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CORRELATION OF PARAMETERS FOR LABORATORY HYDROCYCLONE OPERATION

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ABSTRACT

Desliming of sub-sieve size particles in the laboratory is normally accomplished by several hours of settling and decanting. Several empirical expressions can be used to design a hydrocyclone capable of desliming sub-sieve size particles very quickly and in a way that more closely simulates the techniques used in production plants.

INTRODUCTION

One of the objectives of batch flotation experiments is to simulate production conditions on a very small scale, thus making it possible to study the changes resulting from variations in operating parameters with more detail. The scrubbing, conditioning and flotation phases can be simulated so that conditions can be scaled to pilot plant work. One operation that is not being simulated in batch experimentation is desliming.

The most practiced method of batch phase desliming is to agitate a sample in a bucket of water, let the sample settle for a period of time and then decant the water through a screen that is close to the size at which you wish to deslime. This method is normally repeated to effectively deslime the sample but does not simulate plant conditions. In production, desliming is normally accomplished by using cyclones. This method inherently allows oversized material to enter the flow of undersized slimes and vice versa. With settling and decanting, there is no chance for oversized material to pass through a screen. Thus, this conventional method of desliming does not accurately simulate the desliming circuit of a pilot plant flowsheet.

More importantly, settling and decanting is limited to the settling time and available screen sizes. If it is desired to deslime material that is quite fine, the settling time may be in excess of one hour.

Irregardless of the settling time, very fine material will easily pass through the finest mesh screens and give no indication of the effectiveness of the settling procedure. This is especially true of the fine feldspar filter cake tailings from the Spruce Pine, North Carolina, area. These tailings contain as much as 75% by weight of material which is minus 400 mesh. In order to effectively deslime at as fine a size as possible, several hours of settling and decanting are required.

Using a small laboratory hydrocyclone would eliminate the long settling time required to deslime material that is much finer than 400 mesh, and do so in a manner that closely simulates the procedure in pilot plant as well as production flowsheets.

MATERIALS AND METHODS

Equipment

The apparatus used throughout the testing was a Liquid-Solid Separations Limited Laboratory Hydrocyclone Pump Unit. This unit was designed for use at high pressures and has a capacity of 1.6 to 21 litres per minute. The hydrocyclone attachment also contains interchangeable feed heads, feed inlets, vortex finders and apex nozzles.

The sizing of the hydrocyclone overflow and underflow was done by US Standard Testing Sieves. The finer material (-200 mesh) was sized by using a Warman Cyclosizer. Several tests were also completed using a hydrometer (ASTM - Procedure D422-61T), as well as a Micromeritics Sedigraph 5000 D.

Sample

The hydrocyclone feed was a feldspar filter cake tailings product produced by International Minerals and Chemical Corporation in Spruce Pine, North Carolina. The sample was collected over a one week period while the plant was operating under normal conditions. The filter cake consisted of fine material packed together in lumps having variations in their respective moisture contents. In order to obtain representative samples with known moisture content, the entire sample was thoroughly dried at 200°F and screened on a 20 mesh screen to break up all lumps. The entire dried sample was then mixed thoroughly so that a small representative sample could be obtained by simply scooping from the larger sample. Details of the sampling procedure and sample description are available by referring to Laboratory Notebook No. 439.

Procedure

The general procedure was to vary the hydrocyclone operating parameters and construct efficiency curves for the various operating conditions. An initially dried 500 gram sample was screened on 35 mesh to break up any lumps and remove any coarse material that could clog the hydrocyclone. The sample was slurried to approximately 15% solids and poured into the hydrocyclone sump. The operating parameters were recorded and the slurry was allowed to circulate for one minute before the separation was made. Both the overflow and underflow were saved in buckets while clear water was added to the sump. The separation was completed when the sump water was clear. Sulphuric acid was added to the two buckets containing the overflow and underflow, and the material was allowed to settle for four hours. At this point, the water was siphoned from the buckets and the samples were dried.

The dried weights were recorded, and screen analyses were completed. Because as much as 75% of this material was minus 400 mesh, screen blinding became a problem. To remedy this, screening was done only as fine as 200 mesh. The minus 200 mesh material was sized by alternate methods.

Because of the extremely fine nature of this material, several methods of sub-sieve size analysis were employed to maintain as high a degree of accuracy as possible. The Warman Cyclosizer was the most used method. The Cyclosizer sample was prepared with 3 cc of 2.5% TSP to insure that any flocculated material was completely dispersed. Settling and hydrometer tests were employed to check the results of the Cyclosizer. Settling tests were run as suggested in Laboratory Notebook No. 236, while hydrometer tests were run according to ASTM-D422-61T. Several size distribution analyses were also provided by using a Micromeritics Sedigraph 5000 D. To maintain consistency, the results of the Warman Cyclosizer were used for all calculations, with other sizing methods serving as a check.

THEORY

The major forces acting upon a particle as it passes through a cyclone are a centrifugal force, F_c, and a drag force, F_d. If $F_c > F_d$, the particle will move toward the cyclone wall and eventually exit through the apex. If $F_c < F_d$, the particle will exit via the overflow. However, if $F_c = F_d$, the particle is said to be in equilibrium. It is generally assumed that a particle in equilibrium has an equal chance (50%) of reporting to either the overflow or the underflow. This particle size is referred to as d_{50} or the cut size.(1)

The effects of changing parameters in cyclones are very complex, in that all parameters are interrelated. It is almost impossible to select a cyclone to give the precise separation required, and it is nearly always necessary to adjust feed inlet, vortex finder, apex opening, and pulp pressure and dilution.(2) There are, however, many empirical equations which can be used to accurately estimate the efficiency of a cyclone. Perhaps the most widely used has been derived by Dahlstrom(3):

$$d_{50} = \frac{81\ (D_o D_i)^{0.68}}{Q^{\ 0.53}} \quad \frac{(1.73)^{0.5}}{(S-L)^{0.5}}$$

where d_{50} = cut size (microns),
D_o = overflow diameter (inches),
D_i = inlet diameter (inches),
Q = total flow rate (U.S. gallons/minute),
S = specific gravity of solids,
L = specific gravity of liquid.

Using this formula to predict the performance of the Laboratory Hydrocyclone, it was possible to make a size separation within the measuring parameters of the available equipment. After the separation was made, size analyses could be compared with empirical estimations.

Dahlstrom's equation gives only partial consideration to the operating parameters of the Laboratory Hydrocyclone because of the interrelation of all parameters. Several other formulas have been derived to take into account all parameters as independent variables. One is that of Plitt[4]:

$$d_{50} = \frac{35\ D_c^{0.46}\ \ D_i^{0.6}\ \ D_o^{1.21}\ \ \exp\ (0.08\phi/F_{50}^{0.052})}{D_u^{0.71}\ \ h^{0.38}\ \ Q^{0.45}\ \ (S\text{-}L)^{0.5}}$$

where ϕ = volume fraction of solids in the feed slurry,

F_{50} = median size of the feed solids (microns),

Q = volumetric flow rate (ft^3/min).

h = height of cyclone (inches),

D_u = apex diam. (inches),

D_c = cyclone diam. (inches).

Q can be determined by collecting the cyclone overflow and underflow and measuring the quantity collected, or by the following expression:

$$Q(\text{cfm}) = \frac{0.21\ P^{0.56}\ \ D_c^{0.21}\ \ D_i^{0.53}\ \ h^{0.16}\ \ (D_u^{\ 2} + D_o^{2})^{0.49}}{\exp\ (0.0031\ \phi)}$$

where P = pressure drop across cyclone (psi).

Perhaps the most common method of representing hydrocyclone efficiency is by the Tromp Curve, which relates the percentage of each particle size recovered in the underflow to the particle size. The cut size can be graphically determined by this method. The efficiency of the separation is expressed by the slope of the central portion of the curve; the closer the slope is to vertical, the higher the efficiency.

The Tromp Curves included in this report were constructed from the experimental data shown in Table 1. Since the main area of interest was the determination of d_{50} and size of particles recovered, the distribution of particles finer than the cut size was represented by a smooth curve originating at 0%. The remainder of the graph was determined by plotting data points.

TABLE 1

COMPARISON OF EFFICIENCY OF SEPARATION

Size*	Test V2 Wt. O.F.	Test V2 Wt. U.F.	Test V2 % Feed In U.F.	Test K Wt. O.F.	Test K Wt. U.F.	Test K % Feed In U.F.	Test W Wt. O.F.	Test W Wt. U.F.	Test W % Feed In U.F.
+74.0	7.1	77.4	91.6	4.7	49.0	91.2	6.5	76.4	92.2
42.1	0	23.7	100.0	0	20.8	100	0	22.6	100.0
35.8	0	47.1	100.0	0.3	48.5	99.3	0	46.6	100.0
26.2	0.3	64.8	99.5	1.2	60.9	98.0	0.4	63.5	99.4
18.6	0.5	60.4	99.2	4.0	59.3	93.6	0.7	58.9	98.8
13.5	0.3	41.4	99.3	5.8	38.1	86.7	0.5	39.7	98.8
-11.9	64.6	96.5	59.9	51.6	98.0	65.5	79.6	82.5	50.9

*Geometric mean of size interval (microns).

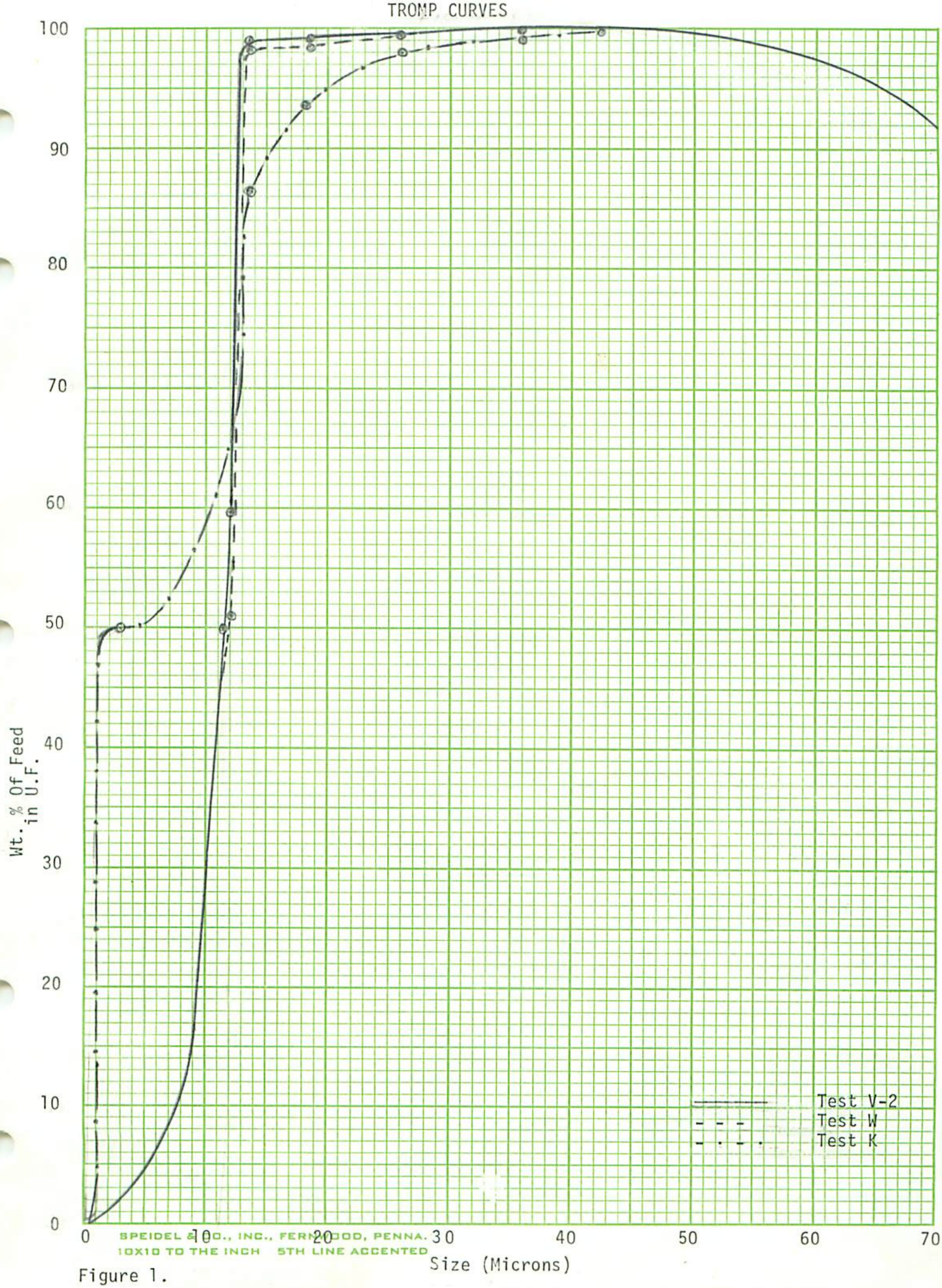
TROMP CURVES
100
90
80
70
60
50
40
30
20
10
0
Wt. % Of Feed in U.F.
0
10
20
30
40
50
60
70
Size (Microns)
Test V-2
Test W
Test K
SPEIDEL & CO., INC., FERNWOOD, PENNA.
10X10 TO THE INCH 5TH LINE ACCENTED

Figure 1.

DISCUSSION

Although the Tromp Curves were constructed without examining the particles finer than 11.5 microns, it is evident from the slopes of the curves that a definite separation is being made with very high recovery. Test V-2 was completed and it was determined that the cut size obtained was 11.5 microns. This size is too fine to be examined with the Cyclosizer, so adjustments were made. By examining Dahlstrom's equation, it became evident that a cut size of 11.9 microns could be obtained by reducing the quantity of slurry pumped in Test V-2 and maintaining all other variables. This cut size can be examined using the Cyclosizer. Results of Test W indicate that 50.9 % of the material finer than 11.9 microns reported to the underflow, which is very close to the mathematical prediction.

The coarse oversized material in the overflow was almost totally composed of mica. Since this material has a large surface area, it is subject to larger drag forces in comparison to centrifugal forces. This should account for the coarse mica in the overflow of these three tests.

Because of the short length of time that the Laboratory Hydrocyclone was operated for each test, the flow rate, percent solids and size distribution of the feed were difficult to control. Realizing this, it stands to reason that the equation giving more weight to these parameters would be more inaccurate. This is why the Dahlstrom equation gives a cut size that checks closely with the Cyclosizer results, and Plitt's equation determines the cut size to be quite different than the experimental results (Table 2). However, if all variables could be accurately maintained over a period of time, Plitt's equation could be more useful in hydrocyclone design due to the weight put in all operating variables.

TABLE 2

OPERATING PARAMETERS
FOR
HYDROCYCLONE TESTS

Parameters	TEST V-2	TEST K	TEST W
D_c	1.25	1.25	1.25
D_u	0.0591	0.0591	0.0591
D_o	0.2953	0.0738	0.2953
D_i	0.2953	0.0738	0.2953
h	8.25	8.25	8.25
Q_{gpm}	2.02	0.79	1.75
d_{50}*	11.5	2.8	11.9
d_{50}**	21.3	2.6	21.9
d_{50}***	11.0	3.0	11.5

*Determined by Dahlstrom's equation.

**Determined by Plitt's equation.

***Actual

CONCLUSIONS

It is possible to use the Liquid-Solid Separations Laboratory Hydrocyclone to deslime very fine material for batch flotation tests. By changing the operating parameters and employing the proper empirical expressions, the results can be predicted with reasonable accuracy. This provides an alternative to the time consuming method of settling and decanting, and does so while more closely simulating the desliming techniques used in production.

No empirical expression will give exact results for every testing situation, but when properly employed, mathematical expressions can be quite valuable. The equations mentioned in this report can be used to determine the capabilities of a hydrocyclone before it is actually put into operation.

SUGGESTIONS

Based upon the findings of this report, several areas for future consideration may be suggested:

1. Study of results obtained from multi-staged hydrocycloning.

2. More detailed analysis of -11.5 micron material with more accurate equipment, such as Micromeritics Sedigraph 5000 D.

3. Improvements to Laboratory Hydrocyclone that provide more control over feed rate, pressure drop, and size distribution of the feed.

4. Consideration of use of a shorter hydrocyclone to obtain a coarser cut size.

REFERENCES

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