ON-LINE TESTING OF A HORIZONTALLY-BAFFLED FLOTATION COLUMN IN AN OPERATING COAL-CLEANING PLANT

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ABSTRACT

A horizontal-baffle arrangement has been developed to prevent excessive axial mixing in flotation columns. These baffles have been shown in previous work to improve the grade/recovery performance of both a laboratory-scale column and a pilot-scale column (Kawatra and Eisele, 1993). In this paper, results are given for continuous on-line operation of the pilot-scale baffled column in a commercial coal-cleaning plant. These results show its ability to operate for extended periods without plugging, to produce a consistent-quality product even while the feed quality was fluctuating, and to remove much of the pyritic sulfur from the coal.

INTRODUCTION

Flotation columns have been widely adopted in many applications in recent years, because they are more efficient separators than conventional flotation machines. Columns are more effective because they establish a long concentration gradient between the froth product and the sinks product, so that several meters are available over which the separation can take place. This is in contrast to conventional flotation machines, where the separation mainly occurs at the pulp/froth interface. Froth washing in the columns, which reduces entrainment of gangue into the froth, further improves the separation. However, in order for the concentration gradient to be established properly and for froth washing to work well, the column should approach plug-flow, where the vertical velocity of the pulp is approximately constant across the entire cross-section of the column (Finch and Dobby, 1990).

In flotation columns, vertical mixing along the axis of the column (axial mixing) causes the slurry flow in the column to deviate from plug-flow. This is generally harmful, as it tends to reduce the product recovery and to make the separation less selective (Finch and Dobby, 1990). As columns are increased in size from laboratory or pilot scale to full scale, the amount of axial mixing tends to increase, as larger diameter columns generally have a smaller height/diameter ratio than smaller columns. This axial mixing not only harms the performance of larger-diameter columns, but also makes scale-up calculations more difficult. A related problem is the formation of large bubbles, which cause the froth to “churn” when they go through the froth layer. If it is severe, the churning caused by large bubbles can disrupt the froth layer, causing a loss of selectivity. These large bubbles will form when the bubble generators are not working.
properly, when air is entrained into the feed stream, or when bubbles coalesce as they rise through the column.

Work has been done in the past using vertical baffles to subdivide the column and reduce the apparent diameter, with the goal of reducing axial mixing, but this has been found to introduce bubble-distribution problems (Finch and Dobby, 1990) and has been found to have only a small effect on performance in any case (Alford, 1992). In previous work by the authors (Eisele and Kawatra, 1994a,b), the use of horizontal baffles to reduce axial mixing was described. It was found that the best results were obtained in the laboratory when the baffles had between 29 and 38% open area and when they were present both above and below the feed inlet. A pilot-scale column of the same design as was developed in the laboratory was then built and tested off-line, to determine whether there were any serious scale-up problems (Eisele and Kawatra, 1994b). In this paper, the results of continuous on-line tests with the pilot-scale column in an operating coal-cleaning plant are discussed. These results demonstrate the ability of the column to operate stably and produce a consistent-quality froth with normal feed-quality variations (31-39% ash, 3.8-4.8% total sulfur, 2.2-3.6% pyritic sulfur).

THEORETICAL DISCUSSION

In the most common type of flotation column, there is no restriction to flow along the axis of the column. Rising air bubbles therefore are free to carry slurry up along the axis, which then returns to the bottom along the sides of the column, producing strong axial mixing. This can be controlled by using microbubble generators, by carefully aligning the column, and by closely controlling the column operation. However, if a disturbance forms for any reason, then there is nothing to prevent the disturbance from rapidly growing into a major disruption of the column operation. For example, if a malfunction of the bubble generators occurs that allows some large bubbles to form, these bubbles will tend to coalesce with other bubbles to grow still larger, and will expand further as they rise in the column due to the decreased water pressure. Because they rise very rapidly, such bubbles will contribute significantly to axial mixing, and if they are large enough they will disrupt the froth layer and degrade the column performance still further.

Horizontal baffles, such as those described in this paper, provide a simple method for suppressing such disturbances and preventing axial mixing, as shown in Figure 1. The horizontal baffles have openings large enough to keep them from being plugged by solid particles, but small enough to break up vertical mixing currents, so that slurry cannot be rapidly swept along the axis of the column. This provides a much closer approximation to plug flow, and therefore improves the separation. Horizontal baffles are suitable for retrofitting existing columns, as they are simple to make and install. They can also be made of wear-resistant and corrosion-resistant materials, so that they will be low-maintenance.

There are two important effects of horizontal baffling, as follows (Kawatra and Eisele, 1993): 1. Baffles that are installed below the feed entry point increase the minimum residence time of particles in the column. This ensures that all floatable particles will have a better chance of attaching to air bubbles, and so recovery will be improved. 2. Baffles installed above the feed inlet point keep the bubbles from becoming too large. This prevents churning and mixing of the froth layer by coarse bubbles, which is a common problem in unbaffled columns. Froth washing is more effective when the froth layer is not being churned, and so the product quality will be improved by baffles above the feed inlet.
Figure 1. Comparison of flow patterns in regular and horizontally baffled columns. In the regular, unbaffled column, slurry can be carried up by the air bubbles in the center, which produces axial mixing along the entire height of the column. Horizontal baffles can break up the currents, so that axial mixing is limited to shorter distances. Packed columns can also prevent axial mixing (Yang, 1988), but in these columns the flow restriction is much greater than in the baffled column, and so they can be prone to plugging.

CONDITIONS AND PROCEDURES

Plant Characteristics

A pilot-scale Deister Flotaire column was modified and installed in the Empire Coal processing plant, Gnadenhutten, Ohio. The flowsheet of the Empire fine coal cleaning circuit is given in Figure 2, showing the location of the flotation column.

Feed Characteristics

This plant processed a mixture of bituminous coals from the Lower and Middle Kittanning seams, with the main gangue mineral in the -0.6 mm particles being fine clay. The feed used for the tests described in this paper was taken from the waste fines produced by the clean coal dewatering screens.

Pilot-Scale Column Design

The column was derived from a Deister Flotaire unit, 20.3 cm in diameter and 9.1 meters tall. A schematic of the column is given in Figure 3. Air bubbles were injected at 4.5 meters and 9.1 meters below the froth overflow lip. The column contained 9 upper baffles, and 17 lower baffles, as shown in Figure 3, each with 34% open area. The bubble generators were a design manufactured by the Deister Concentrator Co., which injected an air-water mixture at a volume ratio of 7.5/1. The units used each had maximum flowrates of 28.3 standard liters/min of air, and 3.78 liters/min of water.
Figure 2. Flowsheet for the fine-coal processing circuit at Empire coal. Column feed was taken from the dewatering screen waste fines, which had a nominal top size of 0.6 mm (28 mesh).

The column was operated with a froth depth of 61 cm. Measuring from the froth overflow lip, the end of the feed inlet tube was at a depth of 122 cm. This long feed tube was needed so that there would be enough room between the froth base and the feed inlet to install baffles. The upper baffles extended from a depth of 71 cm to 117 cm, and the lower baffles extended from 147 cm to 234 cm. The washwater spray ring was immersed 5 cm below the froth surface, and the washwater flowrate was 7.57 liters/min. Frother
Figure 3. Schematic of the pilot-scale baffled flotation column. The column was 8\" (20.3 cm) in diameter and 30\' (9.1 meters) tall, with the upper bubble generator 15\' (4.5 meters) down from the top. The ratio of air to water in the bubble generators was 7.5:1 by volume.

was added to the froth washwater at the same rate as it was added to the feed and to the bubble generator water, to ensure a stable froth.

The baffles caused the froth to be much more quiescent, because they broke up large bubbles into smaller bubbles, and made them rise more slowly. This was mostly beneficial, as it prevented the froth from churning. However, it also allowed parts of the top of the froth to dry slightly into a semisolid, sticky mass that adhered to the feed tube. Over time, this would form a cap and eventually plug the top of the column. This was corrected by installing spray nozzles above the froth, spraying a mist of water at 1
liter/min to keep the top of the froth moist and fluid. With the water sprays running, the froth overflowed cleanly without adhering to the feed tube.

Reagents and Analytical Methods

The frother used for these tests was Dow DF 1012, a strong polyglycol frother. This was selected to ensure a stable, consistent froth. The collector was composed of #2 fuel oil and Dow M210 froth conditioner. The froth conditioner was added because, in earlier laboratory tests, the coal was found to be poorly floatable with fuel oil alone.

The reagents were mixed in the following proportions before adding them to the column feed stream: Frother, 50%; Fuel oil, 40%; Froth conditioner, 10%. The reagents were combined both to emulsify the collector so that it would disperse more readily into the feed, and to simplify the reagent addition. The dosage rate for the complete reagent mixture was 0.5-0.75 ml/min (0.9-1.0 kilograms/metric ton total; 0.45-0.5 kg/mt frother; 0.36-0.4 kg/mt fuel oil; 0.09-0.1 kg/mt froth conditioner).

Analyses were carried out using ASTM standard methods (ASTM, 1989). Ash was measured using Method D3174, and pyritic sulfur was determined using Method D2492. Total sulfur was measured using a LECO SC-132 sulfur determinator, and calorific value was measured using a LECO AC-300 automatic calorimeter.

Ash and pyritic sulfur rejections were calculated using the following formula:

\[ \text{%Rejection} = \left( \frac{\text{Wt. in Tails} \times \text{Tails Wt.}}{\text{Wt. in Feed} \times \text{Feed Wt.}} \right) \times 100 \]

RESULTS AND DISCUSSION

Continuous on-line experiments were conducted using the clean coal dewatering screen underflow, with the feed's particle size and composition varying as shown in Table 1.

| TABLE 1: Average characteristics of the dewatering screen underflow during the final series of on-line experiments. This table is a composite of the assays of each feed sample for the on-line tests summarized in Table 2. |
|----------------------------------|--------------|--------------|
| 80% passing size (µm) | 306.7 | 3.8 |
| 20% passing size (µm) | 42.0 | 0.6 |
| % Ash | 34.8 | 2.66 |
| % Sulfur | 4.41 | 0.34 |
| % Pyritic Sulfur | 3.1 | 0.50 |
| BTU/lb | 9275 | 365 |
TABLE 2: Summary of the froth product results for on-line tests, using the dewatering screen underflow product. Samples for each test were collected for a minimum of 45 seconds, sampling the entire stream. The feed quality was 31-39% ash, 3.8-4.8% total sulfur, and 2.2-3.6% pyritic sulfur.

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<th>%Ash</th>
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Figure 4. Grade-recovery results for the on-line continuous flotation tests, all baffles installed, with water sprays on the froth top. The ash content of the feed for each test is also given. In spite of the wide variation in feed ash contents, the ash content of the froth product is quite constant.
Figure 5. Pyritic sulfur and ash rejections as a function of BTU recovery in the on-line continuous tests with all baffles installed. This shows that between 40 and 65% of the pyritic sulfur is being rejected by the column, even at high BTU recoveries, and that over 80% of the ash is consistently being rejected.

Slurry was pumped directly from the dewatering screen underflow at 10% solids and 0.5-0.8 kg of solids per minute. Samples of the froth, tails, and feed were collected after allowing a full hour for the column to stabilize. The samples were taken by collecting the entire froth, tailings, and feed streams for a minimum of 45 seconds. A summary of the results is given in Table 2.

Figure 4 shows the grade/recovery performance of the column on-line for removing both ash and pyritic sulfur. The % ash of the feed for each test is also plotted. From this graph, it can be seen that in spite of large variations in the feed quality, the grade of the froth product was very uniform regardless of recovery variations. The BTU recovery was consistently greater than 75% and all but two tests were above 80% BTU recovery, with a high of 91.2%. The ability of the column to remove pyritic sulfur is clearly shown by Figure 5, which plots pyrite and ash rejections against BTU recovery. The rejection values are the percentages of the weights of pyrite and ash originally in the feed which is rejected to the tailings. This figure shows that the column is rejecting between 40% and 62% of the pyritic sulfur from the coal, while simultaneously rejecting from 80% to 93% of the ash.

CONCLUSIONS

From the work with the baffled column, the following conclusions were reached:

1. In conventional, open-pipe flotation columns, there is little to prevent initially small disturbances from growing into major disruptions of the column performance. As a result, even slight problems with the column operation can be rapidly amplified to the point where they degrade the column performance. Fully packed columns can prevent this from occurring, but these are prone to plugging and excessive wear. Horizontal baffling has been found to be sufficient to prevent excessive axial mixing and to prevent
the formation of unusually large bubbles, and such baffles are sufficiently open and durable that plugging and rapid wear are not problems.

2. The capacity of a coal flotation column is limited by the rate at which the clean coal can be withdrawn from the froth. The horizontal baffles increase the residence time of the tailings, but they do not directly affect the froth layer, and so their effect on the capacity of coal flotation columns is minimal.

2. The column equipped with horizontal baffles could operate stably and produce a consistently high-quality product while encountering normal variations in plant feed characteristics.

3. The horizontally-baffled column produced a high-quality product in a single stage from a high-clay feed coal, rejecting up to 87% of the ash and 50% of the pyrite while recovering 91% of the heating value.

4. The baffles were designed for use with particles as coarse as 2 millimeters. As a result, they never plugged in operation, and upon disassembly after several months of testwork, no evidence of plugging or rapid baffle wear was found.

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