REPORT No. 10
OF 1949.

FUEL RESEARCH INSTITUTE

OF SOUTH AFRICA.

SUBJECT:

A GRAPHICAL METHOD FOR ASSESSING THE RELATIVE SUITABILITIES OF COAL WASHING PROCESSES FROM FLOAT AND SINK AND RELEVANT DATA.

DIVISION:

ENGINEERING.

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SUMMARY:-

The problem of predicting practical yield and ash values when washing coal in a specified type of washer on the basis of (theoretical) float and sink data obtained from laboratory tests is discussed in this report.

A method of approach is suggested whereby the data are presented graphically in such a form that cumulative yield and ash content, at any specific gravity, are expressed as areas.

Utilising the Tromp distribution factor curves of the specified washer these graphical representations are modified to give a clear picture of the nature of the separation that can be expected. The yield and character of the product can be evaluated by measuring appropriate areas.

The application of this method is illustrated by an example in which the performance of two washers is estimated assuming the same feed and specific gravity of separation in both cases.

Formulae for determining the efficiency of a washing process are derived from the diagrams, and these are compared with one of the recognised efficiency expressions.

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A GRAPHICAL METHOD FOR ASSESSING THE RELATIVE SUITABILITY OF COAL WASHING PROCESSES FROM FLOAT AND SINK AND RELEVANT DATA.

INTRODUCTION:

As many coal deposits are of comparatively low grade on account of the presence of high ash or mineral constituents, it is frequently necessary to investigate the possibility of improving the quality of the coal mined by subjecting it to a washing process. An investigation of this nature can be divided broadly into two phases, viz. the study of the coal to be treated and the selection of a washing process capable of effecting the desired separation on a commercial scale.

The first phase of the investigation normally consists of float and sink analyses of the raw coal, crushed to various sizes. From the results of these tests, one can determine whether the coal is amenable to washing, the optimum size at which it should be treated and the specific gravity at which the separation should be effected. This part of the investigation does not present appreciable difficulties. Having obtained this information the next step is to select a suitable washer for commercial operation. It is frequently found difficult to arrive at a completely satisfactory solution to this phase of the problem.

The difficulty of the washing problem(1) may be assessed by determining the $\pm$ 0.1 specific gravity distribution at the desired specific gravity of separation and, as experience has shown that coal washers can be classified according to the maximum $\pm$ 0.1 specific gravity distribution at which they may be expected to operate satisfactorily, it is possible to decide which type of washer would probably satisfy the requirements. The size grading of the feed, capital cost of plant, washing costs, etc., will then have to be taken into account before a final decision can be made. A washer selected on the basis of the above data may produce a product of the desired quality with reasonable efficiency but there is no assurance that it will be the best washer to instal. As a rule, assurance can only be obtained with a degree of certainty if the final selection is preceded by laboratory and pilot plant washing tests using the various types of washers potentially suitable for the required separation.

A detailed investigation of this nature is not always possible and, in any event, is likely to be prolonged and costly. This work would be simplified materially if it were possible to estimate the yield and ash content of the product which would be obtained in practice when using particular washers. Such information may rule out a number of types immediately and would reduce pilot plant tests appreciably. As no description or reference to a method for arriving at this information was found in the available literature a procedure was worked out and is presented herewith.

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THE TROMP DISTRIBUTION FACTOR CURVE:

The method adopted is based on the "Tromp distribution factor curve" of a washer(2). This curve may be considered a characteristic of a particular washer and is independent of the composition of the coal but is influenced to a certain extent by the size grading of the feed. It is assumed that every manufacturer of coal washing equipment will be able to make available sufficient detailed data of actual washing tests conducted in their plant to enable one to determine the Tromp distribution factor curve of the particular type of washer when treating coal of similar size grading to that which it is proposed to wash. The distribution factor curve of the washer can then be used in conjunction with the float and sink data of the raw coal to estimate the yield and ash content which would be obtained in practice.

The significance of the Tromp distribution factor curve is probably so well known as to require little further comment. For the sake of completeness, however, a brief explanation will be given. The reader is referred to Tromp's paper(2) for a more detailed treatise.

A typical Tromp distribution factor curve is shown in Figure I. This curve is derived from individual float and sink analyses of the product and tailing obtained during a test and shows what percentage of the feed, at any particular specific gravity, has gone to the product and what has gone to the tailing. Thus, Figure I shows that 90% of the feed having a specific gravity of Xa has been recovered in the product and that 10% has been rejected to the tailing. The specific gravity of separation in the original test is defined as the specific gravity at which half the material present goes to the product and half to the tailing (i.e. specific gravity X in Figure 1). It may also be mentioned in passing that the slope of the distribution factor curve is a measure of the efficiency of the washer, the steeper the curve, the higher the efficiency of separation.

THE WASHABILITY CURVES OF THE FEED:

As stated previously, it is necessary to carry out a float and sink analysis of the raw coal to determine whether the coal is amenable to washing. To facilitate interpretation of the results, it is customary to plot the "cumulative yield - specific gravity" and "cumulative yield - cumulative ash" curves as shown in Figure 2, these curves being known as the washability curves of the coal. By using the washability curves, the theoretical yield and ash content at any specific gravity of separation may be determined quite readily. The separations achieved in commercial coal washing equipment are generally less accurate so that these theoretical values cannot be applied directly. In order to arrive at more practical data, washability data, modified on the basis of Tromp distribution factor curves have been used.

MODIFIED PRESENTATION OF WASHABILITY DATA:

In order to enable one to predict the actual yield and ash content under practical conditions of separation, it is found expedient to express the washability data in such a form that relevant values are represented as areas. Two curves are required for this purpose and these will be termed the "Quantity distribution curve" and the "Ash distribution curve", respectively, both being derived from the washability curves as indicated below. As frequent reference will be made to one or other of the washability curves it is proposed to

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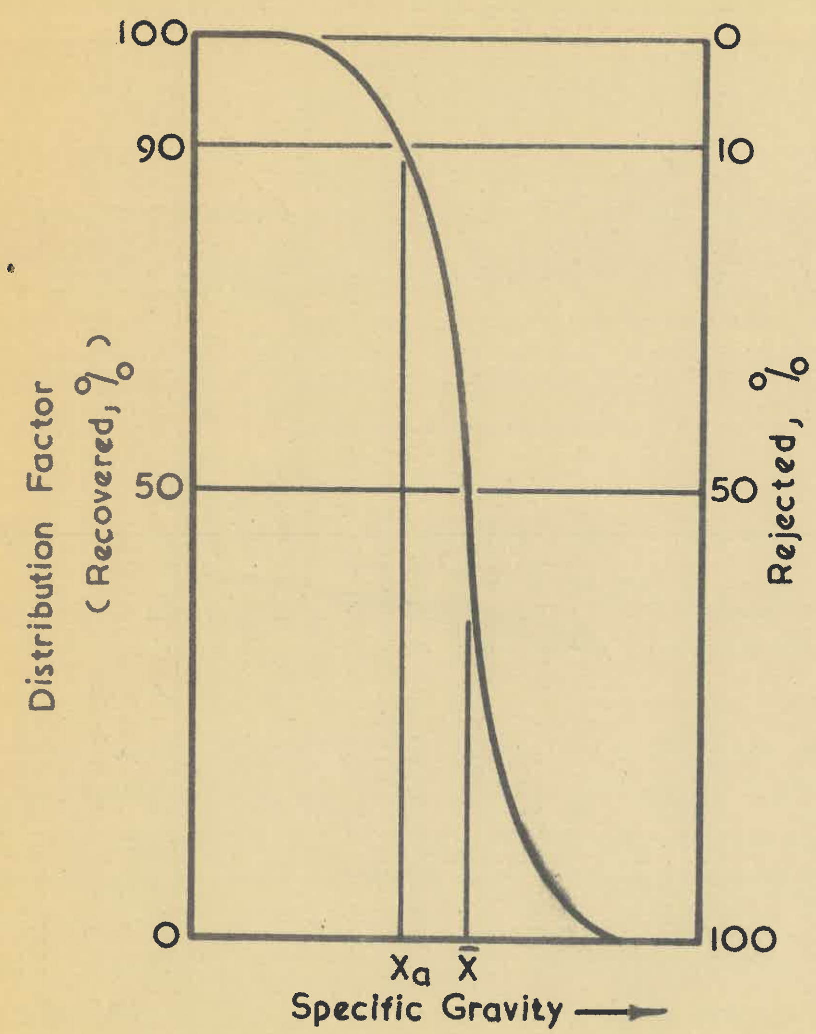

FIGURE 1 A typical Tromp distribution factor curve

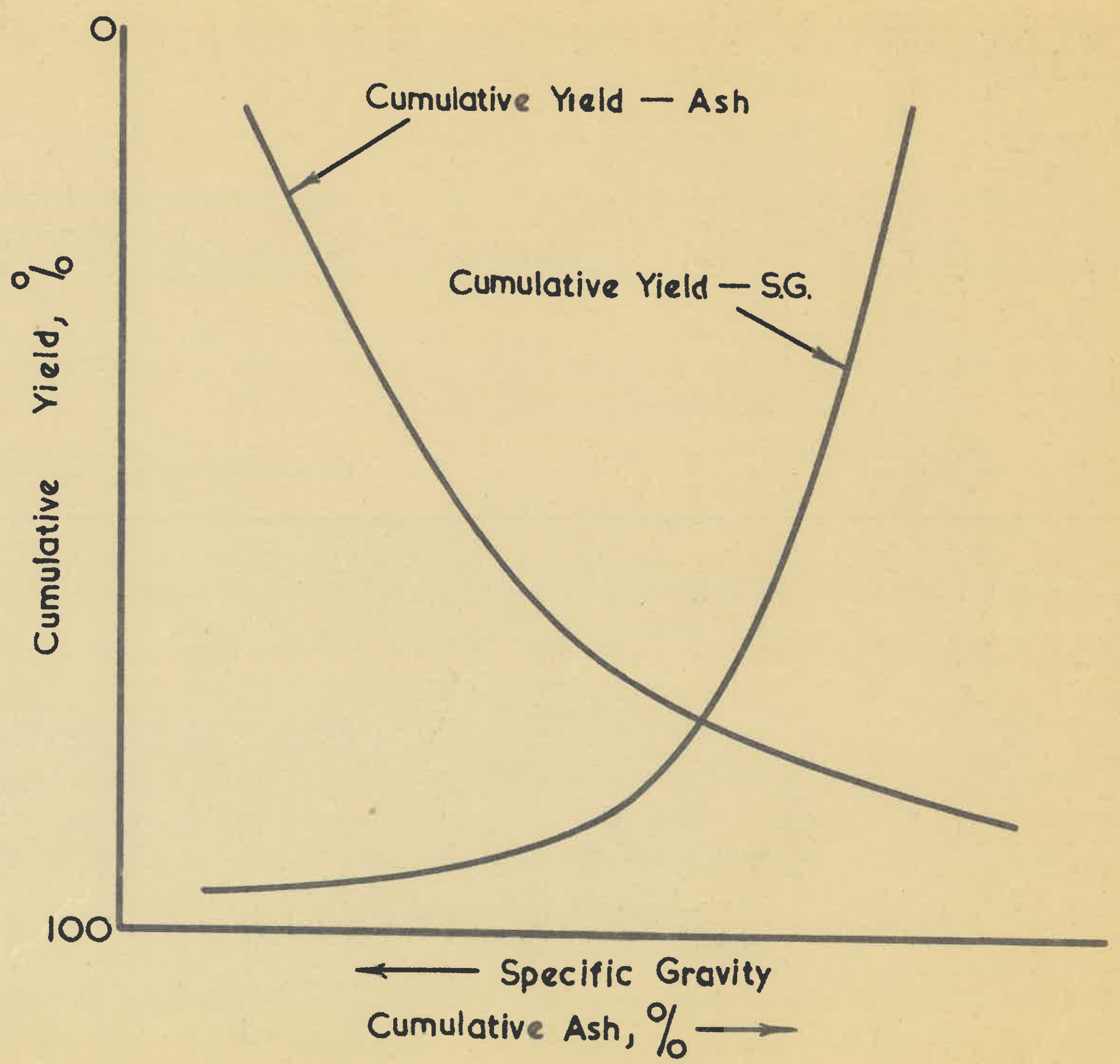

FIGURE 2 Typical washability curves

distinguish the cumulative yield - specific gravity curve from the cumulative yield - ash curve by naming them the "Quantity characteristic curve" and "Ash characteristic curve" respectively.

THE QUANTITY DISTRIBUTION CURVE:

Mathematically the "Quantity distribution curve" is the derivative of the "Quantity characteristic curve" and shows the rate of change of yield with respect to specific gravity. Theoretically this curve should be derived by determining the slope of the Quantity characteristic curve at various specific gravities. It will be sufficiently accurate for all practical purposes, however, merely to determine the fractional yield over a small interval of specific gravity at each point selected as shown in Figure 3.

It will be seen that the Quantity distribution (D_X) at specific gravity, X, is given approximately by

$$D_X = \frac{Y_b - Y_a}{X_b - X_a} \quad \left(\text{theoretically } \frac{\Delta Y}{\Delta X}\right)$$

By proceeding in this manner, the complete Quantity distribution curve can be obtained. It will be clear that the area of the elementary strip, X_aLMX_b, is equivalent to the fractional yield between the specific gravities Xa and Xb, i.e. elementary area $= D_X \times (X_b - X_a)$

$$= \frac{Y_b - Y_a}{X_b - X_a} \times (X_b - X_a)$$

$$= Y_b - Y_a.$$

Therefore, since the cumulative yield at a specified specific gravity, X, is given by the sum of the fractional yields up to that point, it will be appreciated that the cumulative yield, Y_X, is given by the shaded area, P, under the quantity distribution curve. This may be expressed mathematically as:-

$$\text{cumulative yield at specific gravity } X, = Y_X = \int_{X'}^{X} D\,dX = \text{Area P.}$$

As the Quantity distribution curve could generally be expected to have no simple equation, it is proposed that this integration should be done mechanically by means of a planimeter or by some other recognised method of determining areas.

THE ASH DISTRIBUTION CURVES:

As a first step in obtaining, what is termed, the "Ash distribution curve" it is necessary to determine a curve indicating the instantaneous ash at all specific gravities, i.e. a curve showing the actual ash content of the particles. The "Instantaneous ash - specific gravity curve" may be determined from the float and sink data as shown in the following example:

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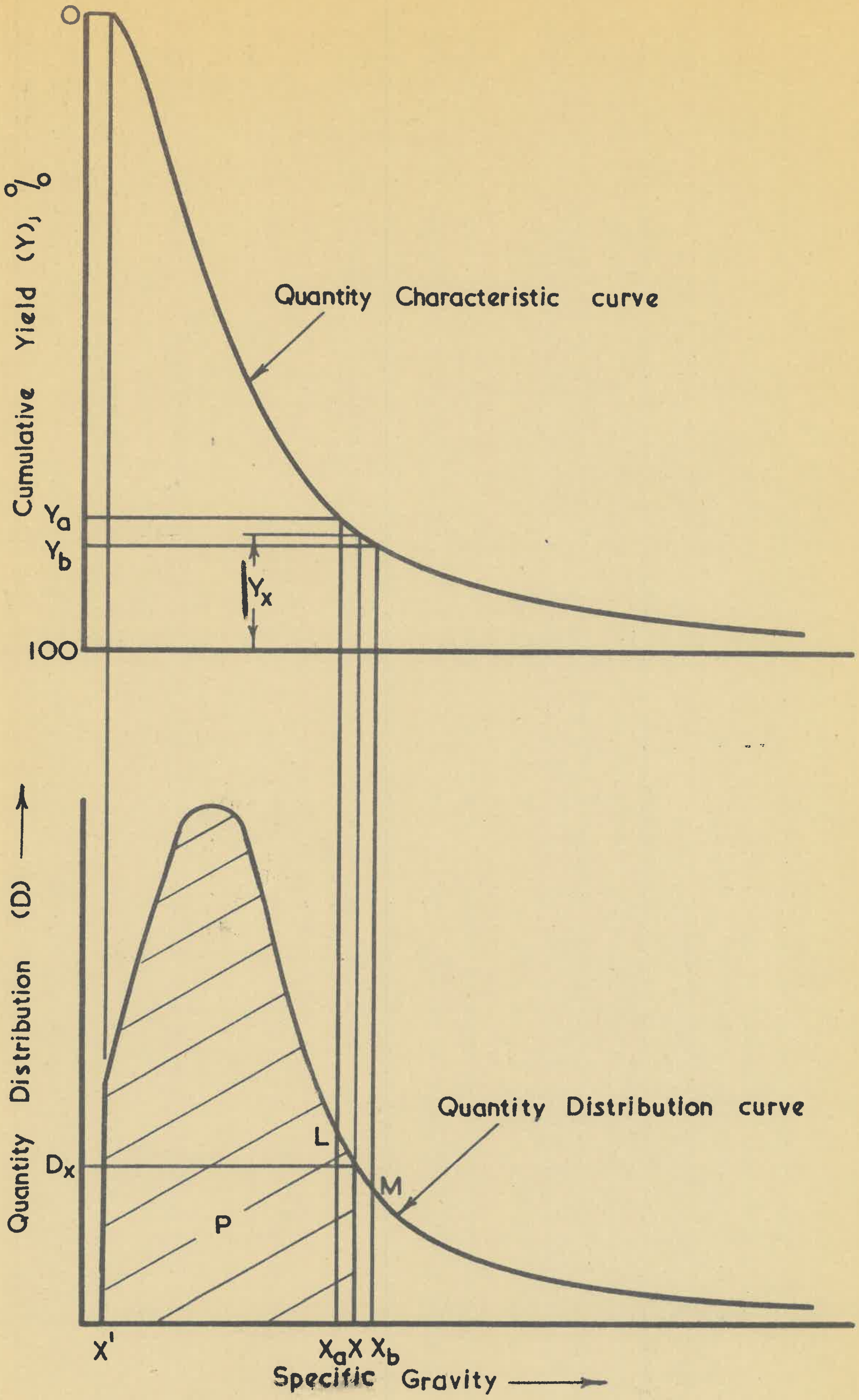

FIGURE 3 Derivation of the Quantity Distribution curve

TABLE 1.

Specific Gravity Interval.	Fractional Yield %.	Fractional Ash %.
1.275	0	0
1.275-1.28	1.2	3.1
1.28-1.30	5.7	3.4
1.3-1.35	21.6	5.7
1.35-1.4	17.7	8.1

If the float and sink analysis of the raw coal has been carried out fractionally, the results may be used directly, but if the float and sink analysis was done cumulatively it will be necessary to determine the relevant fractional values by calculation. Assume that Table 1 represents the fractional float and sink analysis of the feed. It will be seen that 1.2% of the coal lies in the specific gravity range 1.275-1.28 and has an average ash content of 3.1%. Now all particles of this fraction do not have an ash content of 3.1%. The lightest particles present have a lower ash content while the heaviest particles have a higher value. If a linear relationship is assumed over the specific gravity range 1.275 to 1.28, it follows that the particles represented at the mean specific gravity would have an ash content of exactly 3.1% i.e. particles having a specific gravity of 1.2775 would have an ash content of 3.1%. Similarly, the instantaneous ash content at 1.29 specific gravity would be 3.4%. By proceeding in this way the Instantaneous ash - specific gravity curve of the general form shown in Figure 4 can be drawn. The method is approximate but is sufficiently accurate if the interval of specific gravity used for the float and sink analysis is small (say, 0.05 specific gravity).

Now, the ash content of a sample of coal depends not only on the ash content of the particles at each specific gravity, but also on the number of particles at each specific gravity. In other words, the cumulative ash content is a function of the Quantity distribution and the Instantaneous ash. It will readily be seen that the product of instantaneous ash and quantity distribution at a particular specific gravity is a measure of the ash contributed by the particles at that specific gravity. A summation of these products over the whole range of specific gravity would then be a measure of the ash content of the whole coal. The curve which is obtained when the products of instantaneous ash and quantity distribution are plotted against specific gravity will be termed the "Ash distribution curve" and is of the general form shown in Figure 5, the area under this curve being a measure of the ash content.

The actual cumulative ash at specific gravity X is then given by the equation

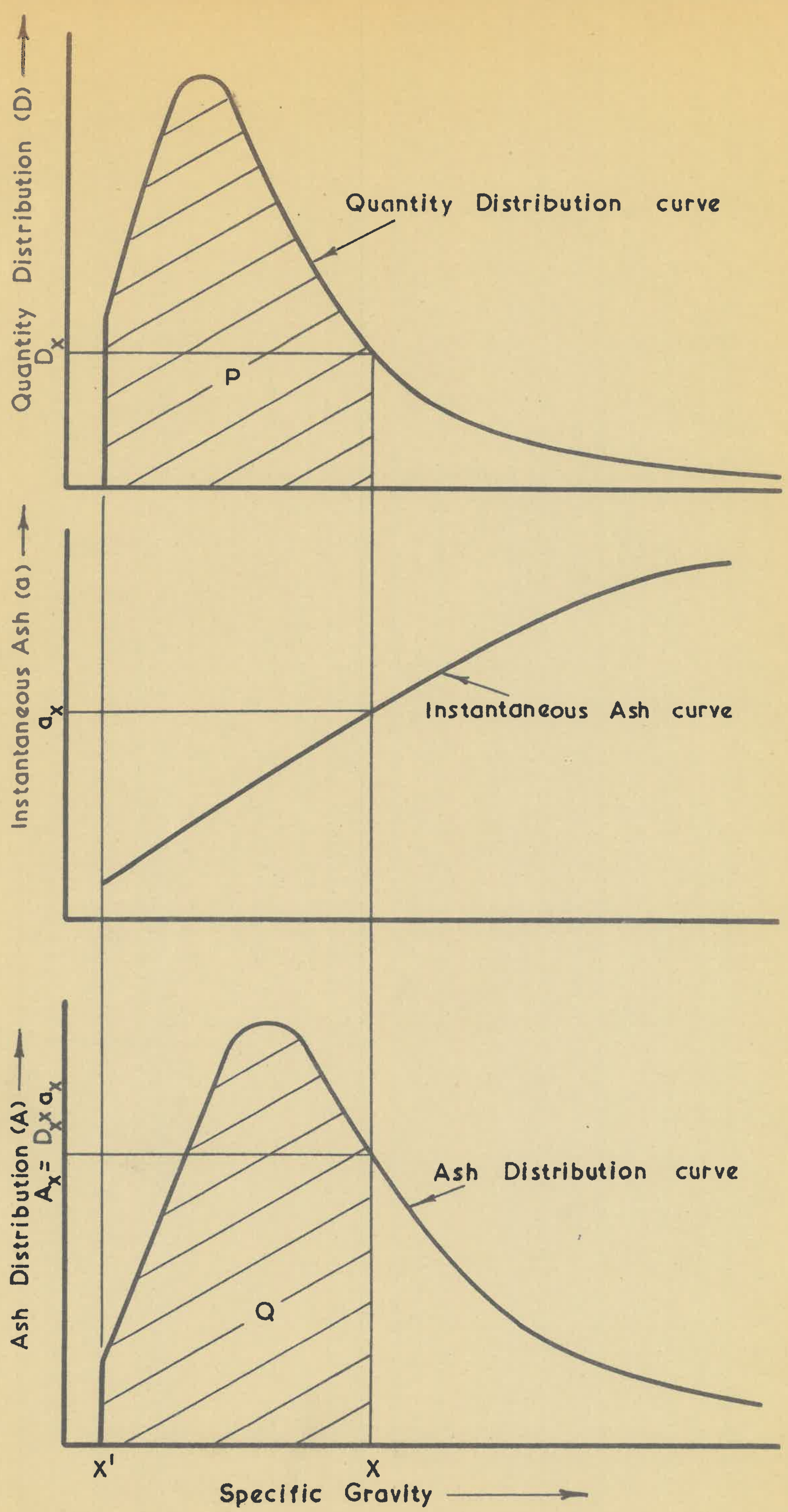

FIGURE 5 Derivation of the Ash Distribution curve

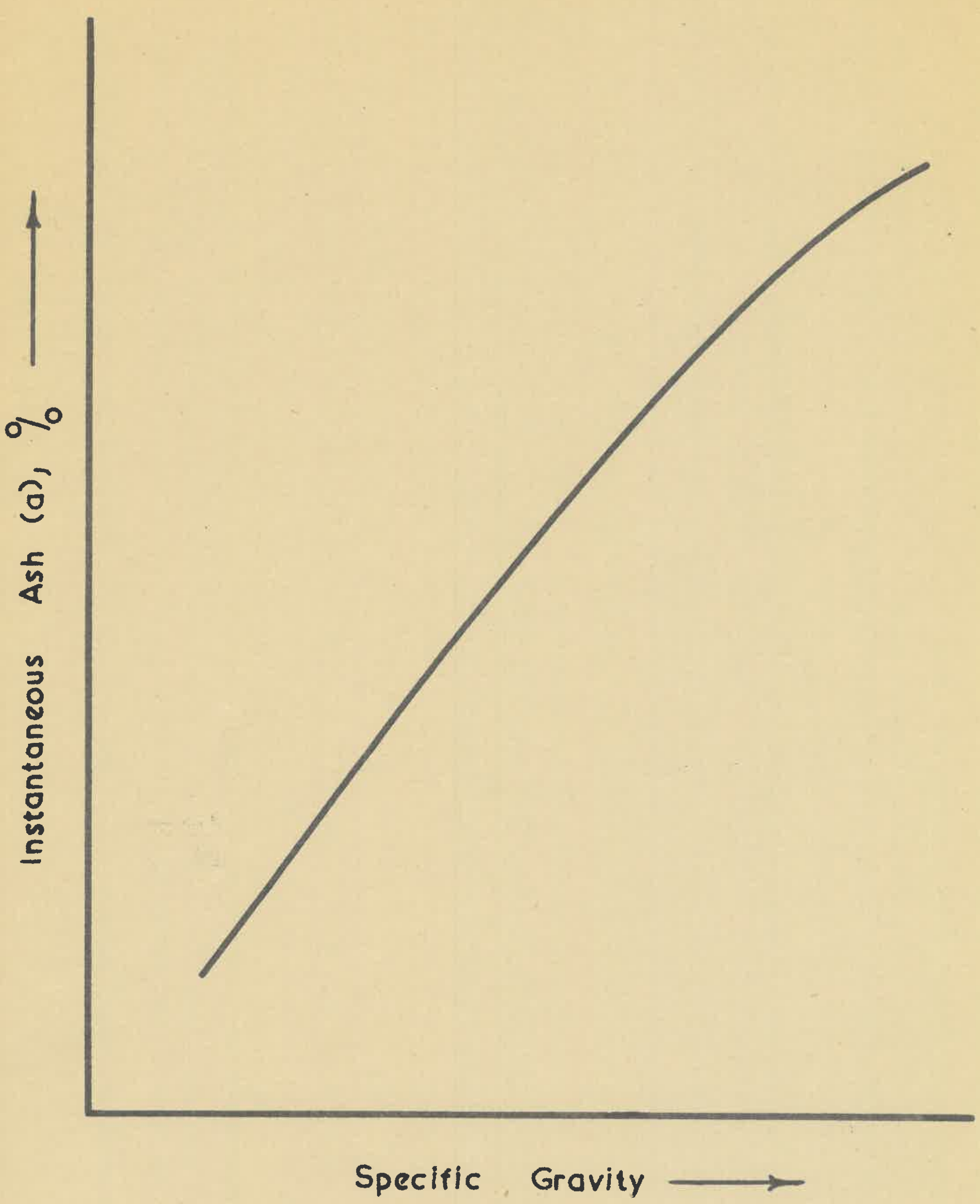

FIGURE 4 A typical Instantaneous Ash curve

$$\text{Cumulative ash at specific gravity } X = \frac{\int_{X'}^{X} A\,dX}{\int_{X'}^{X} D\,dX}$$

$$= \frac{\text{Area } Q}{\text{Area } P}$$

ESTIMATION OF THE YIELD AND ASH CONTENT UNDER PRACTICAL CONDITIONS:

As shown above, the Quantity distribution and Ash distribution curves may be used to enable one to express the theoretical yield and ash content of any specific gravity fraction in terms of areas.

By using the Tromp distribution factor curve of a particular washer in conjunction with these two curves it now becomes a comparatively easy matter to forecast the yield and ash content likely to be obtained in practice.

The Quantity distribution curve shown in Figure 6 will be considered first and it will be assumed that it is desired to effect a separation at specific gravity $\bar{X}$.

If the separation were perfect, the "cutting line" would be $\bar{X}A$ and the yield would be given by the area $X'PA\bar{X}$. In practice, however, the separation will not be perfect. Let it be assumed that it will deviate from the ideal separation as indicated by the Tromp distribution factor curve shown in Figure 7. This curve shows that all material having a specific gravity lower than X_a will be recovered in the product, while all material having a specific gravity greater than X_c will be rejected in the tailing. The two extremeties of the "cutting line" will therefore be points B and X_c, Figure 6. For specific gravities between X_a and X_c, a varying percentage of the material present at any specific gravity is recovered in the product the remainder being discarded. Thus, Figure 7 shows that 80% of the material having specific gravity X_b will be recovered in the product. At this specific gravity, the quantity of feed present is represented by the line X_bC (of thickness ΔX) (Figure 6). The quantity which would be recovered in the product will then be represented by the line $X_bD = 0.8\ X_bC$.

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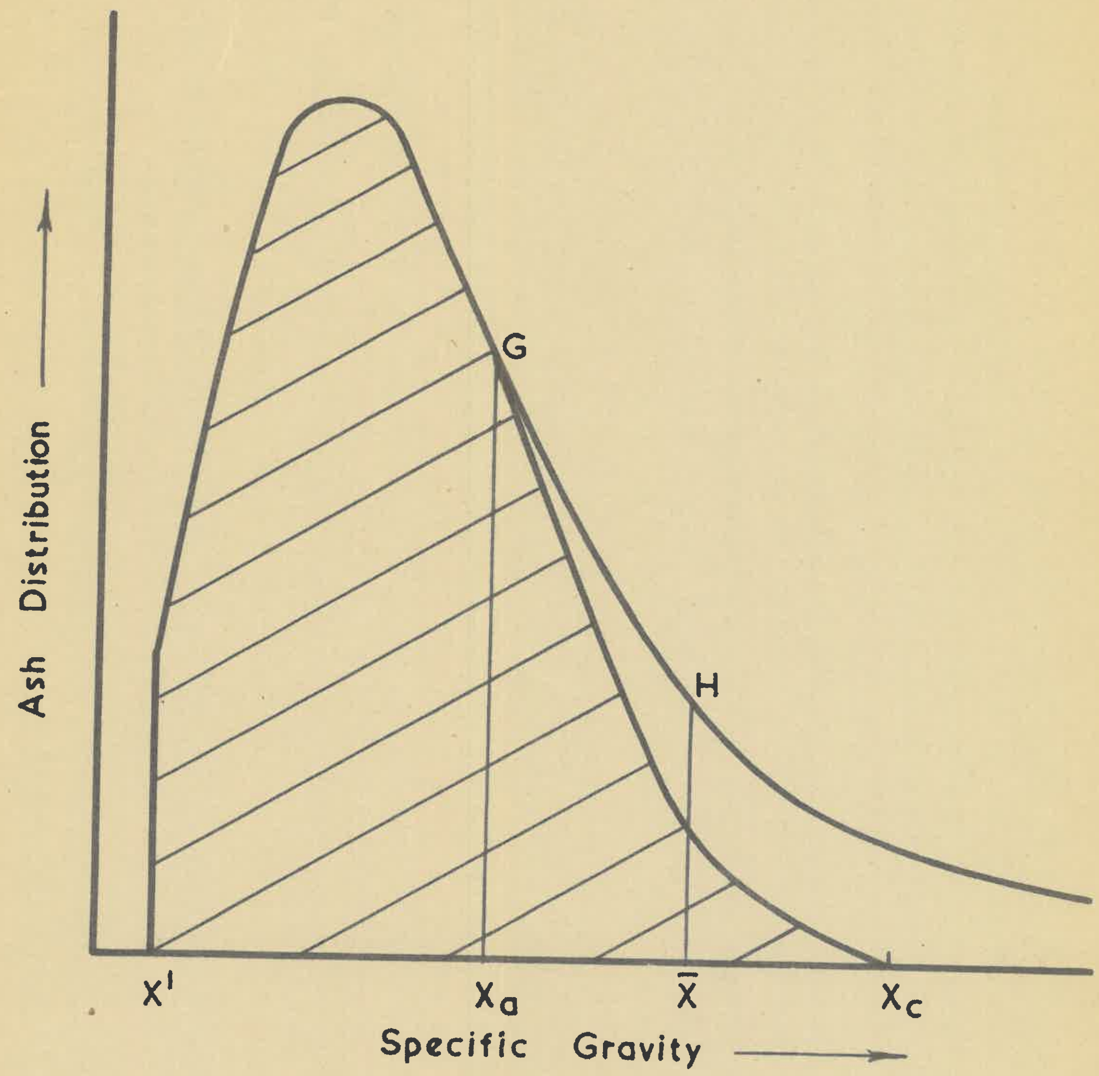

FIGURE 8 Ash Distribution curve showing the actual separation

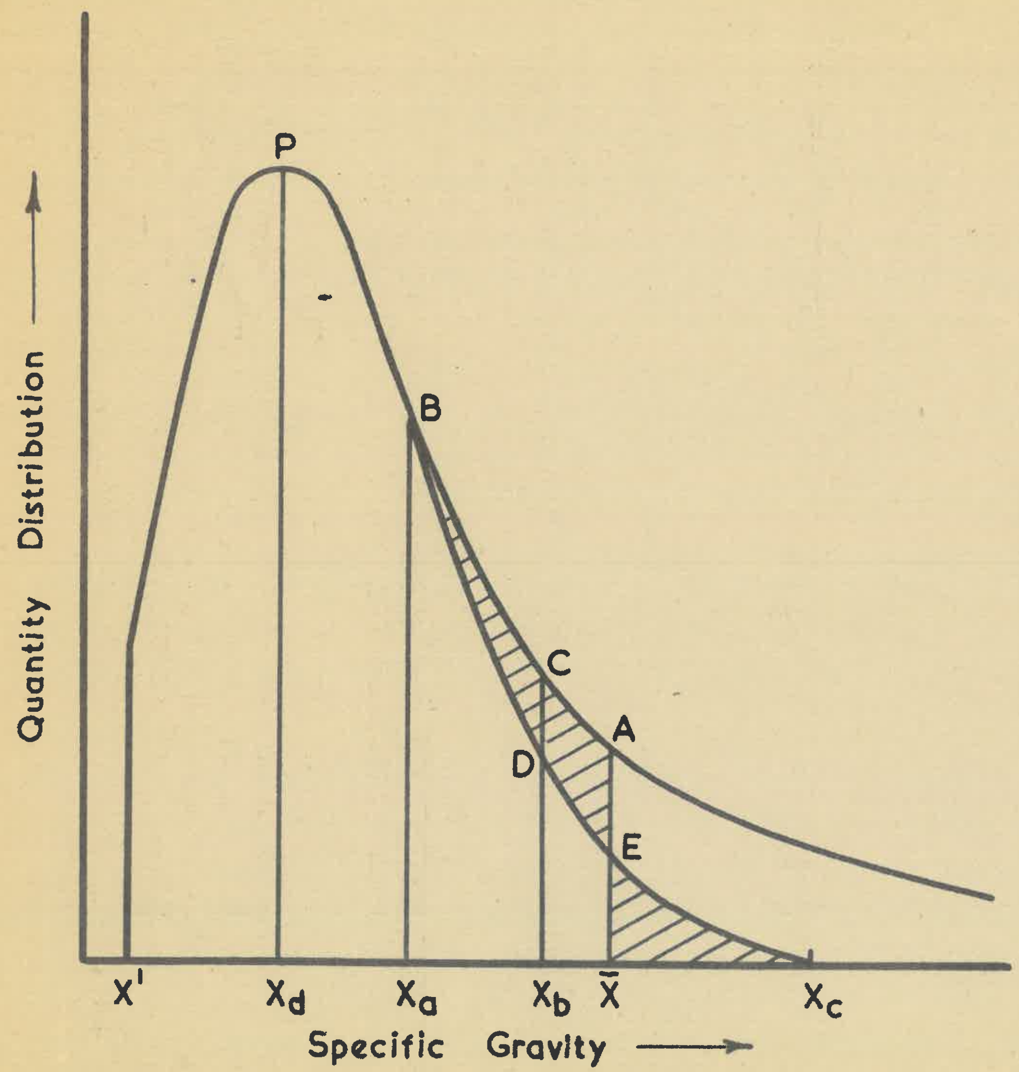

FIGURE 6 Quantity Distribution curve showing the actual separation

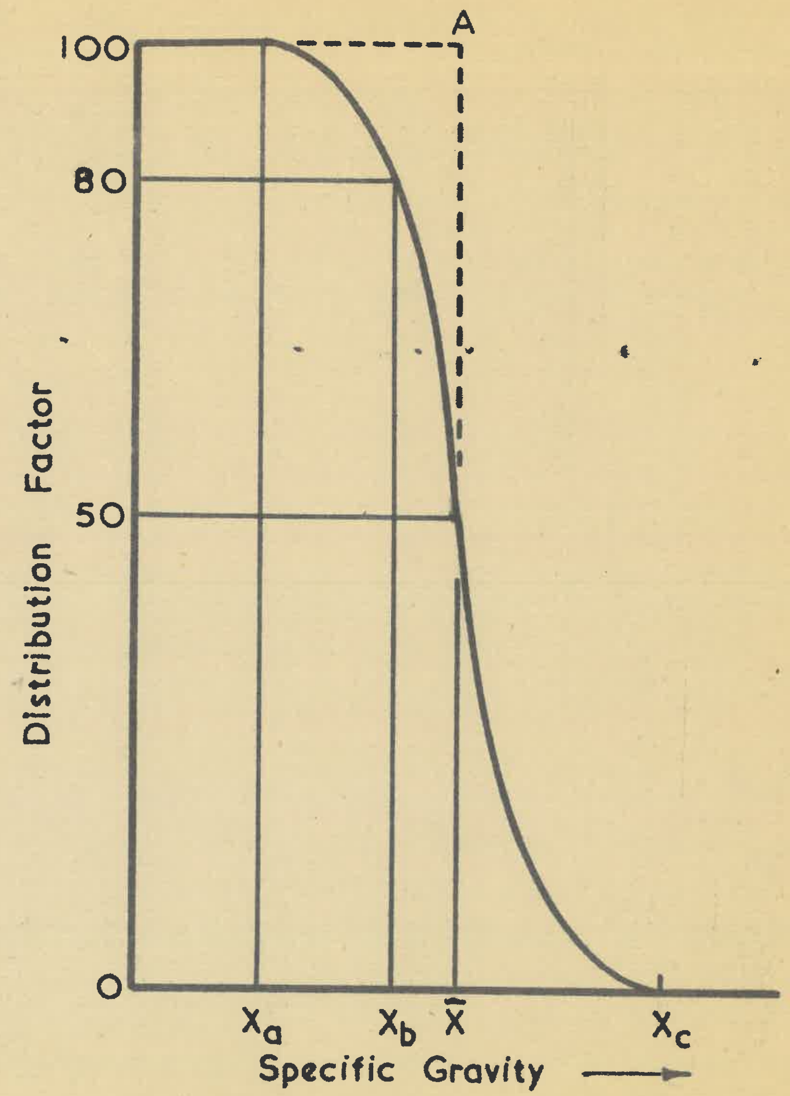

FIGURE 7 Distribution Factor curve

Similarly, at the specific gravity of separation, $\bar{X}$, the quantity recovered will be represented by the line $\bar{X}E = 0.5\ \bar{X}A$. The actual "cutting line" will, therefore, be BX_c and the actual yield of washed product is given by the area $X'PBX_c$. Area BAE represents "clean" coal lost in the tailing and area $\bar{X}EX_c$ represents "tailing" recovered in the washed coal.

In the same way, the Tromp distribution factor curve may be used in conjunction with the Ash distribution curve to obtain the actual "cutting line", GX_c, in terms of ash units as shown in Figure 8. The area $X'GX_c$ will then represent the actual ash content of the washed coal, the value of which can be calculated from the following expression:-

$$\text{Actual ash content of washed coal} = \frac{\text{Area } X'GX_c \text{ (Fig. 8).}}{\text{Area } X'PBX_c \text{ (Fig. 6).}}$$

GENERAL FEATURES OF THE GRAPHICAL REPRESENTATION OF FLOAT AND SINK DATA:

In addition to the estimation of the yields and ash contents which may be expected in practice, this method has also been found to be of great assistance in studying the performance of a washing plant. By virtue of the fact that all losses, etc., are clearly shown graphically one is able to assess the overall efficiency at a glance. Having a clear picture of what is actually taking place, the operator is in a better position to take the appropriate steps to rectify matters should this be necessary. The Quantity distribution curve also provides a very clear conception regarding the difficulty of the washing problem at various specific gravities. For example, Figure 6 indicates that it would be extremely difficult to effect a separation with reasonably high overall efficiency at specific gravity X_d and that only a washer which is capable of a very exact separation would be suitable. In the vicinity of specific gravity $\bar{X}$, however, the Quantity distribution is relatively low, consequently the areas BAE and $\bar{X}EX_c$ resulting from the use of a comparatively inefficient washer would be small compared with $X'A\bar{X}$ and the overall efficiency is likely to be high. At this point, therefore, the use of a washer capable of effecting very sharp separation, would probably be of little advantage.

The use of the method will now be illustrated by an example.

EXAMPLE OF THE APPLICATION OF THE GRAPHICAL METHOD:

The results of a float and sink analysis on a sample of duff coal from the Witbank Coalfield screened $-\frac{1}{4}$" + 1 mm. are shown in Table 2. The corresponding cumulative values were calculated from these data and are shown in Table 3 and graphically in Figure 9. In this case the Instantaneous ash curve can be plotted directly from the data in Table 2 (see Figure 9). The quantity distribution and ash distribution curves were then derived from these data as follows:

/........7.

TABLE 2.

Fractional Analysis of Duff from Witbank Coal-field Screened $-\frac{1}{4}$" + 1 mm.

Specific Gravity Interval.	Fractional Yield %.	Fractional Ash %.
<1.28	1.2	3.1
1.28-1.3	5.7	3.4
1.3-1.35	21.6	5.7
1.35-1.4	17.7	8.1
1.4-1.45	19.1	10.7
1.45-1.5	14.0	14.5
1.5-1.55	7.6	18.7
1.55-1.6	3.9	23.5
1.6-1.65	1.9	27.8
1.65-1.7	1.3	32.0
1.7-1.75	0.4	38.1
1.75-1.8	0.62	40.2
1.8 -1.85	0.34	42.8
1.85-1.9	0.24	44.5
1.9-1.95	0.24	48.0
1.95-2.0	0.15	49.8

TABLE 3.

Cumulative Analysis of the Witbank Duff Screened $-\frac{1}{4}$" + 1 mm.

Specific Gravity.	Cumulative Yield. %.	Cumulative Ash %.
1.28	1.2	3.1
1.30	6.9	3.3
1.35	28.5	5.1
1.40	46.2	6.3
1.45	65.3	7.6
1.50	79.3	8.8
1.55	86.9	9.7
1.60	90.8	10.2
1.65	92.7	10.6
1.70	94.0	10.9
1.75	94.4	11.1
1.80	95.02	-
1.85	95.36	-
1.90	95.60	-
1.95	95.84	-
2.00	95.99	-
Whole Coal.	100.0	13.4

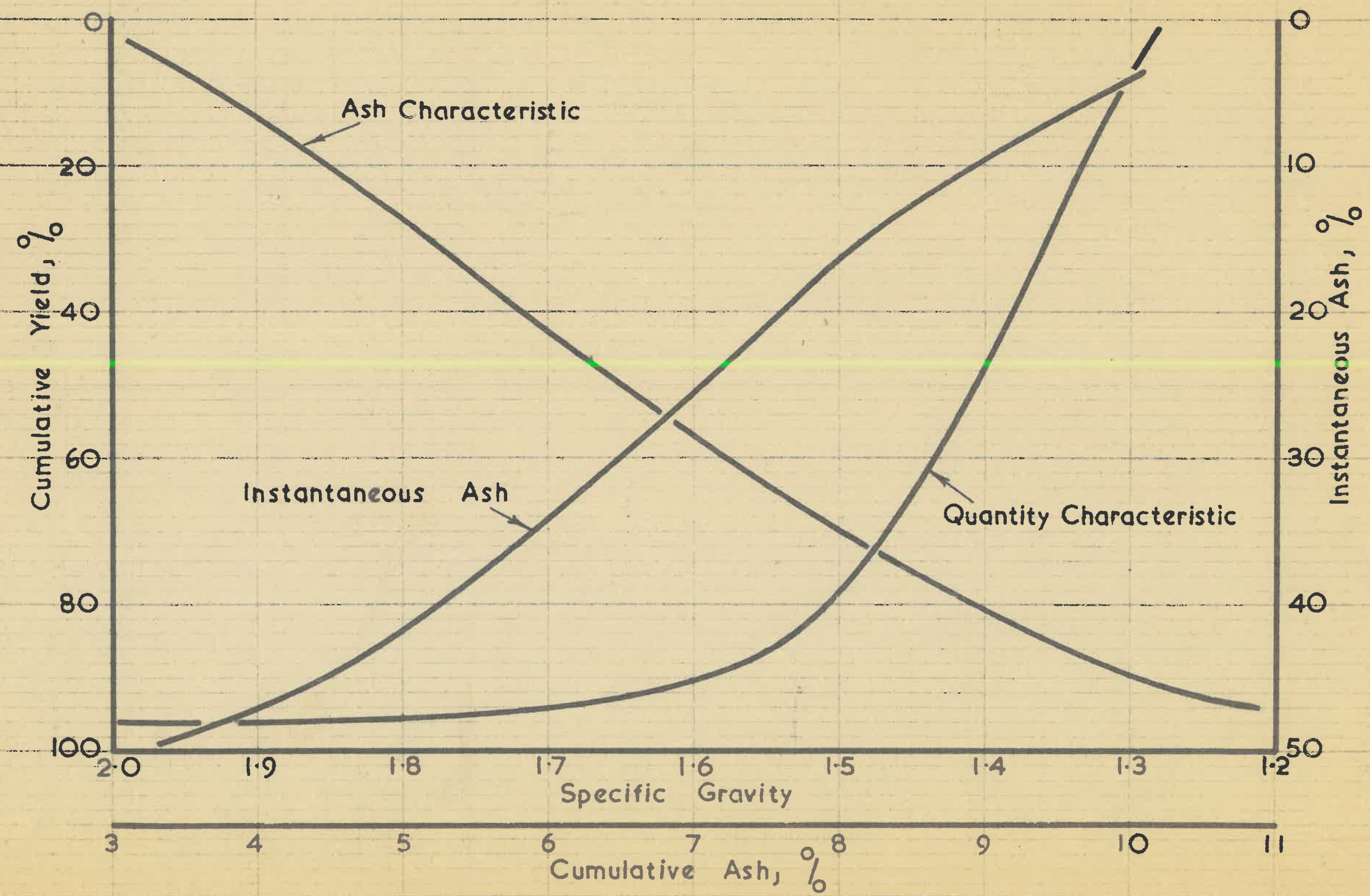

FIGURE 9 Characteristic curves of the screened duff

Points on the quantity distribution curve were obtained by determining the fractional yield within ±0.01 specific gravity of the point being considered. Thus, at specific gravity 1.5, it will be seen from the quantity characteristic curve that the cumulative yields at 1.51 and 1.49 specific gravity are 80.5% and 76.5% respectively. The fractional yield between 1.51 and 1.49 specific gravity will then be 80.5% - 76.5% = 4.0% and hence the quantity distribution at 1.5 specific gravity $= \frac{4.0}{1.51-1.49} = \frac{4.0}{0.02} = 200.$

By proceeding in this way the quantity distribution values shown in Table 4 were obtained.

TABLE 4.

Quantity Distribution Values at various Specific Gravities.

Specific Gravity X.	Cumulative Yield at X+0.01 S.G. %	Cumulative Yield at X-0.01 S.G %	Fractional Yield at X±0.01 S.G. %	Quantity Distribution.
1.285	5.3	0	5.3	265
1.3	10.7	3.9	6.8	340
1.35	31.0	22.8	8.2	410
1.4	50.5	42.5	8.0	400
1.45	68.7	62.0	6.7	335
1.475	75.5	70.2	5.3	265
1.5	80.5	76.5	4.0	200
1.55	87.75	85.5	2.25	112
1.6	91.2	90.0	1.2	60
1.65	93.0	92.4	0.6	30
1.7	94.0	93.6	0.4	20
1.75	94.8	94.5	0.3	15
1.8	95.3	95.1	0.2	10
1.85	95.5	95.3	0.2	10
1.9	95.7	95.5	0.2	10
1.95	95.9	95.7	0.2	10

The ash distribution values were obtained by multiplying the quantity distribution in Table 4 by the corresponding instantaneous ash figures, the latter being obtained from the Instantaneous ash curve in Figure 9. Calculated figures are shown in Table 5.

TABLE 5/........9.

TABLE 5.

Ash Distribution Values at Various Specific Gravities.

Specific Gravity.	Quantity Distribution D.	Instantaneous Ash a.	Ash Distribution D x a.
1.285	265	3.1	821
1.3	340	4.0	1360
1.35	410	6.9	2830
1.4	400	9.5	3800
1.45	335	12.4	4150
1.475	265	14.4	3820
1.5	200	16.1	3220
1.55	112	20.8	2340
1.6	60	25.4	1520
1.65	30	30.2	906
1.7	20	35.3	706
1.75	15	39.0	585
1.8	10	41.9	419
1.85	10	44.4	444
1.9	10	46.7	467
1.95	10	48.8	488

The "quantity distribution" and "ash distribution" curves were then plotted from the data in Tables 4 and 5 and are shown in Figure 10. The actual scales which were used are:-

0.05 specific gravity = 1 inch, quantity distribution of 50 = 1 inch and ash distribution of 500 = 1 inch.

In order to check the accuracy of the quantity distribution and ash distribution curves, the cumulative yields and ash contents were determined at various specific gravities by actual measurement of the appropriate areas subtended by the curves using a planimeter. The results of this work are shown in Table 6 together with the corresponding values obtained by actual float and sink analysis (see Table 3).

As an example of the calculations involved in converting the areas obtained into percentage yield and ash content, consider a separation at the specific gravity 1.5. The cumulative yield in this case is represented by an area of 203.1 square centimeters $= \dfrac{203.1}{(2.54)^2}$ square inches.

$= 31.5$ square inches.

Now, from the scales used, 1 square inch = 0.05 x 50 % yield.

= 2.5% yield.

Therefore, the cumulative yield at 1.5 specific gravity is 2.5 x 31.5 = 78.75% (say, 78.8%).
Similarly the cumulative ash content is represented by 178.2 square centimeters = 27.65 square inches and 1 square inch = 0.05 x 500 (yield x ash units)

= 25 (yield x ash units).

Therefore, the cumulative ash at 1.5 specific gravity

is $\dfrac{25 \times 27.65}{78.75}$ % = 8.77% (say 8.8%).

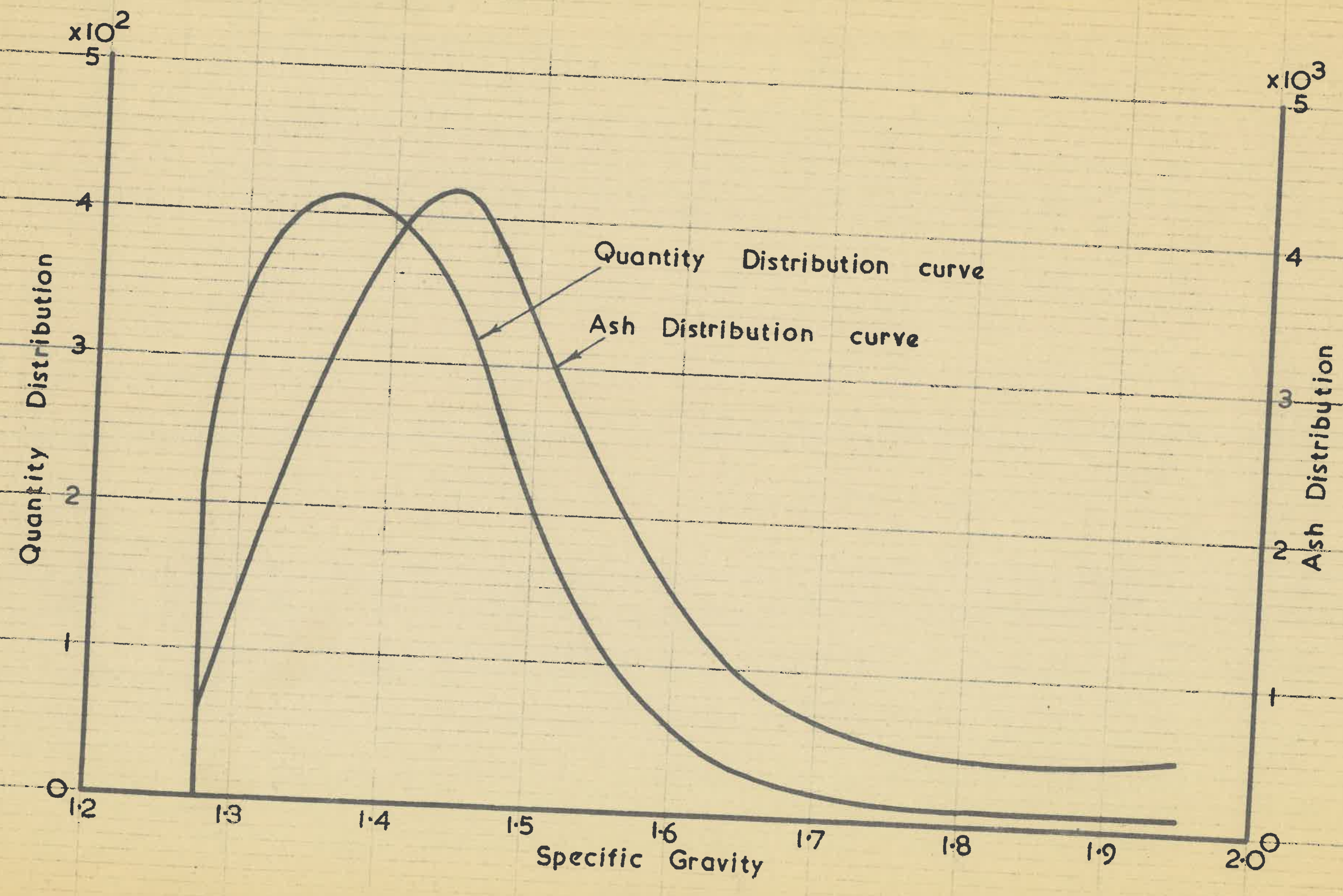

FIGURE 10 The Quantity and Ash Distribution curves of the screened duff

TABLE 6.

Comparison of the Cumulative Yields and Ash Contents Obtained Graphically and by Actual Float and Sink Analysis.

Specific Gravity.	Graphically.				Float & Sink.	
	Quantity Distribution Curve.		Ash Distribution Curve.		Cum. Yield %.	Cum. Ash %.
	Area Sq. cms.	Cum. Yield %.	Area Sq.cms.	Cum. Ash %.		
1.3	17.7	6.9	5.7	3.2	6.9	3.3
1.35	68.0	26.4	33.9	5.0	28.5	5.1
1.4	120.8	46.8	77.5	6.4	46.2	6.3
1.45	168.2	65.2	130.1	7.7	65.3	7.6
1.5	203.1	78.8	178.2	8.8	79.3	8.8
1.55	222.0	86.0	213.8	9.6	86.9	9.7
1.6	232.0	89.9	239.4	10.3	90.8	10.2
1.65	238.0	92.2	254.0	10.7	92.7	10.6
1.7	241.2	93.5	264.2	11.0	94.0	10.9
1.75	243.2	94.3	272.4	11.2	94.4	11.1
1.8	244.5	94.8	-	-	95.0	-

It will be seen from Table 6 that the yields and ash contents as determined graphically, agree very closely with those actually obtained by float and sink analysis. This shows that the "quantity distribution" and "ash distribution" curves can be drawn with great accuracy in spite of the approximations which have been made during their derivation. It would also appear that the errors in the determination of the areas involved are small when exercising average care.

In order to illustrate the method of predicting the yield and ash content under practical conditions the following cases may be considered:

(a) A separation at 1.65 specific gravity to produce a higher quality steam coal than the raw material.

(b) A separation at 1.35 specific gravity in order to recover a coking fraction which is known to be present.

It will be assumed that it is required to determine the suitability of (1) a trough type washer and (2) a cyclone washer for these separations. The Tromp distribution factor curves of these two washers when treating coal of approximately the same size grading as the screened duff sample are shown in Figure 11. For simplicity, it has been assumed that the distribution factor curves did not vary with the specific gravity of separation. The specific gravity divisions of the distribution factor curves were consequently taken as ($\bar{X}$ -0.05), $\bar{X}$ (specific gravity of separation), ($\bar{X}$ +.05) etc., these values being readily converted into actual specific gravities e.g. when $\bar{X}$ = 1.65, ($\bar{X}$ +.05) = 1.7 and so on.

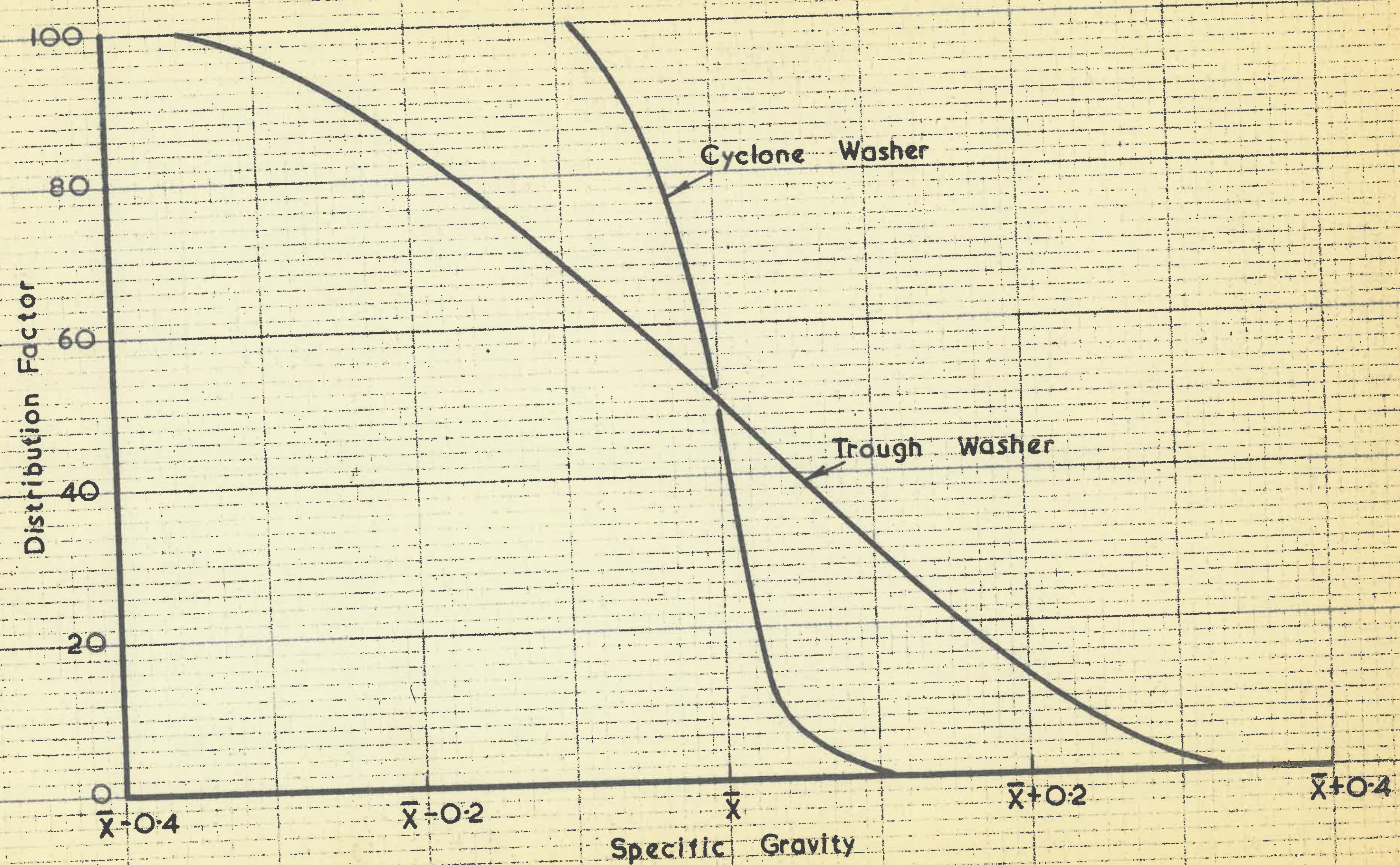

FIGURE 11 Distribution Factor curves of the Cyclone and Trough washers

(a) Separation at 1.65 Specific Gravity:

(1) Trough Washer:

Values of the Tromp distribution factors, Feed Quantity distribution and Feed Ash distribution were read off the graphs (Figure 11 and Figure 10) at appropriate specific gravities and were tabulated as shown in Table 7. Points on the actual "cutting lines" were then calculated from these data and the actual cutting lines were drawn on the quantity distribution and ash distribution curves as shown in Figure 12.

TABLE 7.

Determination of the Actual Cutting Lines for the Trough Washer at 1.65 Specific Gravity.

Sp Specific Gravity.	Tromp Distribution Factor Curve.		Quantity Distribution Curve.		Ash Distribution Curve.	
	Relative Specific Gravity.	Distr. Factor %.	Feed Quantity Distribution.	Cutting line b x a/100	Feed Ash Distr.	Cutting line d x a/100
		a	b	c	d	e
2.0	X+0.35	0	-	0	-	0
1.95	X+0.3	1.0	10.0	0.1	488.0	4.9
1.90	X+0.25	5.0	10.0	0.5	467.0	23.3
1.85	X+0.2	13.5	10.0	1.35	444.0	60.0
1.80	X+0.15	22.5	10.0	2.25	419.0	94.2
1.75	X+0.1	31.5	15.0	4.72	585.0	184.0
1.70	X+0.05	41.0	20.0	8.2	706.0	289.0
1.65	X	50.0	30.0	15.0	906.0	453.0
1.60	X-0.05	58.5	60.0	35.1	1520.0	890.0
1.55	X-0.1	67.5	112.0	76.0	2340.0	1580.0
1.50	X-0.15	77.0	200.0	154.0	3220.0	2480.0
1.45	X-0.2	85.0	335.0	284.0	4150.0	3525.0
1.40	X-0.25	92.0	400.0	368.0	3800.0	3500.0
1.35	X-0.30	97.5	410.0	400.0	2830.0	2760.0
1.30	X-0.35	100	340.0	340.0	1360.0	1360.0

The areas ABCD and AEFD, under the quantity distribution and ash distribution curves were then determined by planimeter and converted to percentage yield and ash content as explained previously.

(2) Cyclone Washer:

A similar procedure was adopted in this case, but to simplify the diagram only the quantity distribution curve is shown in Figure 13. The results for both the trough and cyclone washers are shown in Table 8 together with the corresponding theoretical values as obtained by float and sink analysis. The efficiency of separation was determined by the Frazer and Yancey expression[3].

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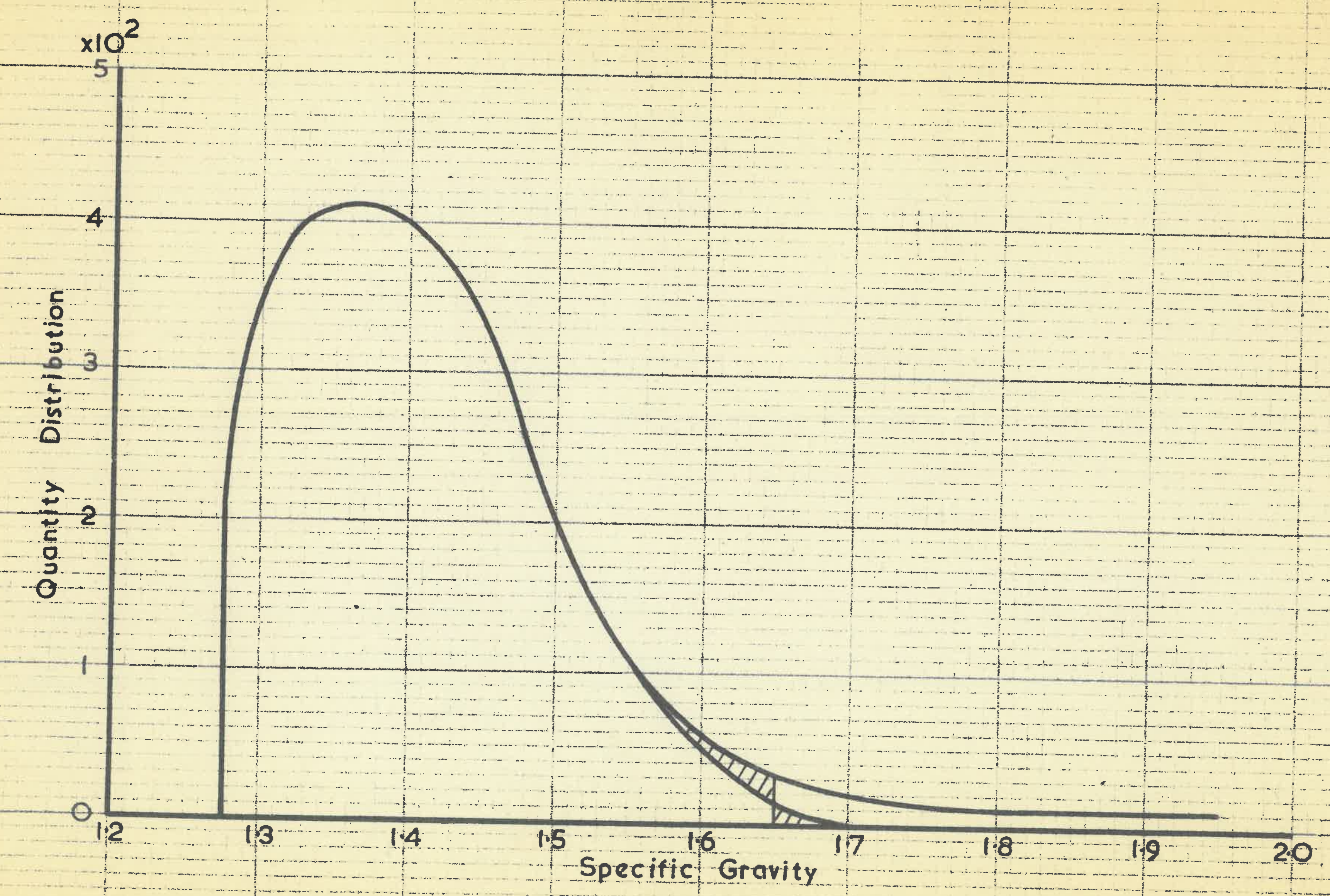

FIGURE 13 Quantity Distribution curve showing Cyclone separation at 1·65 S.G.

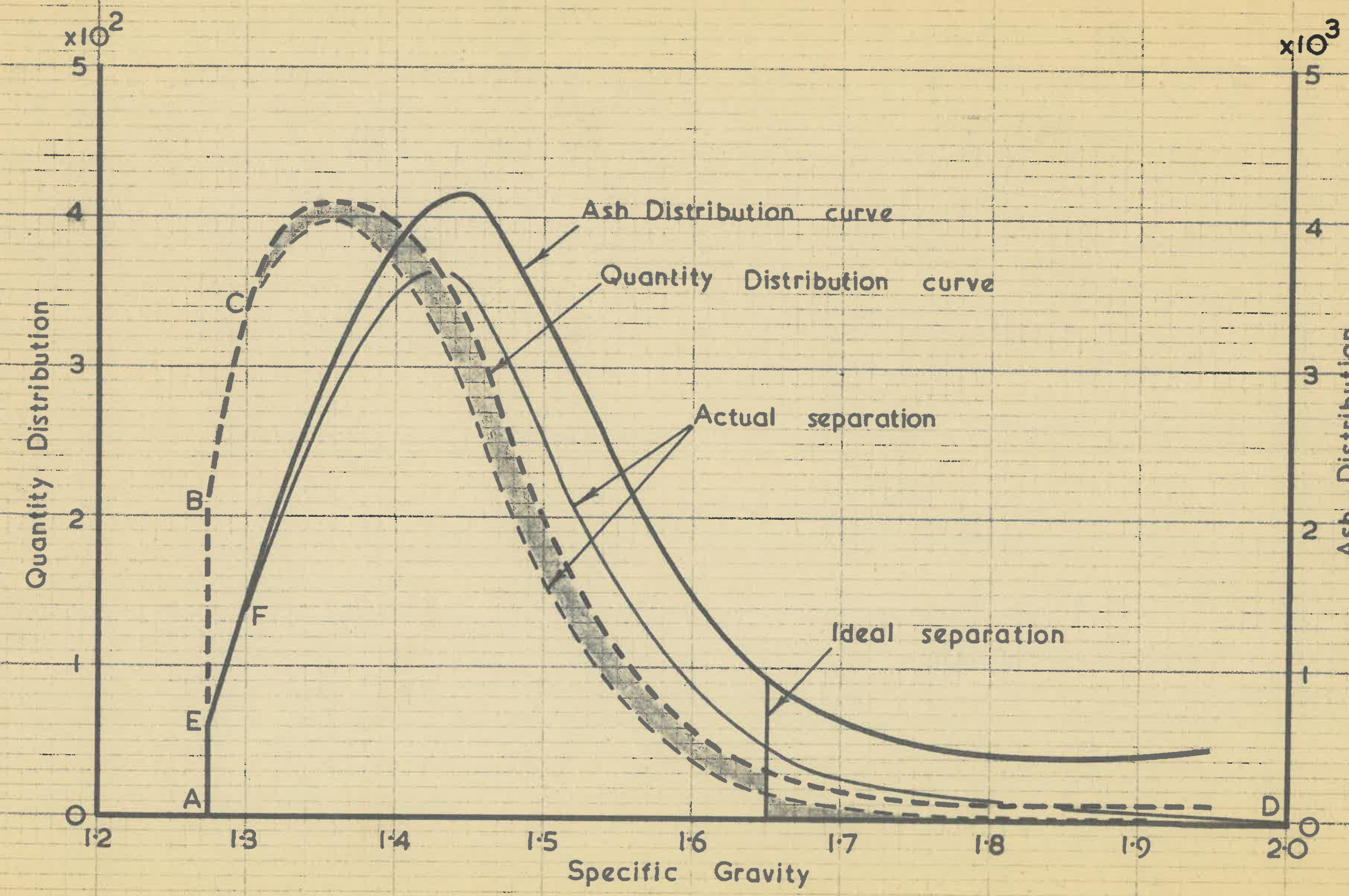

FIGURE 12 The Quantity and Ash distribution curves showing Trough separation at 1·65 S.G.

$$\text{General efficiency} = \frac{Y_a}{Y_t} \times \frac{A_f - A_a}{A_f - A_t}$$

where Y_a = actual yield %.

Y_t = theoretical yield.

A_f = Ash content of the feed.

A_a = Actual ash content of the product.

A_t = Theoretical ash content of the product.

TABLE 8.

Comparison of the Performances of the Trough and Cyclone Washers when Effecting a Separation at 1.65 Specific Gravity.

	Trough Washer.	Cyclone Washer.	Theoretical (float & sink)
Area under quantity distribution curve, sq.cm.	212.4	236.9	-
Area under ash distribution curve, sq.cm.	220.5	251.5	-
Yield, %.	82.3	91.8	92.7
Ash content of product, %.	10.4	10.6	10.6
Ash content of feed, %.	13.4	13.4	13.4
Efficiency, %.	95.0	99.1	100

It will be noted when comparing the Tromp distribution factor curves in Figure 11 that the cyclone is considerably more efficient than the trough washer considered in this case.

Table 8 shows, however, that the trough washer would be able to effect a separation of the screened duff at 1.65 specific gravity with a fairly high overall efficiency (95%) while the cyclone would give an almost theoretical separation at this specific gravity.

Although the efficiency figures are high in both cases, the shaded areas in Figures 12 and 13 indicate that rather more good coal would be lost in the tailing when using the trough washer than when using the cyclone washer.
On the grounds of efficiency, preference would naturally be given to the cyclone. But this is not the only criterion and other considerations (e.g. capital investment, washing costs, market requirements,) may indicate that it would be more economical to instal the trough washer. In either event, the final decision would be comparatively easy as estimates of the yield and ash content of the product are available on which to base the cost calculations.

(b) Separation at 1.35 Specific Gravity:

The practical yields and ash contents were estimated for the two washers as previously described and are reported in Table 9. The cutting lines obtained are shown in Figure 14.

TABLE 9.

Comparison of the Performances of the Trough and Cyclone Washers when Effecting a Separation at 1.35 Specific Gravity.

	Trough Washer.	Cyclone Washer.	Theoretical (Float & Sink).
Area under quantity distribution curve, sq.cms.	93.6	65.5	-
Area under ash distribution curve, sq. cms.	79.7	36.6	-
Yield, %.	36.3	25.4	28.5
Ash content of product, %.	8.5	5.6	5.1
Ash content of feed, %.	13.4	13.4	13.4
Efficiency, %.	75	84	100

In this case there is little doubt as to which washer would be the more suitable for the separation at 1.35 specific gravity. Table 9 clearly shows that the trough washer would be quite unsuitable. Figure 14, however, is probably more instructive. If it is assumed that all coal lighter than 1.35 specific gravity is coking coal and that all coal heavier than this has no swelling properties, it will be apparent that about half the coking coal (shaded area) would be lost if the trough washer were used. The product would also be contaminated with a large percentage of non-coking coal. The overall result would be a product having poor swelling properties and a high ash content. The separation as effected by the cyclone would be a marked improvement in this respect.

THE INFLUENCE OF QUANTITY DISTRIBUTION AND SPECIFIC GRAVITY OF SEPARATION ON THE OVERALL EFFICIENCY:

For the purpose of the examples discussed above it was assumed that the Tromp distribution factor curve of each washer remained constant at all specific gravities of separation. As has also been pointed out, the slope of the Tromp distribution factor curve is a measure of the efficiency of separation of a washer. The above assumption in effect implies that the efficiency of separation of each washer is the same at both the specific gravities considered. However, Tables 8 and 9 show that the overall efficiency, as determined by the Frazer and Yancey expression was in both cases materially lower at 1.35 specific gravity than at 1.65 specific gravity. This is not surprising, since the quantity distribution of the duff, considered in the example, is considerably higher at the lower specific gravity and larger actual

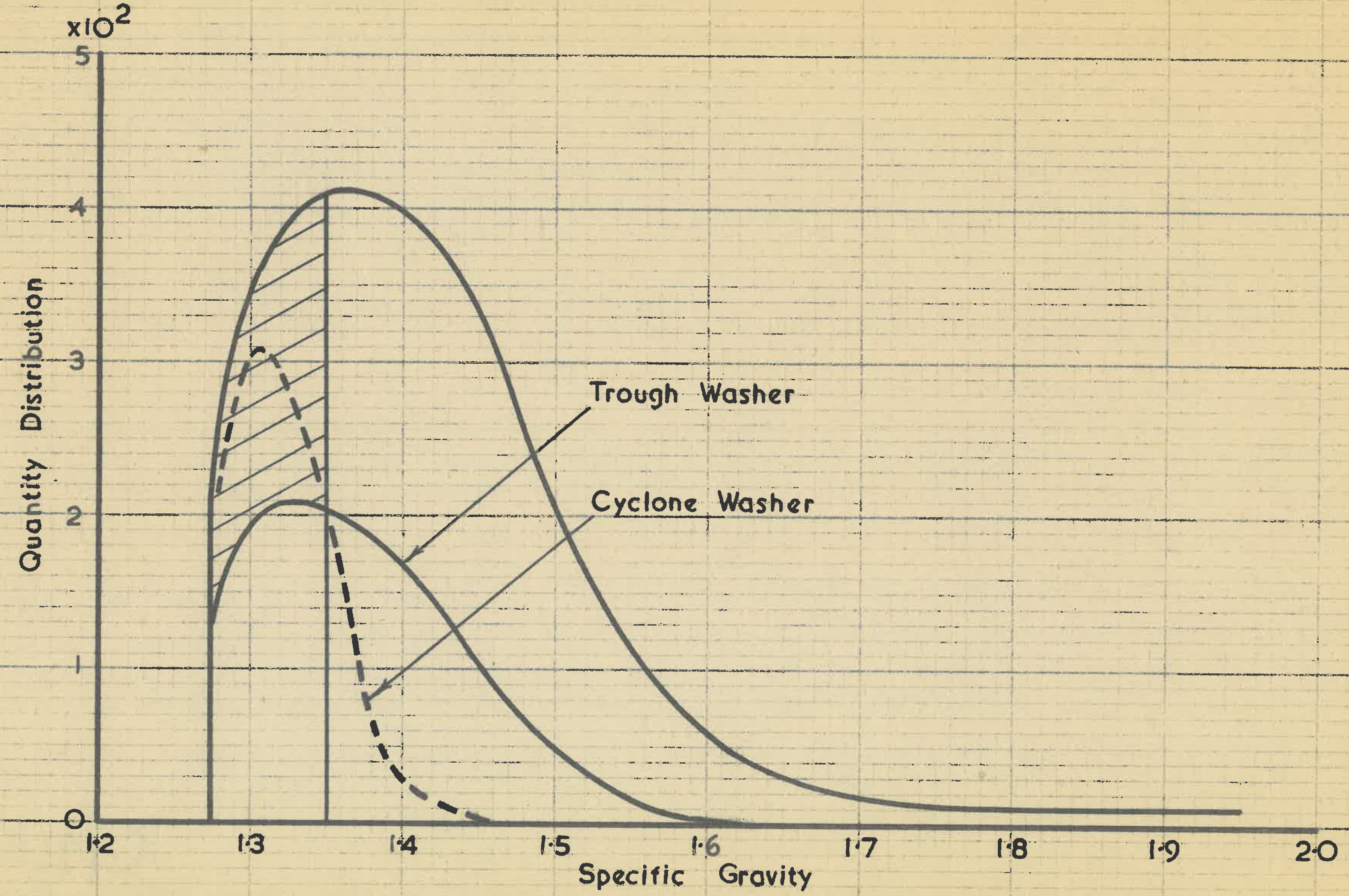

FIGURE 14 Quantity Distribution curve showing the actual separations at 1·35 S.G.

quantities are consequently lost and gained. The overall efficiency is, thus, a function of the quantity distribution at the specific gravity of separation and the efficiency of the washer. It will consequently not be possible to compare the performance of washers by means of the overall efficiency unless they are cutting the same coal at the same specific gravity. The necessity for distinguishing between the overall efficiency of the process and the efficiency of the washer itself will, therefore, be appreciated. The author has found it convenient to term these efficiencies, "washing efficiency" and "washer efficiency" respectively. The former is determined by one of the recognised expressions and the latter may be derived from the Tromp distribution factor curve.

AN EXPRESSION FOR THE OVERALL EFFICIENCY DERIVED FROM THE ASH DISTRIBUTION CURVE:

Several expressions have been evolved to determine the overall efficiency of a washing process and in the majority of cases the final formula combines a quantitative and qualitative factor. In other words, the efficiency is assessed both from a yield and an ash content point of view. This appears to be the primary requirement of any such efficiency expression, as not only the quantity but also the quality of washed coal obtained is of economic importance. Most of the "quantitative" and "qualitative" efficiency expressions used are difficult to interpret, however, and one is consequently in some doubt as to whether they have any real value. As an example, consider the Frazer and Yancey expression which is probably the least complicated.

In this expression the general efficiency = Quantitative factor x Qualitative factor.

where, Quantitative factor = $\frac{\text{Actual Yield}}{\text{Theoretical yield at the S.G. of separation}}$

and Qualitative factor = $\frac{\text{Ash of feed - Actual ash of product}}{\text{Ash of feed - Theoretical ash of product}}$

$= \frac{\text{Actual ash reduction}}{\text{Theoretical ash reduction}}$.

The significance of the quantitative factor is quite plain but, as will be seen from the estimated performance of the trough washer shown in Table 9, it is possible for this factor to be greater than unity. This results in a reasonably high overall efficiency value being obtained although the diagrams show that the separation would be poor. Here also, a quantitative factor greater than unity is undesirable as it implies that the coking fraction has been contaminated by non-coking coal. The impression one gains from the overall efficiency value is, therefore, misleading.

The qualitative factor is based on a difference of ash contents and there is some doubt as to whether this has any real meaning.

While studying the graphical method with which this paper is concerned, it occurred to the author that an efficiency

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expression could be evolved which would perhaps enable a clearer conception of the efficiency of a washing process to be obtained. It is agreed that both the quantity and quality of the washed coal should be taken into account and it is proposed to achieve this by basing the expression on the ash distribution curve as the area under this curve represents the product of ash content and yield. Since the quantity of "good" coal lost and the quantity of "poor" coal gained have an important bearing on the final product (especially in the case of a separation of the Witbank duff to recover the coking fraction) it was decided to deduce expressions which would represent the "Recovery efficiency" and the "Reject efficiency." These expressions are readily derived from the ash distribution curve shown in Figure 15. Thus theoretical recovery of "good" coal is represented by the area $X'AB\bar{X}$ while actual recovery is represented by the area $X'AC\bar{X}$ (area ABC represents "good" coal lost).

$$\text{Hence, Recovery efficiency} = \frac{\text{Area } X'AC\bar{X}}{\text{Area } X'AB\bar{X}}$$

Similarly, the theoretical reject is given by area $\bar{X}BE$ and actual reject by area DCBE, so that

$$\text{Reject efficiency} = \frac{\text{Area DCBE}}{\text{Area } \bar{X}BE}$$

(It will be clear that neither of these efficiencies can ever exceed unity).

The overall efficiency may then be inferred as follows:-

Overall efficiency = Recovery efficiency x Reject efficiency.

These expressions are now capable of conversion into terms of float and sink data on the actual product and tailing obtained.

Suppose a float and sink analysis of the product and tailing was carried out at specific gravity $\bar{X}$ with the following results:-

Assume Product = Y% of feed and tailing = (100-Y)%

<u>Float and Sink on Product.</u>

Percentage of product floating at $\bar{X}$	$= P_f$ %
Percentage of product sinking at $\bar{X}$	$= (100-P_f)$ %
Ash content of product floats	$= A_{pf}$ %
Ash content of product sinks	$= A_{ps}$ %

$\therefore$ Product floating as % of the feed $= \frac{P_f \; Y}{100}$ %

& Product sinking as % of the feed $= \frac{(100 - P_f) \; Y}{100}$ %

$$\therefore \text{Area } X'AC\bar{X} = \frac{(P_f \; Y) \; A_{pf}}{100}$$

$$\text{and Area } \bar{X}CD = \frac{((100 - P_f) \; Y) \; A_{ps}}{100}$$

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Float and Sink on Tailing:

Percentage of tailing floating at $\bar{X}$ = T_f %

Percentage of tailing sinking at $\bar{X}$ = $(100-T_f)$ %

Ash content of tailing floats = A_{tf} %

Ash content of tailing sinks = A_{ts} %

∴ Tailing floating as % of feed = $\frac{(T_f\ (100-Y))}{100}$ %

& " sinking " " " " = $\frac{((100-T_f)\ (100-Y))}{100}$ %.

∴ Area ABC = $\frac{(T_f\ (100-Y))\ A_{tf}}{100}$

& Area BCDE = $\frac{((100-T_f)\ (100-Y))\ A_{ts}}{100}$

Hence Area X' AB$\bar{X}$ = Area X' AC$\bar{X}$ + area ABC.

$$= \left\{ (P_f\ Y)A_{pf} + (T_f(100-Y))A_{tf} \right\} \div 100$$

and area $\bar{X}$BE = area $\bar{X}$CD + area BCDE.

$$= \left\{ ((100-P_f)\ Y)\ A_{ps} + ((100-T_f)(100-Y))A_{ts}. \right\} \div 100$$

∴ Recovery efficiency = $\frac{P_f\ Y\ A_{pf}}{(P_f\ Y\ A_{pf}) + (T_f(100-Y)A_{tf})}$

$$= \frac{1}{1 + \frac{T_f(100-Y)A_{tf}}{P_f\ Y\ A_{pf}}} = \frac{1}{1 + \frac{\text{\% tailing floats x \% tailing x \% ash of tailing floats.}}{\text{\% product floats x \% product x \% ash of product floats.}}} \quad - (1)$$

& Reject efficiency = $\frac{(100-T_f)(100-Y)A_{ts}}{(100-T_f)(100-Y)A_{ts} + (100-P_f)YA_{ps}}$

$$= \frac{1}{1 + \frac{(100-P_f)Y\ A_{ps}}{(100-T_f)(100-Y)A_{ts}}} = \frac{1}{1 + \frac{\text{\% product sinks x \% product x \% ash of product sinks.}}{\text{\% tailing sinks x \% tailing x \% ash of tailing sinks.}}} \quad - (2)$$

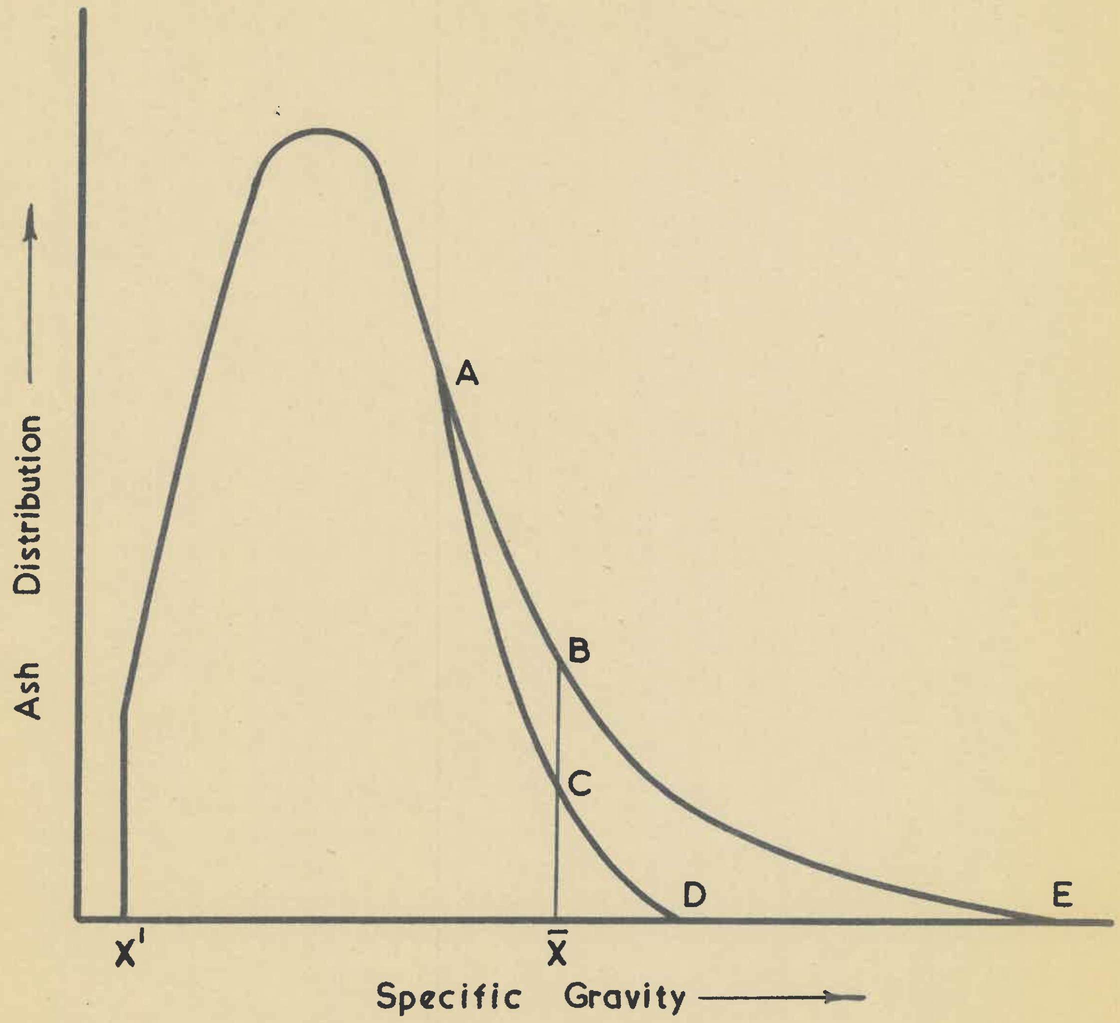

FIGURE 15 Ash Distribution curve

The recovery, reject and overall efficiencies were determined for the trough and cyclone washers when effecting a separation at 1.35 specific gravity. These results are shown in Table 10 together with the overall efficiency as calculated by the Frazer and Yancey expression.

TABLE 10.

	New Expression.			Frazer & Yancey.
	Recovery eff.	Reject eff.	Overall eff.	Overall eff.
Trough Washer.	54.3	80.4	43.7	75
Cyclone Washer.	75.2	96.5	72.5	84

It will be seen that the overall efficiencies as determined by the new expression are materially lower than those obtained by the Frazer and Yancey expression. A study of Figure 14, however, suggests that the lower figures are a truer reflection of the actual position. In addition, the difference in efficiency between the two washers appears to be more clearly indicated by the new values.

To facilitate reference to the new expression for the overall efficiency of a washing process it is proposed to refer to it as the "Fuel Research Institute Efficiency Formula," i.e. Fuel Research Institute efficiency

= Recovery efficiency X Reject efficiency

= expression (1) X expression (2).

MODIFIED FUEL RESEARCH INSTITUTE EFFICIENCY FORMULA:

As already pointed out, it is considered that the yield and ash content should both be taken into account in order to obtain an expression which will truly reflect the efficiency of a washing process. This was achieved above by basing the formula on the Ash Distribution Curve, the ash distribution representing the product of quantity and quality.

The resultant formulae are cumbersome, however, and require at least four ash determinations in addition to float and sink analysis of the product and tailing at the specific gravity of separation.

In order to simplify the expression for the Recovery and Reject Efficiencies and to minimise analyses the possibility of using modified formulae based on the Quantity distribution curve of the feed was investigated.

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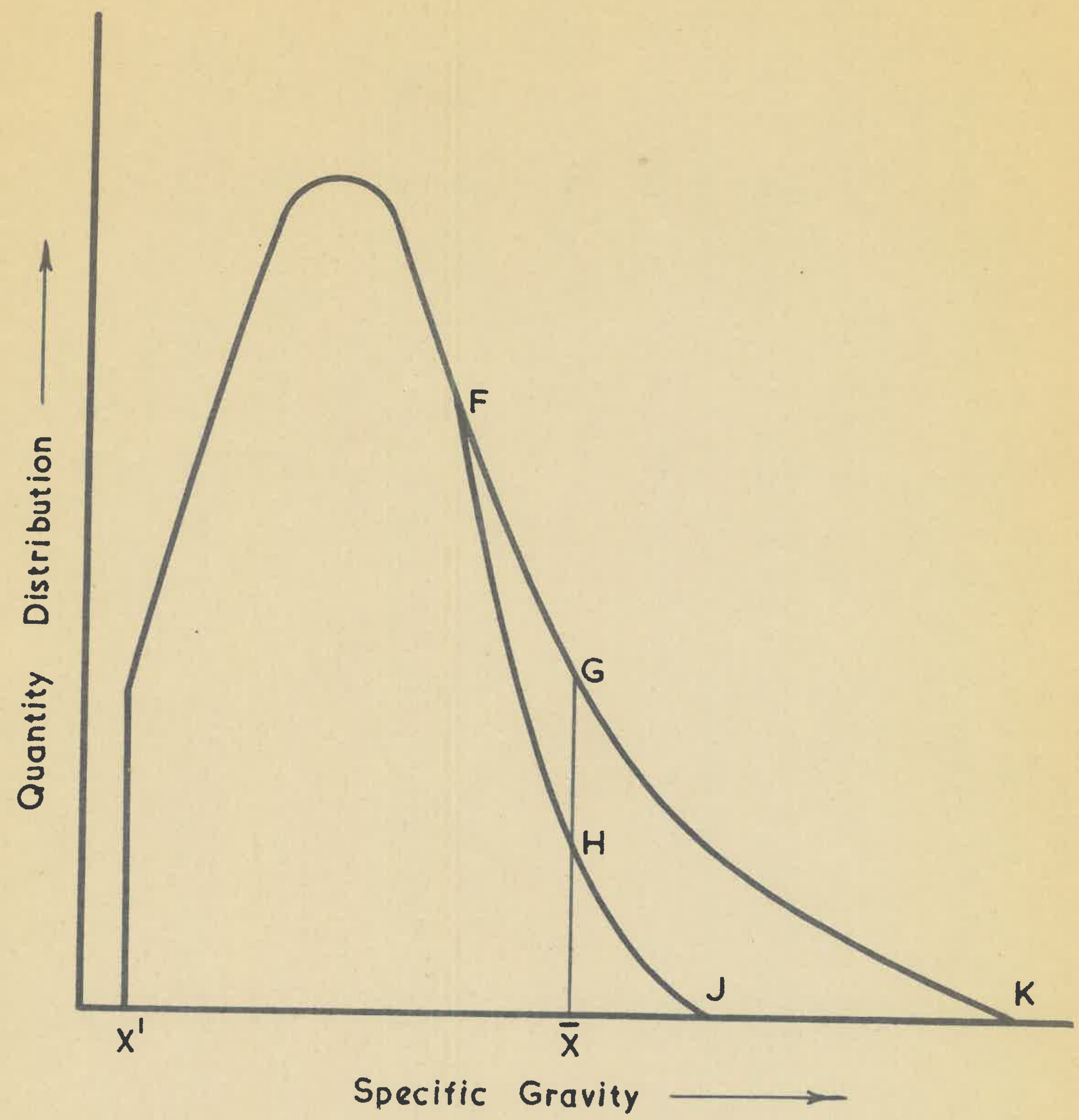

FIGURE 16 Quantity Distribution curve

Consider the Quantity distribution curve shown in Figure 16 and assume that FJ represents the actual cutting line in a washer effecting a separation at specific gravity $\bar{X}$. The Recovery and Reject Efficiencies may then be defined as follows:-

$$\text{Recovery Efficiency} = \frac{\text{Area } X'FH\bar{X}}{\text{Area } X'FG\bar{X}}$$

$$= \frac{\%\text{ product floats at SG}\bar{X} \times \%\text{ product}}{\%\text{ feed floats at S.G. } X}$$

$$= \frac{\%\text{ product floats} \times \%\text{ product}}{(\%\text{ product floats} \times \%\text{ product}) + (\%\text{ tailing floats} \times \%\text{ tailing}).}$$

$$= \frac{1}{1 + \dfrac{\%\text{ tailing floats} \times \%\text{ tailing}}{\%\text{ product floats} \times \%\text{ product}}} \quad - (3)$$

$$\text{Reject Efficiency} = \frac{\text{Area GKJH}}{\text{Area GK}\bar{X}}$$

$$= \frac{\%\text{ tailing sinks} \times \%\text{ tailing.}}{\%\text{ feed sinks.}}$$

$$= \frac{1}{1 + \dfrac{\%\text{ product sinks} \times \%\text{ product.}}{\%\text{ tailing sinks} \times \%\text{ tailing.}}} \quad - (4)$$

and modified Overall Efficiency = (3) x (4).

The overall efficiency was then determined graphically by both methods for the trough and cyclone washers when cutting the screened Witbank duff at 1.35 and 1.65 specific gravity. The values obtained are shown in Table 11.

TABLE 11.

Comparison of the Overall Efficiencies Obtained by Using the Two Fuel Research Institute Formulae.

Specific Gravity of Separation.	Washer.	Fuel Research Institute Formula.			Modified F.R.I. Formula.		
		Recovery effic.	Reject eff.	Overall eff.	Recovery effic.	Reject eff.	Overall eff.
1.35	Cyclone.	75.2	96.5	72.5	74.2	92.0	68.3
1.65	Cyclone.	97.8	96.2	94.1	99.2	95.0	94.2
1.65	Trough.	82.0	86.5	71.0	88.5	91.0	80.5

The results in Table 11 suggest that the two methods of determining the overall efficiency would be in close agreement in the case of the cyclone washer. This is particularly the case when the separation is effected at a high specific gravity where the distribution is low. In practice the majority of separations are effected under these conditions so that the modified formula may be used with confidence.

Referring to Figure 11, it will be noted that the trough washer is comparatively inefficient. This apparently accounts for the large difference in the values of the overall efficiency as determined by the two expressions even for a separation at a point of low distribution.

It appears then, that the modified expression is only applicable when the separation is effected in a very efficient washer such as one of the heavy medium type. These formulae wil require thorough testing in commercial installations, however, before one is able to assess their practical value and determine their relative merits.

9th May, 1949.

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