

New Methodology Enables Improved Evaluation of Flotation Collectors

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ABSTRACT

Flotation reagents are critical to the optimum performance of flotation circuits. How a flotation reagent performs within the first few cells of a flotation train is a key indicator of how well it will perform throughout the entire circuit. A method to compare reagent performance was recently developed by Ashland Water Technologies. The procedure involves collecting a timed sample of concentrate from each cell and then measuring the volume of the settled solids. An estimate of the percentage of concentrate collected from each cell can then be mathematically determined, providing an understanding of the recovery changes in each cell. Data from trials at a coal flotation circuit are used to demonstrate the method's validity.

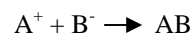
INTRODUCTION

When studying the performances of different collectors in a flotation circuit, laboratory tests are used to estimate the best potential collectors to try in the plant. Lab tests indicate which collector will float the valuable minerals faster, leading to possible grade and/or recovery increases. However, lab tests are batch tests while flotation circuits are continuous feed systems. While lab tests can produce flotation kinetics data indicative of each cell in a flotation circuit, they do not scale up to plant operations well. Plant operations, on the other hand, generally do not allow for obtaining data for flotation kinetics calculations on a cell by cell basis. This is especially true in the first few cells of a flotation circuit where the flotation kinetics are the most pronounced.

FLOTATION KINETICS

Collectors are generally considered better if they can float valuable particles faster with less gangue minerals. Flotation kinetics follow the same principles of reaction kinetics followed by all chemistry. Mathematically,

reaction kinetics are determined by the following functions (Houston 2006):



$$R = Ce^{k[A][B]}$$

A is the floating particle, B is the collector, AB is the reaction product of the floating particle and the collector, R is a measure of the speed of the reaction, C and k are rate constants and [A] and [B] are concentration values of A and B. In flotation, the kinetics equation shows that kinetics are driven by the concentration of the floating particle (A^+) and the collector (B^-). Since the floating particle concentration is highest in the early cells of the flotation circuit, this is where the distinctions between collectors are best determined.

PROBLEMS WITH PLANT TRIALS OF COLLECTORS IN A FLOTATION CIRCUIT

When conducting a plant trial of a collector in a flotation circuit, the individual cells are sampled to track grade improvements of the valuable minerals, but without knowing the weight pull of each cell, recovery cannot be calculated. Most circuits only track the weight of the final concentrate using a densitometer flow meter and confirm the results using the three assay method.

The three assay method eliminates the need to have actual weights to calculate recovery. Mathematically, the weight of concentrate recovered can be determined by using assays of a tracking metal with the following formula:

$$\frac{FA-TA}{CA-TA} \times FT = CPW$$

FA is the assay of the feed into the circuit, TA is the assay of the tails leaving the circuit, CA is the assay of the combined concentrate pulled from the cells of the circuit, FT is the tonnage of dry feed going into the circuit and CPW is the total concentrate pull weight. With this formula, performance over the whole circuit can be calculated. However, performance in individual cells cannot be calculated; thus neither can flotation rates of the different collectors.

Circuit retention time is a factor in determining if recovery differences between collectors can be determined. Two retention time factors are important in collector comparison testing: mechanical retention time, which is a fixed amount determined by total cell volume and slurry flowrate, and flotation retention time, which is the flotation time it takes to achieve the desired recovery using a particular collector. As mentioned earlier, collectors show improvement by increasing the flotation rate of the valuable minerals. This decreases the flotation retention time of a flotation circuit. If the circuit has a mechanical retention time higher than the flotation retention time required for best recovery with one collector, then any decrease in the flotation retention time offered by another collector is not apparent in the overall recovery. The latter can only be determined if recovery can be calculated at the individual cell level.

As an example of the retention effects, Figure 1 shows the recovery curves for two collectors. Collector A is a fast floating reagent, creating a recovery curve that is steep at the front and trails off toward the end. Collector B is a slow floating collector that, given enough time, will float to the same recovery as the fast floating collector. If the flotation circuit has a mechanical retention time equal to the point marked C, Collector A will be determined to be faster than Collector B. If the circuit has a mechanical retention time equal to the point marked D, the test will show no difference between the two collectors.

Not only can the mechanical retention time affect how well a collector's performance can be determined, but also the grade of the valuable metal in the feed is a factor and one that generally varies over time as ore grades change. As the grade of the valuable metal in the ore falls, the amount of flotation retention time needed to float to the best recovery is shortened. Figure 2 is an illustration of that effect, where a collector flotation retention time with the 4% feed grade is equal to the mechanical retention time required to achieve 82% recovery. If the feed grade falls to 3.5% and the flotation kinetics do not change in the first cell, recovery rate increases due to the

total amount of the valuable metal available to float being less. In the end, both grades of ore achieve approximately 82% recovery, but the recovery occurs faster with the lower grade ore.

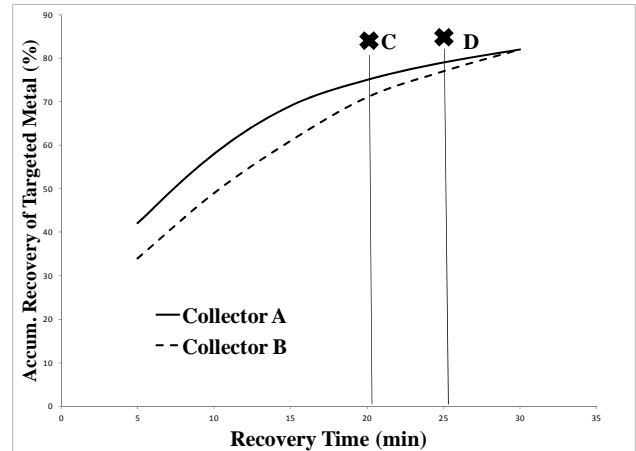


Figure 1. Flotation Kinetics of Two Collectors

Concentrate weight pull from the first couple of cells is the best way to evaluate the flotation kinetics of one collector over another. To do so, a method must be developed to allow at least an estimated calculation of weight pull from the individual cells. The method developed is the Settled Solids Method that involves taking samples from each cell in a flotation train, allowing them to settle and using the volume to estimate weight pulls from the individual cells.

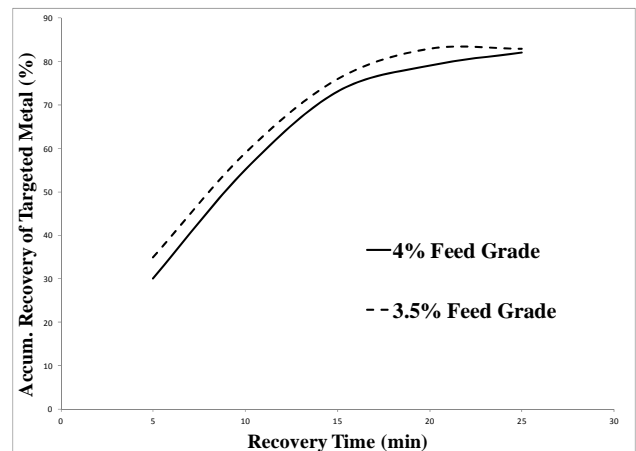


Figure 2. Changes in Recovery Due to Feed Grade Reduction

METHOD FOR ESTIMATING PULL WEIGHT RECOVERIES FOR INDIVIDUAL CELLS (SETTLED SOLIDS METHOD)

Since measuring flow of concentrate or taking a sample of the tails from each cell is very difficult, an indirect method was devised for calculating each cell's weight pull. This new method, Settled Solids Method (SSM), assumes a direct correlation exists between concentrate weight and how much volume the concentrate occupies. By collecting a timed sample of concentrate from a cell and letting it settle, the volume of the settled solids can be measured and that measurement represents the weight pull of that cell. Carry out the same procedure on all the cells in a train and the total weight of concentrate, calculated using the three assay method, can be divided to determine the weight pull of each cell.

Calculations

The calculations for weight pull require the following data points:

1. Assay of the combined concentrate solids from the cell train.
2. Assay of the tails solids from the cell train.
3. Assay of the feed solids feeding into the cell train.
4. Tonnage of dry ore being fed to the cell train per minute, hour or day.
5. Timed sample collections volumes from all the cells in the cell train and the volume of their settled solids measured.

Using the Three Assays method, a concentrate weight percent can be calculated for the weight pull from the cell train. Adding the volumes measured for each cell yields a total volume that represents the weight pull value for the entire cell train. Dividing the individual cell weight pull volumes by the cell train weight pull volume gives the ratio of the total cell train pull weight that was pulled from the individual cells. Table 1 gives an example of the calculations.

Sampling

The sampling technique needs to be consistent in timing and designed to best fit the amount of concentrate coming off a float cell. For Denver cells with paddles, determining the timing is easy. For tank cells overflowing concentrate, consistent timing is a little more difficult to achieve. The sampling vessel collecting the sample needs

Table 1. Calculations Used to Determine Pull Weight for Individual Cells

Conc	Volume (mLs)	Ratio of Total	Conc Wt. (tons)	Assays	(%)
Conc 1	55	41%	26.5	Feed	1.50
Conc 2	25	33%	21.7	Tails	0.04
Conc 3	20	15%	9.7	Conc	22.45
Conc 4	15	11%	7.2	Tons	1000
Total	135	100%	65.2		

to be placed in the same location each time on each cell. Transferring the slurry collected into a graduated cylinder must be done in a way to maximize the solids transfer. And lastly, where froth on the cylinder retains a significant amount of the solids, a rinse stage is needed.

The sampling equipment sizing and timing procedure is dependent on the flotation circuit.

Controllable Error Possibilities

When using the Three Assay Method, a few factors could cause significant errors in estimating weight pull values. The first and foremost factor is variability, from one cell to the next, of the specific gravity of the settled solids. Any significant variance could distort the volume measurement's correlation to the amount of weight pulled by a cell. Analyzing the particles' settling characteristics and then adjusting the ratio calculations accordingly will help to correct for different specific and bulk densities of settled solids.

Particle size variance is another factor that could distort the volume correlation to weight pull. Smaller particles settle into a smaller volume than larger particles. Analyzing the particles' size and then adjusting the ratio calculations accordingly will help to correct these types of errors.

The sampling itself has to be consistent from cell to cell. Factors such as the timing, cell surging, settling time and rinsing the froth in the graduated cylinder need to be considered. These procedures must be performed as consistently as possible from cell to cell, from sampling period to sampling period and for each sampling point. If cell surging occurs in the cell train, then the concentrate from the cell that comes up and over the weir varies, usually in a short, cyclical manner. The sampler must observe the cell, get into the rhythm of the surge and find the point between low concentrate flow and high concentrate flow to obtain the timed sample that will be the most representative.

Consistent sampling techniques and preparation will allow for the control of these errors.

Ore Variability

Changes in the feed grade of the ore to the flotation circuit can affect how much concentrate is pulled from each cell. A circuit may experience wide swings in feed grade over the course of a test depending upon the nature of the ore that is being processed. No way exists to control this phenomenon, however these changes will affect the overall concentrate pull. It follows then that each individual cell may be affected differently (flotation kinetics change, redistributing concentrate weight pulls over the circuit). Since the first cell will likely be affected the most, data collected over time and ore variation should produce standard deviation calculations of the total concentrate weight pull similar to the standard deviation calculations of the first cell weight pull. It would also follow that subsequent float cells downstream would see less variance in weight pull because flotation kinetics slow down as the slurry proceeds through the circuit. In other words, the method should be self-correcting for ore variability.

DATA FROM A PLANT TRIAL

To test the validity of the volume/weight pull correlation as a way of calculating individual float cell recoveries, the Settled Solids Method was employed during a long term plant trial at a coal preparation plant. The plant’s flotation circuit was comprised of four trains containing four cells each. One of the trains was set up as a baseline where no reagents were changed. Different coal feed blends were fed throughout the trial. Tests showed that particle sizes and specific gravities of the concentrates for the four cells were not significantly different even as the feed blend varied. Each feed blend was fed into the plant for at least a three hour period, or three sampling periods. Five sampling periods worth of data was collected for the two blends studied in this paper.

The plant used Denver flotation cells with rotating paddles to move the concentrate and each cell had approximately a 15 second surge cycle that was generally consistent. Using a large sampling cup (2L), samples were taken approximately four seconds after the peak of the cycle; two paddles worth of concentrate was collected, averaging about 60 mL of slurry. The cup was swirled to defroth the solids as much as possible and then transferred into a 100 mL graduated cylinder. The cylinder was

briefly and carefully rinsed, without causing it to overflow, to knock down the small amount of solids locked to the water surface. The sampling period was every hour, so the solids were allowed to settle for an hour before the volume was measured. Then the cylinders were cleaned and prepared for the next sampling period.

The tables list the volume measurements and the percent weight calculations for the concentrates using the Three Assay Method as well as recovery per cell calculations, average weight pull percentages and standard deviation calculations. Two coal blends are presented for five sampling periods each.

DATA INTERPRETATION

Table 2 shows the data from the tests conducted using Coal Blend 1, the calculations and the standard deviations derived from the Coal Blend 1 data. The total weight pull standard deviation over the five tests was 3.01%. A similar standard deviation of 2.69% is calculated with the weight pull calculations of Cell 1, with diminishing standard deviations for the subsequent cells. The actual millimeters (mLs) of solids settled varied much more for Cell 1, but much less for Cells 2, 3 and 4. This would be expected as any large variance in the solids collected would be from Cell 1. Therefore, the amount of solids collected is related to the feed grade and the Settled Solids Method corrects for the variance

Table 2. Data from Coal Blend 1 Sampling

Sample	1	2	3	4	5
Feed Grade (%)	80.84	74.72	76.72	78.99	76.09
Tails Grade (%)	58.88	47.49	48.36	49.34	49.40
Conc Grade (%)	92.19	92.29	92.78	93.06	92.22
Cell 1 (mLs)	50	50	50	65	60
Cell 2 (mLs)	45	35	40	40	35
Cell 3 (mLs)	30	25	28	30	30
Cell 4 (mLs)	20	20	20	20	20
Total (mLs)	145	130	138	155	145

Percent Weight Pulls Calculated from Coal Blend 1 Data

Sample	1	2	3	4	5
Cell 1	22.73	23.38	23.13	28.44	25.79
Cell 2	20.46	16.36	18.51	17.50	15.05
Cell 3	13.64	11.69	12.95	13.13	12.90
Cell 4	9.09	9.35	9.25	8.75	8.60
Total	65.93	60.78	63.85	67.82	62.88

Average Weight Pulls and Standard Deviation
Calculations for the Coal Blend 1 Data

Weight Percent of Cells	Avg (%)	Std Dev (%)
Cell 1 Conc Weights	24.69	2.69
Cell 2 Conc Weights	17.58	1.74
Cell 3 Conc Weights	12.86	0.83
Cell 4 Conc Weights	9.01	0.26
Total Conc Weights	64.14	3.01

Table 3 shows the data from the tests conducted using Coal Blend 2, the calculations and the standard deviations derived from the Coal Blend 2 data. The feed grade varies more (SD=4.80%) than with Coal Blend 1, but again we see similar standard deviations for total concentrate and Cell 1 weight pulls (SD=5.37%) with the same type of deviation reductions for Cells 2, 3 and 4. In tests 1 and 2, the total concentrate weight pull was considerably higher (most of which would be expected to be pulled from Cell 1) than in tests 3, 4 and 5. As the data shows, the Cell 1 weight pull calculations do indeed show higher pull weights when the feed grade rises. Cells 2, 3 and 4 run about the same for all five tests. This shows that the Settled Solids Method for calculating individual cell pull weights does self correct for ore variations in the grade of the ore.

Table 3. Data from Coal Blend 2 Sampling

Sample	1	2	3	4	5
Feed Grade (%)	81.33	82.59	78.85	79.45	77.74
Tails Grade (%)	49.03	56.76	53.71	48.96	49.09
Conc Grade (%)	91.78	90.91	91.97	92.49	92.86
Cell 1 (mLs)	70	55	30	30	30
Cell 2 (mLs)	40	35	25	25	25
Cell 3 (mLs)	30	30	25	25	25
Cell 4 (mLs)	25	25	15	15	15
Total (mLs)	165	145	95	95	95

Percent Weight Pulls Calculated from Coal Blend 2 Data

Sample	1	2	3	4	5
Cell 1	32.05	28.69	20.75	22.12	20.67
Cell 2	18.32	18.26	17.29	18.43	17.23
Cell 3	13.74	15.65	17.29	18.43	17.23
Cell 4	11.45	13.04	10.37	11.06	10.34
Total	75.56	75.64	65.71	70.04	65.46

Average Weight Pulls and Standard Deviation
Calculations for the Coal Blend 2 Data

Weight Percent of Cells	Avg (%)	Std Dev (%)
Cell 1 Conc Weights	24.86	5.37
Cell 2 Conc Weights	17.90	0.53
Cell 3 Conc Weights	16.47	2.04
Cell 4 Conc Weights	11.25	1.13
Total Conc Weights	70.48	4.80

CONCLUSIONS

The Settled Solids Method of calculating weight pull from individual flotation cells yielded a good estimate of the weight pulls from each cell in the flotation train. This allowed useful recovery values to be calculated for each cell in the flotation circuit. The flotation kinetics study of different collectors can be carried out when the collectors are used with multiple grades of coal.

FUTURE WORK

Although the Settled Solids Method proved to have merit in the simple coal preparation plant where it was tested, more study across several types of flotation circuits and cells, is required. Tank cells do not have paddles, so the timing for the taking of samples from tank cells needs to be studied. Testing using the Settled Solids Method in a flotation circuit where particle sizes and specific gravities change as flotation slows is needed to prove if these variances can be controlled in the calculations or if they are even significant enough to need addressing. Finally, a sampler cup design that includes the graduated cylinder as part of the sample cup would eliminate the solids transfer step and yield a more precise solids volume measurement from sample to sample.

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