cent ash coal for each size.

It is clear that, in the coal above 1/4 in., 16.39 per cent of additional floats carrying 13.2 per cent ash (i.e. 2.16 ash units) will be found on washing at 1.407 gravity; while we shall lose at this specific gravity 4.32 per cent of the coal below 1/4 in. carrying 22 per cent ash, i.e. 0.95 ash units. The nett gain will be 12.07 (i.e. 16.39-4.32) per cent of coal carrying 1.21 ash units, i.e. coal of ash of 10 per cent on an average. The nett result is that, when we wash the unsized coal at 1.407, we increase the yield of 10 per cent ash coal by 12.07 per cent over the total obtained by washing each of the sized fractions separately to give 10 per cent ash coal.

These figures are verified in columns (k) to (q) of Table 15 where cumulative values are given.

It will be seen that the coal washed unsized at 1.407 consists of (a) 33.45 parts of large coal (above 1/4 in.) having 11.7 per cent ash and (b) 13.15 parts of small coal (below 1/4 in.) having only 5.7 per cent ash, the overall ash being 10 per cent nevertheless.

Table 13 shows that the increased yield should be 13 per cent while Table 15 shows that it is 12 per cent. The difference is due to sampling and other errors.

The upshot of the above experiments is to prove that if we need coal of definite ash and definite size, we shall have to screen first and then wash. But if we are going to break

TABLE 16

| YIELD,<br>per cent | ASH PER CENT OF<br>SAMPLE No. 1 |                     | ASH PER CENT OF<br>SAMPLE No. 2 |                     |
|--------------------|---------------------------------|---------------------|---------------------------------|---------------------|
|                    | Part A<br>(sized)               | Part B<br>(unsized) | Part A<br>(sized)               | Part B<br>(unsized) |
| 10                 | 4.3                             | 4.5                 | 3.9                             | 4.0                 |
| 20                 | 6.4                             | 6.5                 | 7.3                             | 7.6                 |
| 30                 | 7.9                             | 8.1                 | 10.2                            | 10.6                |
| 40                 | 9.1                             | 9.4                 | 12.5                            | 12.9                |
| 50                 | 10.3                            | 10.4                | 14.4                            | 14.8                |
| 60                 | 11.4                            | 11.6                | 16.1                            | 16.4                |
| 70                 | 12.8                            | 12.9                | 17.8                            | 18.0                |
| 80                 | 14.6                            | 14.5                | 19.6                            | 19.8                |
| 90                 | 17.3                            | 17.1                | 21.5                            | 21.8                |
| 100                | 21.5                            | 21.4                | 23.9                            | 24.0                |

down the coal later (as for coking) or if the average ash of the unsized coal will serve independently of the size of the pieces of which it is constituted, then sizing prior to washing is *definitely to be avoided*. We may, however, be compelled to screen or size the coal to some degree because of the functioning and/or limitations of the coal washer. Thus, for a gravity washer, we may have to screen off coal below  $\frac{1}{2}$  in. In such cases it would seem to be advisable to explore the possibilities of washing the larger coal to give a somewhat increased ash (above the stipulated figure) in order to get a much increased yield. At the same time it will be necessary to wash the smaller coal, below  $\frac{1}{2}$  in., to give less than the overall average ash. The degree to which the ash in the smalls should be reduced can be assessed from a careful examination of the washability curves, and from experiments on the above lines.

It remains to say that the procedure of sizing and individual testing of each size in the sink and float tests gives the same overall washability curves and results as does the testing of the unsized coal. Table 16 summarizes experimental tests on different yields to verify this.

The results show that in the laboratory we may size and then carry out the sink and float tests, or we may do the tests on the

unsized coal direct, according to our requirements.

It is important not to confuse the results given in Table 16 with the results of the earlier tests wherein it was shown that, by washing coal unsized at a fixed specific gravity, a higher yield of coal of stipulated ash (say 10 per cent) can be obtained than that given by washing each of the sized fractions to give coal of 10 per cent ash. The explanation is that, in the latter case, we vary the specific gravity of separation for each size to give the maximum yield of 10 per cent ash coal for that size. In Table 16, however, the tests on the sized and the unsized samples are first done at certain specific gravities; the yield curves (total floats/ash) are obtained, and the total floats found for each *specific gravity*. This involves summation for the sized coal, but not for the unsized. The values show, therefore, that, if we cut at one definite specific gravity, the total yield is identical whether the coal has been sized or not. But if we cut each size to give a certain ash, say 10 per cent, (and this will involve a number of different specific gravity cuts) the total yield may be far from identical with the yield of 10 per cent ash coal obtained by washing the unsized sample as a whole at one specific gravity.

*CPR*