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Classifier Efficiency; an Experimental Study

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MOSCOW, IDAHO

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Classifier Efficiency; an Experimental Study*

By A. W. Fahrenwald,† Moscow, Idaho

(New York Meeting, February, 1930)

The function of the classifier in modern fine-grinding practice is to remove a finished product from the grinding-mill discharge, leaving material that needs further comminution. The classifier, therefore, makes two products: (1) "finished" product, which overflows the rim of the classifier tank, sometimes referred to as "slimes" or as "classifier overflow," and (2) "unfinished" product, which settles to the sloping bottom of the classifier tank and is removed by dragging or raking. This product is generally referred to as "sands" or "oversize."

One of the outstanding features of the closed-circuit classifier is its ability automatically to return the unfinished product of the ball-mill discharge to the feed end or scoop box of the ball mill. This is a distinct advantage because it avoids dilution of the ball-mill feed, and, furthermore, the particular method of removing the settled sand, by raking it up the inclined bottom of the classifier, gives a classifier discharge containing a minimum of water. This leads to maximum classifier efficiency, in this type of classifier, because the maximum volume of water is displaced upward by the settling sands.

The closed-circuit classifier is required to deliver a finished pulp of closely specified density requirements, therefore added hydraulic water generally is not permitted.

Relation of Classifier Efficiency to Grinding Efficiency

The energy of crushing, and therefore the cost, according to Rittinger's Law,[1] is proportional to the new surface exposed in crushing. Since the new surface produced in crushing is nearly proportional to the reciprocals of the diameters crushed to, it is obvious that the cost of crushing in the finer sizes is tremendously greater than in the coarser sizes for equal ratios of reduction. High circulating load of finished sand in the circuit of the classifier and grinding mill is therefore obviously expensive practice. It is the classifier's function to reduce this to a minimum.

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* Printed without author's corrections. Subject to revision.

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[1] The correctness of this law has been definitely established by J. Gross and S. R. Zimmerley: *Repts. of Investigations*, U. S. Bur. Mines, Serial No. 2880 (1928). Also by G. Martin and coworkers: *Trans.* Ceram. Soc. (England) (1925–26) **25**, 51.

Classifier Efficiency

It is the purpose of this paper to present a new experimental method of measuring classifier efficiency. A need for it may be brought out by a discussion of the present method and its limitations.

In the literature, the only method described of measuring performance of the closed-circuit classifier is based on sieve analyses of the classifier products. The formula used is:

$$E = \frac{10{,}000\ (b - a)(a - c)}{a(100 - a)(b - c)}$$

where E = over-all efficiency of the classifier,
a = percentage of finished sand in classifier feed,
b = percentage of finished sand in classifier overflow,
c = percentage of finished sand in classifier dragover.

This formula gives over-all classifier efficiency and is the original formula developed by H. W. Newton of the Dorr Co. The derivation is given, among other sources, in Taggart's Handbook of Ore Dressing, pp. 1235–1239. The efficiency of the classifier as a remover of finished product, granting that everything in the overflow is finished, is given by the formula,

$$E_1 = \frac{100b(a - c)}{a(b - c)}$$

If tonnages are known these formulas are much simpler. The latter formula of course, is identical with the well-known formula giving screening efficiency.

Critical Consideration of Size Analysis as Basis of Measuring Classifier Efficiency

Some interesting mathematics may be indulged in to show the fallacy of sieve sizing as a basis of measuring classifier efficiency.

If all sand grains obtained by the use of a pair of sieves of small difference in mesh opening—for example adjacent sieves of the Tyler screen scale—behaved similarly in a rising column of water or fell at the same rate in a static body of water or other medium of appreciable density, classifier performance could be determined on a sizing analysis basis. This, however, is not the case because both grain density and configuration are variable and enter into the problem. If it is assumed that the classifying property of a sand grain is expressed by such a factor as W/S (weight divided by surface) or specific weight of the grain, the fallacy of the sizing basis of measuring classifier efficiency may be shown in a few cases quantitatively.

Calculation of the W/S of sand grains of various assumed configurations which pass an r-mm. square aperture follows:

A spherical grain that will pass an r-mm. square aperture (Fig. 1A) has a surface area, $S = 4\pi\left(\frac{r}{2}\right)^2$, and a weight, $W = \frac{4}{3}\pi\left(\frac{r}{2}\right)^3 d$. The W/S of the grain is, therefore,

$$W/S = \frac{rd}{6}.$$

The maximum cubical grain that will pass the r-mm. aperture (Fig. 1B) has a surface, $S = 6r^2$, and a weight, $W = r^3d$, and therefore,

$$W/S = \frac{rd}{6}.$$

The cube of minimum W/S (Fig. 1B) that will pass the r-mm. aperture, when one of its faces is parallel to the sieve surface, has a surface,

$$s = 6\left[\left(\frac{\sqrt{r^2}}{2}\right)^2\right] = 3r^2,$$

and a weight,

$$W = d\left(\frac{r^2}{2}\right)\sqrt{\frac{r^2}{2}} = \frac{r^3d\sqrt{\frac{1}{2}}}{2}$$

and

$$\frac{W}{S} = \frac{\frac{r^3d\sqrt{\frac{1}{2}}}{2}}{3r^2} = \frac{rd\sqrt{\frac{1}{2}}}{6}$$

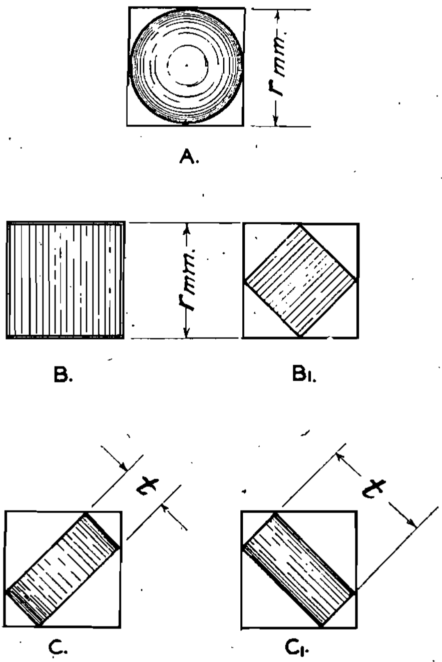

FIG. 1.—RELATION OF GRAIN CONFIGURATION TO THAT OF SIEVE OPENING.

If the cubical grain passes the aperture so that a diagonal through two apexes is normal to the sieve surface, the surface of the cube that just touches all four sides of the mesh is $S = 6\,\frac{3r^2}{4 + 2\sqrt{3}}$, the weight is $W = \frac{dr^3 \cdot 3^{3/2}}{(4+2\sqrt{3})^{3/2}}$ and $W/S = \frac{dr}{2\sqrt{12+6\sqrt{3}}}$.

The case of the cylindrical grain is more complicated. The disk or cylinder (Fig. 1C) of length t that will just pass the r-mm. sieve opening has a surface

$$S = 2\pi\left(\frac{r\sqrt{2} - t}{2}\right)t + 2\pi\left(\frac{r\sqrt{2} - t}{2}\right)^2 = \frac{\pi(2r^2 - t^2)}{2}$$

and a weight,

$$W = \frac{\pi(r\sqrt{2} - t)^2 td}{4}$$

and, therefore, a

$$\frac{W}{S} = \frac{2\pi(\sqrt{2}\,r - t)^2 td}{4\pi(2\,r^2 - t^2)} = \frac{(\sqrt{2}\,r - t)td}{2(\sqrt{2}\,r + t)}$$

The cylindrical grain of maximum W/S, which just touches the four wires of the mesh, has a length, t calculated as follows:

$$\frac{\partial}{\partial t}\left(\frac{W}{S}\right) = \frac{2(\sqrt{2}\,r + t)\cdot\dfrac{\partial(\sqrt{2}\,r - t)dt}{\partial t} - (\sqrt{2}\,r - t)dt\cdot\dfrac{\partial[2(\sqrt{2}\,r + t)]}{\partial t}}{4(\sqrt{2}\,r + t)^2}$$

$$= \frac{2(\sqrt{2}\,r + t)(\sqrt{2}\,rd - 2dt) - (\sqrt{2}\,r - t)dt\cdot 2}{4(\sqrt{2}\,r + t)^2}$$

$$= \frac{2(\sqrt{2}\,r + t)(\sqrt{2}\,r - 2t) - (\sqrt{2}\,r - t)t\cdot 2}{4(\sqrt{2}\,r + t)^2}$$

$$= \frac{4r^2 - 2\sqrt{2}\,rt - 4t^2 - 2\sqrt{2}\,rt + 2t^2}{4(\sqrt{2}\,r + t)^2}$$

$$= \frac{2t^2 - 4\sqrt{2}\,rt + 4r^2}{4(\sqrt{2}\,r + t)^2}$$

For minimum value of $\frac{W}{S}, \frac{\partial W}{\partial tS} = 0$ and therefore,

$$\frac{2t^2 + 4\sqrt{2}\,rt - 4r^2}{4(\sqrt{2}\,r + t)^2} = 0$$

or

$$t^2 + 2\sqrt{2}\,rt - 2r^2 = 0$$

and $t = -\sqrt{2}\,r \pm 2r$, but negative values have no meaning and when W/S is a minimum,

$$t = -\sqrt{2}\,r + 2r = 0.584r$$

that is, the cylinder of maximum W/S, passing the aperture in the position specified, has a length just slightly more than one-half the aperture dimension. The W/S for this cylinder is, then

$$\frac{W}{S} = \frac{(\sqrt{2}\,r - t)td}{2(\sqrt{2}\,r + t)}$$

$$= \frac{(\sqrt{2}\,r - 0.58r)0.584\,rd}{2(\sqrt{2}\,r + 0.584r)}$$

$$= \frac{0.48588r^2d}{3.416r}$$

$$= \frac{rd}{7.03}$$

There are tabulated below the W/S values of grains of various assumed shapes which pass a square aperture under the conditions specified.

Grain Configuration	$\frac{W}{S}$ Maximum	$\frac{W}{S}$ Minimum
Sphere	$\frac{rd}{6}$	$\frac{rd}{6}$
Cube	$\frac{rd}{6}$	$\frac{\sqrt{\frac{1}{2}}rd}{6}$
Cylinder	$\frac{rd}{7.03}$	

The W/S of a grain is a function of the product of the aperture through which the grain just passed and its density times a constant, k, the value of which, except in the case of the cube and the sphere, is a function of the grain configuration. The general formula giving the W/S of a grain, then, is:

$$\frac{W}{S} = krd$$

In Table 1 the constant k of a 24/28 (av. dia. = 0.645 mm.) mesh, theoretically spherical grain, of an Ottawa silica sand grain, and of a crushed quartz grain, is given.

TABLE 1.—*Physical Constants of One 24/28 Mesh (0.645 Mm.) Grain*[a]
$d_1 = 2.65$

Grain	$V =$ $0.5283r^3$ Cu. Cm.	$W_1 =$ $0.5283r^3d$ Grams	$W =$ $W_1 - V$ Grams	$\frac{W_1}{V}$	$S =$ $3.1416r^3$ Sq. Cm.	Specific Wt. $= \frac{W}{S}$ Grams per Sq. Cm.	Constant k
Sphere or cube (calc.)	0.0001417	0.0003755	0.0002338	2.65	0.01307	17.72×10^{-4}	0.1666
Ottawa sand (det.)	0.0002030	0.000538	0.0003350	2.65	0.02570	13.04×10^{-4}	0.1216
Crushed quartz (det.)	0.0001885	0.000500	0.0003115	2.65	0.03200	9.73×10^{-4}	0.0916

[a] The volume and weight of the individual grain, in the case of the Ottawa sand and the crushed quartz sand, were determined by weighing a known number of grains and by measuring the volume of a relatively large weight of the grains by displacement in acetone. The surface is calculated from the data given by J. Gross and S. R. Zimmerley: Crushing and Grinding.—I and II. *Tech. Pub.* 46 and 126 (1928–29) A. I. M. E.

If it is desired to know the grain-size segregation that a classifier effects in the treatment of a given feed, a sieve-sizing analysis gives the information; however, if classifier efficiency is wanted, the sieve analysis basis is fundamentally wrong and misleading. Even when grain density is a constant factor, water sizing and square-mesh aperture sizing are not compatible.

This is further brought out in the graph of Fig. 2, which shows the arrangement of particles in an ideal classifier, with respect to their sizes and specific gravities. Shape is constant, but the feed is made up of grains differing widely, and uniformly, in size and specific gravity.

Assuming a classifier separation at x mm. size, the nature and relative quantities of classifier products may be shown by passing lines through the classifier column in the proper directions.

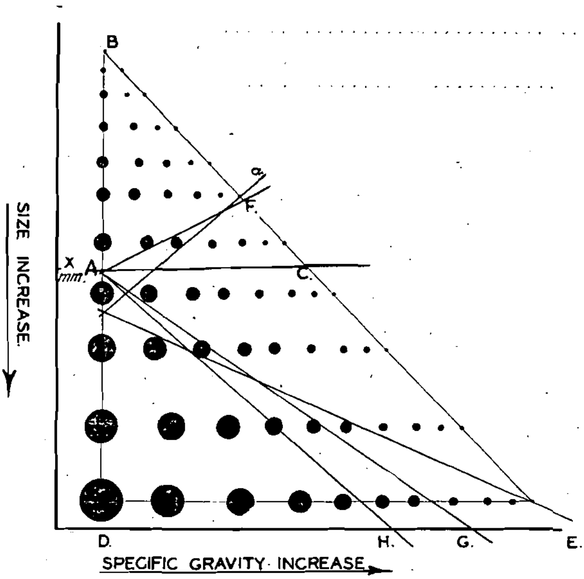

FIG. 2.—CROSS-SECTION OF IDEAL CLASSIFICATION WHEN SIZE AND SPECIFIC GRAVITY OF GRAINS ARE VARIABLE BUT SHAPE CONSTANT.

The horizontal line AC divides the classifier input into two perfect products; namely, finished above the line AC and unfinished below this line. For a classifier less than 100 per cent. perfect some finished product, represented by the portion CAF, remains with the unfinished, and the extent or degree of classification is represented by the portions of the graph above (finished) and below (unfinished) the sloping line AF. Referring to the formula $E_1 = \dfrac{100b(a-c)}{a(b-c)}$, and tying it into this graph, we have:

$$\begin{aligned} CAB &= a \\ CADE &= 100 - a \\ CAF &= c \\ 100 &= b \end{aligned}$$

Therefore $$E = 100\frac{(100)(a-c)}{a(100-c)} = \frac{10{,}000(a-c)}{a(100-c)}$$

and since AC is horizontal, and therefore represents perfect classification,

$$c = 0,$$

$$\text{and } E = \frac{10{,}000(a - 0)}{a(100 - 0)} = \frac{10{,}000a}{100a} = 100 \text{ per cent. efficiency.}$$

If classification were effected entirely on the basis of size, perfect separation at x mm. is indicated by the portion of the feed above and to the right of line AH. Less than perfect separation at the x mm. size is represented by a line such as AG, and

$$\begin{aligned} EBAH &= a_1 \\ HAD &= 100 - a \\ GAH &= c_1 \\ 100 &= b_1 \end{aligned}$$

$$\text{and } E_1 = \frac{10{,}000(a_1 - c_1)}{a_1(100 - c_1)}, \text{ and when } GAH = 0 = c_1$$

$E_1 = 100$ per cent. efficiency on the basis of sieve analyses.

The two efficiency formulas are identical, and for determining screening efficiency it is proper to determine the values of a_1 and c_1 on the basis of sieve analyses. However, it is obvious from Fig. 2 that it is scientifically permissible to determine the values of a and c by sizing only when the material in question is uniform in density and shape. In that case the sloping line AG should approach the horizontal position occupied by AC. However, when density of grain is variable, theoretically a and c should be determined on the principle of operation of the classifier.

Experimental Method Developed

Previous research[5] by the writer suggested to him a method based on the fundamental factors involved in classification. In Fig. 3 is shown the experimental set-up used. It consists of a glass tube t, of suitable bore and length, provided at its top with a funnel f and at its tapered bottom with provision for admitting into the tube adjustable rising currents of water to meet the requirement of the experiment. The provision is a flask pressure chamber p, into which water is controllably admitted through a valve v under constant pressure. The amount of water admitted is dictated by the size and specific gravity of the largest grains in the charge to be studied. The funnel is large enough so that material may be fed to the tube without overflowing any of it through the funnel outlet.

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[5] A. W. Fahrenwald: Hydraulic Classification, Theory, Mechanical Development, and Application in Ore Dressing. U. S. Bur. Mines *Tech. Paper* 403.

Stratification, Theory, and Application in Ore Dressing. *Min. & Met.* (October, 1926), **7**, 437.

The size of the charge to be analyzed is largely determined by the nature of the ore. From 100 to 1000 g. are used, depending on the case in hand. Tubes the size of ordinary burettes to 1 in. dia. or more and 2 ft. or more long may be used. A small charge should not be used in a large tube, nor a large charge in a small tube.

The charge—it need not be weighed out accurately—is washed carefully into the funnel and water is added to give a just hindered-settling condition in the sands at the bottom of the tube. This condition should be allowed to obtain for several minutes, or until the sand grains have had time to adjust themselves and to find their proper static environment with respect to other grains.

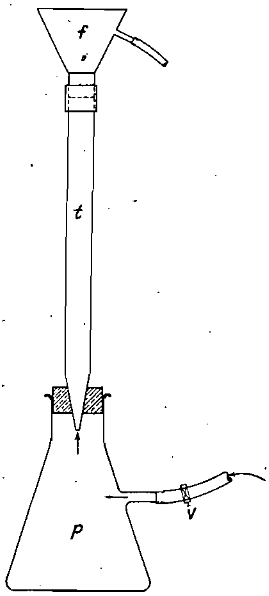

FIG. 3.—HYDRAULIC SIZER SET-UP.

The fluid teeter column is now stirred in a slow circular motion by hand, with a long glass rod, and the water is entirely cut off. The stirring is continued until the charge is entirely compacted, the stirring rod being raised slowly to keep the lower end just above the gradually forming compacted bed. This procedure is to prevent eddy currents in the teeter column, and serves the desired purpose. The stirring is the equivalent of rotating the tube, as in some earlier experiments, but is a more convenient method.

The compacted column of sands in the tube, in which classification of the grains is probably as nearly perfect as may be approached experimentally, now is in condition to be removed from the tube. The removal is accomplished by a siphon method. It should be mentioned here, too, that the compacted bed is removed with much more facility than when the same material is in teeter.

The siphon consists of a pair of glass tubes connected with a rubber tube. The siphon is made operative by placing one tube in the water in the funnel and sucking at the other end with the mouth. Water should be admitted to the funnel from a suitable source in continuous flow before proceeding with the withdrawal of the sands. This is to replace in the column as much water as is removed through the siphon. The end of the tube in the funnel is now lowered toward the compacted bed of sands and as much of the column siphoned out into a pan as desired.

The compacted column may be cut into as many individual small layers as desired. The greater the number of cuts, mathematically, the more nearly the experiment approaches the ideal. It is well to graduate the tube so that approximately equal quantities may be drawn off, if that seems desirable. This is an extremely useful technique in the laboratory study of many ores.

The individual small increments, which, when added up, comprise the whole, are next dried and sieve-sized. If only classifier efficiency is desired, only determination of maximum grain of each product is necessary. If a complete picture of a vertical cross-section through the ideal classification is desired, complete sieve and chemical analyses of each cut is made. Also, if a complete knowledge of the concentratibility of the ore is desired, heavy liquid or microscopic analysis of each weight increment is useful. This same technique gives valuable data in studying flotation tailing.

Experimental Data

In Tables 2, 3 and 4 are given the results of experimental analyses of classifier products from the Morning Mill at Mullan, Idaho, of the Federal Mining and Smelting Co. The number of the increments.

TABLE 2.—*Ideal Classification Analysis of Feed, Morning Mill*

SAMPLE NO.	WT. GRAMS	WT. %	WT. % CUM.	+35	+42	+48	+60	+65	+80	+100	+115	+150	+170	+200	-200
				FEDERAL TYPE CLASSIFIER – FEED.											
1	21.20	11.16	11.16												21.20
2	4.63	2.42	13.58												4.63
3	6.25	3.27	16.85											0.95	5.30
4	6.30	3.29	20.14									0.86	0.88	0.71	3.85
5	7.91	4.14	24.28								1.18	1.47	1.57	1.08	2.61
6	9.16	4.78	29.06							2.37	1.37	1.71	1.51	0.62	1.58
7	7.95	4.16	33.22						1.77	2.25	0.92	1.30	0.78	0.30	0.63
8	8.67	4.53	37.75					2.20	0.56	2.32	0.87	1.27	0.72	0.20	0.53
9	10.37	5.42	43.17				1.06	2.15	0.60	2.72	1.07	1.35	0.55	0.17	0.70
10	11.85	6.18	49.35				1.92	2.91	0.73	2.80	1.17	1.25	0.50	0.09	0.48
11	12.63	6.60	55.95			1.40	1.80	3.15	0.85	2.62	0.98	0.90	0.42	0.11	0.42
12	13.90	7.26	63.21		1.30	1.25	2.20	3.23	0.51	2.65	0.93	0.83	0.43	0.10	0.47
13	70.31	36.79	36.79		25.15	7.10	9.37	12.00	1.57	7.52	2.37	2.30	1.10	0.35	1.48
TOTAL WT.	191.13	100.00	100.00		26.45	9.75	16.35	25.64	6.59	25.25	10.86	13.24	8.54	4.68	43.88
WT. %	100.00				13.54	5.10	8.55	13.40	3.44	13.20	5.68	6.93	4.46	2.44	23.26
WT. % CUM.	100.00			→	13.54	18.64	27.19	40.59	44.03	57.23	62.91	69.84	74.30	76.74	23.26
WT. % CUM.	100.00			←	13.54	86.66	81.56	73.01	59.61	56.17	42.97	37.29	30.36	25.90	23.26

(No. 1 being the top increment), weight, weight per cent., weight per cent. cumulative, and sieve analysis of each increment are given. The summation of the sieve analyses of all of the increments gives the sieve analysis of the head sample. We may thus compare the products as analyzed by sieve sizing with the same products analyzed by hydraulic sizing.

This comparison is made in Table 5. The percentage of the total feed that should overflow the ideal classifier at any given sieve mesh opening is given in column 3. The percentage of the total feed that will pass a given sieve opening, as indicated by a sieve analysis, is given in column 4. The difference is given in the final column.

TABLE 3.—*Ideal Classification Analysis of Dragover Sands, Morning Mill*

SAMPLE NO.	WT. GRAMS	WT. %	WT. % CUM.	+35	+42	+48	+60	+65	+80	+100	+115	+150	+170	+200	-200
				FEDERAL TYPE CLASSIFIER—DRAGOVER											
1	4.72	4.73	4.73												4.72
2	2.83	2.83	7.56									0.30	0.15	0.20	2.18
3	5.90	5.91	13.47						0.12	0.55	0.48	1.01	0.95	0.47	2.22
4	6.13	6.14	19.61					0.30	0.23	1.30	0.82	0.96	0.87	0.38	1.27
5	7.09	7.10	26.71					1.00	0.58	1.66	0.92	1.02	0.80	0.28	0.83
6	6.61	6.62	33.33					1.87	0.49	1.58	0.82	0.84	0.48	0.13	0.47
7	6.68	6.69	40.02					2.31	0.48	1.38	0.73	0.80	0.36	0.10	0.45
8	7.80	7.81	47.83					3.54	0.47	1.37	0.80	0.78	0.29	0.08	0.47
9	5.97	5.98	53.81					3.00	0.20	1.20	0.48	0.46	0.21	0.05	0.37
10	5.28	5.29	59.10					3.12	0.15	0.84	0.34	0.34	0.14	0.05	0.30
11	6.52	6.53	65.63					4.15	0.12	1.05	0.33	0.30	0.17	0.05	0.35
12	34.32	34.37	34.37					27.50	0.55	2.50	0.72	1.10	0.68	0.35	0.92
TOTAL WT.	99.85	100.00	100.00					46.79	3.39	13.43	6.44	7.91	5.10	2.15	14.55
WT. %	100.00							46.80	3.39	13.48	6.45	7.93	5.11	2.15	14.69
WT. % CUM.	100.00			→				46.80	50.19	63.67	70.12	78.05	83.16	85.31	14.69
WT. % CUM.	100.00			←				46.80	53.20	49.81	36.33	29.88	21.95	16.84	14.69

Considering the classifier feed and assuming a separation at 100 mesh, the percentage of material in the feed, as indicated by the hydraulic test, which should overflow the classifier and leave the crushing system as finished sand, is 24.5 per cent. Sieve analysis of the feed shows that there is present 42.97 per cent. of −100-mesh material, the difference being the large figure of 18.47 per cent.

TABLE 4.—*Ideal Classification Analysis of Overflow, Morning Mill*

SAMPLE NO.	WT. GRAMS	WT. %	WT. % CUM.	+35	+42	+48	+60	+65	+80	+100	+115	+150	+170	+200	-200
				FEDERAL TYPE CLASSIFIER—OVER FLOW.											
1	57.90	56.40	56.40												57.90
2	2.70	2.63	59.03												2.70
3	3.55	3.46	62.49											0.20	3.35
4	4.84	4.62	67.11										0.17	0.45	4.22
5	2.16	2.10	69.21										0.19	0.27	1.70
6	4.17	4.01	73.22									0.41	1.06	0.60	2.10
7	6.38	6.16	79.38							0.57	0.83	1.37	1.29	0.52	1.80
8	4.83	4.71	84.09							0.86	0.66	0.82	0.82	0.35	1.32
9	5.05	4.91	88.99					0.22	0.27	1.30	0.76	0.75	0.70	0.20	0.85
10	11.16	11.01	11.01					3.58	0.53	2.42	1.20	1.35	0.79	0.32	0.97
TOTAL WT.	102.74	100.00	100.00					3.80	0.80	5.15	3.45	4.70	5.02	2.91	76.91
WT. %	100.00							3.70	0.76	5.02	3.34	4.58	4.88	2.83	74.89
WT. % CUM.	100.00							3.70	4.46	9.48	12.82	17.40	22.28	25.11	74.89
WT. % CUM.	100.00							3.70	96.30	95.54	90.52	87.18	82.60	77.72	74.89

Similar comparisons may be made at any other assumed overflow mesh, and always there is the striking difference between what actually will overflow, as indicated by the hydraulic test, and the percentage of material in the feed, as indicated by sieve analysis. These figures begin to indicate the fundamental unfitness of the sieve analysis as a basis of gaging classifier performance.

Now turn to a consideration of the classifier (dragover) sands, Table 3. Still assume that the classifier was making a separation at 100 mesh. By the hydraulic test there is actually 10.75 per cent. of finished product in the unfinished sand, which returns to the ball mill for further comminution. The sieve analysis shows 36.33 per cent. of finished sands in the unfinished product, a difference of 25.58 per cent.

Referring to the classifier overflow, Table 4. At a 100-mesh separation, the overflow actually contains 79.0 per cent. finished and 21.0 per cent. unfinished, while a sieve analysis of the overflow shows 90.52 per cent. finished and 9.48 per cent. unfinished product.

TABLE 5.—*Comparison of Classifier Performance by Hydraulic Analysis and by Sieve Analysis*

Ore from Morning Mill, Mullan, Idaho

Material	Separation, Mesh	Finished Product, Per Cent.		
		Theoretical[a]	By Sizing	Difference
Feed from Table 2	200	13.58	23.26	9.78
	170	16.00	25.90	9.90
	150	18.00	30.36	12.36
	115	20.50	37.29	16.79
	100	24.50	42.97	18.47
	80	29.00	56.17	27.17
	65	33.50	59.61	26.11
Dragover sands from Table 3	200	4.72	14.69	9.97
	170	5.75	16.84	11.09
	150	6.75	21.95	15.20
	115	7.70	29.88	22.18
	100	10.75	36.33	25.58
	80	13.50	49.81	36.31
	65	19.50	53.20	33.70
Overflow slimes from Table 4	200	59.03	74.89	15.86
	170	62.49	77.72	15.23
	150	69.21	82.60	13.39
	115	73.22	87.18	14.96
	100	79.00	90.52	11.52
	80	84.09	95.54	11.45
	65	88.00	96.30	8.30

[a] Calculated from graph plotting per cent. through vs. cumulative weight per cent.

The difference in percentage of finished in unfinished product, as indicated by the hydraulic test and as indicated by sieve analysis, is less for the finer overflows than for the coarser overflows in the case of the feed and the dragover products; and the reverse of this order is the case for the classifier overflow. This is quite in order with effect of decrease in size and influence of viscous surface films on hindered-settling ratios.

Using the over-all efficiency formula, page 2, let us examine the efficiencies of the classification recorded herein. Assume, as we have done above, a classifier separation at 100-mesh, then from the data of Table 5

$$a = 24.50$$
$$b = 79.00$$
$$c = 10.75$$

Then, $E = \dfrac{10{,}000(79.00 - 24.5)(24.50 - 10.75)}{24.50(100. - 24.50)(79.00 - 10.75)} = 59.28$ per cent. efficiency on the basis of analyses of classifier products by the hydraulic test.

The efficiency of classification at 100-mesh separation, on the basis of sieve analyses is:

$$a_1 = 42.97$$
$$b_1 = 90.52$$
$$c_1 = 36.33$$

and $E = \dfrac{10{,}000(90.52 - 42.97)(42.97 - 36.33)}{42.97(100 - 42.97)(90.52 - 36.33)} = 22.11$ per cent. efficiency.

At 170-mesh separation the classifier efficiency, by the hydraulic test, is:

$$E = \frac{10{,}000(62.49 - 16.00)(16.00 - 5.75)}{16(100 - 16)(62.49 - 5.75)} = 62.50 \text{ per cent.}$$

and by sieve analysis, 40.20 per cent.

Summary and Conclusions

1. The ratio "weight divided by surface" of sand grains is a widely varying factor for ore grains passing a given sieve aperture.

2. Closed-circuit classifier efficiency is not theoretically accurately expressed on the basis of sieve analysis.

3. Closed-circuit classifier efficiency shows to much better advantage on the basis of ideal classification than on the basis of sieve analyses.

4. The efficiency of the classification studied is about 60 per cent. This suggests opportunity for useful further research in the field of this type of classification.

5. Classifier efficiency on the basis of removal of finished product shows up to better advantage than on the basis of over-all efficiency.