Baffled-Column Flotation of a Coal Plant Fine-Waste Stream

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Abstract. It is common in coal-cleaning operations to produce a fine waste stream which contains a considerable amount of coal, but which is not economical to recover both because it is mixed with large amounts of difficult-to-remove clay slimes, and because the fine coal is often heavily oxidized or contaminated. Conventional froth-flotation machines cannot produce an acceptable product from such material in a single stage of flotation, and even flotation columns often have difficulty cleaning this type of feed.

A new type of flotation column was designed specifically to deal with these problems, and was installed and tested in a coal-cleaning plant in Ohio. The feed coal contained 39.8% ash as fine clay, 2.83% total sulfur, was 80% passing 176 micrometers, and had a heating value of 8401 BTU/lb. The coal was the tailings thickener product for the plant. Plant personnel felt that the coal was too heavily oxidized and contaminated for flotation to be effective, as previous attempts at conventional flotation of this material in the plant had been abandoned. However, using the new column it was possible to recover up to 85% of the calorific value in a product containing less than 11% ash, and up to 60% of the calorific value in a product of less that 8% ash. The bulk of the pyritic sulfur was rejected from the coal as well.

Introduction

Flotation columns have been widely adopted in many mineral beneficiation applications in recent years, because they are more efficient separators than conventional flotation machines (Parekh et al., 1990; Groppo et al., 1994). Columns are more effective because they establish a long concentration gradient between the froth product and the sinks product. 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.

As columns are increased in size from laboratory or pilot scale to full scale, their performance tends to be degraded by increasing axial mixing. In this paper, the use of horizontal baffles is described, which reduce axial mixing by a method that is expected to be suitable for retrofitting existing larger columns.

**Theoretical Discussion**

In flotation columns, vertical mixing along the axis of the column (axial mixing) is generally harmful, as it tends to reduce the product recovery and to make the separation less selective (Finch and Dobby, 1990). In the most common type of flotation column, shown in Figure 1, there is no restriction to flow of air and water 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. Considerable effort has been made to minimize this effect by means such as the use of microbubble generators, by multi-level air injection, and by uniformly dispersing the bubbles across the entire cross-section of the column so that there are no areas where unusual numbers of bubbles are rising and producing a vertical current. While these measures have been reported to show a certain degree of success in columns that are kept in perfect working order at all times, any malfunctions that either allow large air bubbles to form, or that make the distribution of air bubbles non-uniform, will cause axial mixing to occur again. It is therefore important that the column be designed not only to minimize axial mixing when everything is working well, but also to suppress any axial mixing that is produced by equipment imperfections or malfunctions.

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 attempts to design columns that would inherently prevent axial mixing, two different approaches were taken, by Yang (1988) and Dell (1976). Yang (1988) used packing similar to that used in packed distillation columns. While Yang’s column was effective for ultrafine particles finer than 20 micrometers, the packings were very prone to plugging by solids, and so maintenance costs would be high. Coal flotation is typically carried out with a top particle size of nearly 0.5 millimeter, which is far too coarse for the packed column to handle without plugging. Therefore, Yang’s column is not suitable for existing coal-cleaning operations. In the Leeds column, designed by Dell (Degner and Sabey, 1988), a combination of fixed and movable rods in discrete racks was used to horizontally divide what was essentially a conventional flotation machine into a series of stacked chambers. The goal was to mimic the performance of a multi-stage flotation circuit with several stages of froth recleaning. In the Leeds column, the feed was introduced in the bottom chamber which resulted in a considerably cleaner froth, although no attempt was made to improve recovery. Because the rod-racks are fairly thick, the machine is only sectioned into a few chambers. The use of moving parts in the rod-racks is also likely to contribute to excessive wear. Because of these problems, neither of the above columns have been adopted commercially by the coal industry.

The horizontal baffles described in this paper provide many of the advantages of both the regular column and the packed column, while minimizing the drawbacks. The horizontal baffles consist of simple perforated plates, with openings large enough to keep them from being plugged by solid particles, but small enough to break up vertical mixing currents, as shown in Figure 1, 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. The perforated-plate baffles are much simpler and take up less volume than the rod-racks used in the Leeds column (Dell, 1976), and are much more resistant to plugging and wear than closely-spaced packing material. They are also more suitable for retrofitting existing columns, as they are simple to make and install.
In previous work by the authors (Kawatra and Eisele, 1993; Eisele, 1992), it was found that the best results were obtained in the laboratory when the baffles had between 29 and 38% open area and were present both above and below the feed inlet. In the work described in this paper, a pilot-scale column of the same basic design as the laboratory column was tested in an operating coal-cleaning plant, to determine whether there were any obvious scale-up difficulties, such as plugging, with the baffles.

**Procedures**

**Plant Characteristics**

Based on the results of previously-described laboratory studies (Kawatra and Eisele, 1993), a pilot-scale Deister Flotaire column (20.3 cm diameter) 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.

**Feed Characteristics**

This plant processes a mixture of bituminous coals from the Lower Kittanning (#5) seam and the Middle Kittanning (#6) seam, with the main gangue mineral being fine clay. The feed used for the tests described in this paper was collected from the plant filter-press, which dewatered the solids from the plant tailings thickener. This material contained 39.8% ash, 2.83% total sulfur, 2.04% pyritic sulfur, and 8401 BTU/lb. The size distribution was 80% passing 176 micrometers, and 10% passing 3.7 micrometers. The plant had originally included conventional froth flotation in its flowsheet, but the flotation circuit had to be abandoned because it could not produce a sufficiently high-quality product from the coal being processed. Plant personnel felt that the fine coal was too heavily oxidized and contaminated by flocculants and dewatering aids to be floatable by conventional flotation.
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 manufactured by the Deister Concentrator Co, which injected an air-water mixture at a volume ratio of 7.5/1. The two bubble generators used each had maximum flowrates of 28.3 standard liters/min of air, and 3.78 liters/min of water (Eisele, 1992).

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 maintained at 7.57 liters/min.

In initial tests, it was found that the clean-coal froth would immediately collapse unless frother was added to the washwater. This was due to the upper baffles increasing the effectiveness of the washwater, such that the frother rising from the feed slurry or the bubble generator water was flushed back down before it could reach the froth.

The baffles also caused the froth to be much more stable, because they broke up large bubbles into smaller bubbles, and made them rise more slowly. This was beneficial, as it prevented the bubbles from entering the froth layer at high speeds, and disrupting the froth. However, it also allowed parts of the top of the froth to dry slightly into a semisolid mass that stuck to the feed tube. Over time, this would form a cap and eventually plug the top of the column. This was prevented by installing additional spray nozzles above the froth, spraying a mist of water at 1 liter/min to keep the top of the froth moist and fluid, so that it would not become sticky. This spray was in addition to the main washwater ring.
No operational problems were encountered with plugging of the baffles in any of the tests, even when large particles of approximately 1 millimeter in diameter were present in the feed.

**Feed Preparation and Reagents**

For the series of tests described in this paper, approximately 1 metric ton of filtered solids was collected from the plant fine-tailings filter-press, and thoroughly mixed. The collector used was a mixture of 80% #2 fuel oil and 20% Dow M210 froth conditioner (which is more effective for difficult-to-float coal than fuel oil alone). In addition, DF1012 (a very strong polypropylene-glycol-based frother manufactured by the Dow Chemical Co) was also used. This frother was selected because the presence of a dewatering aid in the column feed made it necessary to use a very strong frother in order to maintain a satisfactory froth.

The column was run by preparing a large volume of feed slurry in a 55-gallon drum, and continuously pumping slurry into the column during each test, so that random variations in the plant feed would not disturb the column operation. For each test, 190 liters of a 10% solids slurry was prepared, and conditioned for 5 minutes with the desired reagents. The column was first filled with plant process water and operated until a stable froth layer had formed. The feed slurry pump was then started, with the feed slurry pumped into the cell at a steady flowrate of 7.6 liters/min for 25 minutes. Froth and tailings samples were collected after 20 minutes, which provided sufficient time for the column to reach steady-state. The residence time of slurry in the column was calculated to be approximately 15 minutes.

Two sets of tests were carried out with this feed. The first set was carried out at a constant reagent dosage while the baffle configuration and bubble-generator configuration was varied. The reagent dosage was selected to be less than optimum for these tests, so that the effect of the baffles on the recovery could be clearly seen. The second series of tests used a constant baffle configuration while the reagent dosage was changed, so that the ultimate ability of the column to recover clean coal from this feed could be determined.
Series 1: Baffle Variation

The first test series used a constant reagent dosage (80% #2 fuel oil/20% M210 at 1.1 kg/mt; DF 1012 at 0.36 kg/mt), and duplicate tests were run with each of the following conditions:

1. No baffles, both bubble generators used;
2. Upper baffles installed, both bubble generators used;
3. Lower baffles installed, only upper bubble generator used;
4. Both upper and lower baffles installed, only upper bubble generator used.

When the lower baffles were installed, only the upper bubble generator was used. This was done to determine whether there was any potential for reducing the necessary height of the column when baffles were installed. As a result, the comparison is essentially between an unbaffled column 9.1 meters tall, and a column with lower baffles and an active height of only 4.6 meters. When both bubble generators were used, the air flow was evenly divided between them. The total air flowrate with both generators operating was 35.5 standard liters/min, while the air flowrate with only the upper bubble generator running was 28.3 standard liters/min.

Series 2: Reagent Variation

The tests in the second series were all carried out with all of the baffles in place, and with only the upper bubble generator used. Eleven single-stage tests were carried out in this series, with the collector and frother dosages varied as shown in Table 1, along with the BTU recoveries obtained with each reagent dosage. In two additional tests, the froth product from the column was reflated, to determine whether any significant grade improvement would result from 2-stage flotation.

Results

The effect of the baffles on the column operation is clearly seen in Figure 4. When the baffles are installed in the column, the BTU recovery is increased markedly, from only 15% without baffles, up to 54% with baffles, even though the reagent dosage is unchanged. The reagent dosages used in the baffle variation tests (1.1 kg/mt collector, and 0.36 kg/mt frother) were lower
than the values that were later determined to be needed for high BTU recovery (2.25 kg/mt collector, and 1.26 kg/mt frother), as can be seen in Table 1.

The reagent-variation studies (Figure 5) showed that the column could produce good results in a single stage, even when processing a very high-ash and difficult-to-float coal. With the proper reagent dosage, a product of 10.5% ash could be produced at 85% BTU recovery from the 39.8% ash feed stream. This feed was not considered by plant personnel to be treatable by froth flotation, and was being discarded, but the column flotation product was sufficiently clean to be salable. Reflotation of the froth product in the column did not produce a significant improvement in the grade of the clean coal at a given recovery.

Figure 6 shows that the column is also quite effective for rejecting pyritic sulfur from the coal, where rejection was calculated as:

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

The feed contained 2.04% pyritic sulfur, and over 50% of this was rejected while recovering 85% of the calorific value. Pyrite rejections as high as 70% could be achieved at approximately 60% BTU recovery.

**Conclusions**

The baffled column was tested on a pilot scale in an operating coal-processing plant, to recover clean coal from a high-ash, difficult-to-float coal. No serious operating problems were observed in the course of the tests, and the baffles did not plug or show any buildup of solids. The baffles were found to be effective in increasing the BTU recovery of this difficult-to-float coal compared to operating with the same reagent dosages but without baffles.
The baffled column recovered up to 85% of the calorific value from this fine waste without exceeding 10.5% ash, and simultaneously rejected over 50% of the pyritic sulfur. Reflotation of the froth product showed no further improvement in the grade/recovery performance.

Acknowledgments

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References

3. Dell, C. C., 1976, Froth Flotation, British Patent No. 1,519,075
Table 1: Reagent dosages used in column flotation tests with a complete set of baffles, and the corresponding results.

<table>
<thead>
<tr>
<th>Collector Kg/mt</th>
<th>Frother Kg/mt</th>
<th>%BTU Recovery</th>
<th>% Pyrite Rejection</th>
<th>%Ash Rejection</th>
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Figure 1. Comparison of mixing in regular, packed, and horizontally baffled columns.
Figure 2. Flowsheet for the fine-coal processing circuit at the Empire coal processing plant. Column feed was taken from the filtered thickener product.
Figure 3. Schematic of the pilot-scale baffled flotation column.
Figure 4. Effect of baffles above and below the feed inlet on the grade-recovery performance of a pilot-scale column with respect to ash. (Feed- 39.8% Ash; Collector- 80% #2 Fuel Oil, 20% Dow M210, 1.1 kg/mt; Frother- Dowfroth DF1012, 0.36 kg/mt
Figure 5. Grade-recovery performance of the pilot-scale column at the Empire Coal processing plant, with all baffles installed and using only the upper bubble generator.
Figure 6. Comparison of BTU recovery and pyritic sulfur rejection in the pilot-scale column tests, with all baffles installed and using only the upper bubble generator.