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FALCON CONCENTRATORS: A HIGH CAPACITY FINE COAL CLEANING TECHNOLOGY

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ABSTRACT

Recent research has shown that enhanced gravity separators provide the opportunity to effectively clean 1mm x 37 micron coal. At Southern Illinois University, a detailed experimental program was performed on a continuous Falcon Concentrator, which was found to achieve separations at mass throughput capacity values in excess of 100 tonnes/hour. The apparent particle separation density for 1 mm x 75 micron coal was about 1.60 with relatively high efficiency (Ep = 0.12). Typical ash and sulfur rejection values of 85% and 70% respectively, were achieved while recovering 85% of the combustible material. Metallurgical and efficiency data from the evaluation are presented in this publication.

INTRODUCTION

Research reported by several investigators has shown that gravity-based separators are more efficient in the treatment of middling-type particles than froth flotation. However, until recently, high capacity gravity-based systems used to treat particles finer than 212 µm were inefficient. Over the past decade, several enhanced gravity separators have evolved which have the ability to effectively treat particles that are normally concentrated in froth flotation processes. In fact, a patent has recently been received which covers a circuit using an enhanced gravity separator to compliment a froth flotation system for improving the rejection of sulfur from fine coal (Venkatraman et al., 1995).

The continuous Falcon Concentrator is an enhanced gravity separator that provides efficient separations for fine coal cleaning (Honaker et al., 1995). From a quantitative comparison of the available data from the various enhanced gravity separators, the Falcon Concentrator provided the lowest separation density (D_{50}) as a result of its ability to provide the maximum centrifugal field of 300 g's (Luttrell et al., 1995). However, to date, all available data has been collected from pilot scale units, which are able to handle mass throughput capacity values less than 5 tonnes/hr.

This publication will present the results collected from a full-scale C40 Falcon Concentrator, which was constructed to achieve a mass throughput capacity of approximately 100 tonnes/hr. Metallurgical and process efficiency data are presented and discussed on a particle size-by-size basis.

EXPERIMENTAL

Unit Description

Currently, the C40 Falcon Concentrator represents the largest enhanced gravity concentrator worldwide, although recent developments with other technologies may result in units of nearly equal size. The C40 unit measures 100 cm in diameter and possesses the ability to provide up to 210 g's of centrifugal force. The separation mechanism is based on flowing film principles and has been described in previous publications (Honaker et al., 1995; Honaker et al., 1996; McAlister and Armstrong, 1998). The unit is supported on a 3 x 3 m^2 frame and stands 4.6 m tall. The bowl is sloped at an angle of 10º from vertical to provide a force parallel to the bowl wall, which pushes the packed solids bed towards the 36 discharge chutes that are equally spaced along the circumference near the top of the bowl. The heavy underflow stream can freely flow through the chutes and out of the nozzles or the flow rate can be regulated by the fluctuating inch valves. Complete monitoring and control of the process parameters is provided through a central control system.

The 36 discharge chutes that provide passage for the heavy underflow stream are equipped with a 0.55 cm diameter fixed orifice, which limits the upper particle size to 1mm and, to some degree, the upper feed solids content due to potential plugging. However, recent develops of the C40 Falcon unit include the elimination of the fixed valves, which allows the effective treatment of larger particle sizes without the problem of plugging.

Circuit Description

The circuit consisted of a 20 kL feed tank in which the feed solids content was adjusted to the desired level. The volumetric feed rate was fixed at the required value by manipulation of a 20 cm gate valve on a recirculation line that sent a portion of the stream directly to the product sump. The feed was passed through a 12 mesh screen prior to entering the C40 unit to remove material that could cause potential valve plugging. The overflow and underflow streams were combined into a 5.5 kL sump and subsequently returned to the feed tank to complete the closed circuit. Approximately 8 tonnes of fine coal solids were used to charge the system. Typical volumetric feed flow rates were between 3.7 and 6.7 kL at solid concentrations between 10% and 30% by weight. Other operating parameters include bowl rotational speed and underflow volumetric rate.

After allowing sufficient time or the process to realize steady-state conditions, a representative sample of each product stream was collected. The volumetric flow rate of the underflow stream was measured and recorded. Each of the samples were wet screened using 150 μm (100 mesh) and 37 μm (400 mesh) sieves. The screened samples were filtered, dried and analyzed for weight, ash, total sulfur and, in some cases, pyritic sulfur contents using ASTM procedures. Because of the difficulty in accurately measuring the volumetric flow rate of the product stream, the response variables, which include mass yield, recovery, and ash rejection, were quantified using the two-product formula.

To evaluate the efficiency of the C40 Concentrator, partition curves were obtained by conducting washability analyses on the various particle size fractions in the feed and product samples. All washability analyses were conducted using a centrifugal technique and lithium metatungstate (LMT) solution as the medium.

Sample Description

The fine coal slurry sample was collected from the nominal –0.6 mm (28 mesh) fine circuit feed of an operating coal processing plant treating run-of-mine Pittsburgh No. 8 seam coal. A representative sample of the total bulk was collected for a particle size-by-size analysis. As shown in Table 1, the sample was relatively fine with 42% of the material having a particle size below 37 μm (400 mesh). However, the largest amount of the coal particles existed in the 600 x 300 μm size fraction, i.e., 26%. The sulfur content was relatively high and distributed irregularly within the coal sample.

Table I. Particle size-by-size analysis results of the nominal –0.6 mm Pittsburgh No. 8 seam coal sample.

A centrifugal washability analysis was conducted on the sample from each article size fraction is Table I. The samples from each density fraction were analyzed for weight, ash and total sulfur contents. Table II shows the overall washability results for the +37 μm (+400 mesh) particle size fractions. The coal sample contained a relatively low-to-moderate amount of middling-type particles with only about 5% of the feed particles having a density between 1.6 and 2.0. Thus, the coal sample would be classified as easy-to-clean.

Table II. Particle density-by-density analysis results for the +37 μm (+400 mesh) material in the Pittsburgh No. 8 seam coal sample.

RESULTS AND DISCUSSION

Metallurgical Results

An experimental program based on a statistical design was conducted to evaluate the parametric effects and optimize the performance of the C40 Falcon. A total of 18 experiments were conducted over a range of operating parameter values. The metallurgical results obtained from the treatment of the Pittsburgh No. 8 seam coal sample are compared to the washability curve in Figures 1(a) and (b). On the basis of both ash and sulfur contents, the yield differential increases as the product quality improves, which reflects moderate inefficiencies in the process and is typical of most commercial separators. The relatively efficient separation is indicated by nearly a 75% rejection of ash bearing material and 60% of the sulfur to the tailings stream while recovering 80% of the mass yield to the product. In fact, the organic efficiency (i.e., ratio of actual recovery over theoretical recovery) is about 96%.

(a)

(b)

Figure 1. Metallurgical results obtained on the basis of a) product ash and b) product total sulfur contents from the treatment of the +37 µm (400 mesh) particle size fraction of the Pittsburgh No. 8 coal.

One of the most important uses of enhanced gravity separation in fine coal cleaning involves the rejection of the pyritic sulfur that is normally recovered in flotation. Table III shows the total sulfur reductions realized on a particle size-by-size basis from the treatment of the Pittsburgh No. 8 seam coal using the C40 Falcon unit. Excellent sulfur reductions were achieved for the +75 μm (+200) size fractions while a significant but lower reduction was achieved for the 75 x 27 μm (200 x 400 mesh) size fraction. On should note the high sulfur contents in the tailings material, which should be mostly in the form of pyritic sulfur since a high coal recovery is realized.

Table III. Total sulfur reductions achieved on a particle size-by-size basis from the treatment of the –600 μm Pittsbugh No. 8 coal by the C40 Falcon Concentrator.

The relatively high separation efficiencies achieved by the C40 Falcon Concentrator were realized at mass throughput capacities up to 78 tonnes/hr as shown in Table IV. Factors that limit the mass throughput capacity of the continuous Falcon concentrators include:

1. Excessive volumetric flow rates which provide insufficient residence time for a proper separation;

2. High feed solid contents, which prevent efficient particle stratification;

3. Volumetric constraints of underflow valves, which limits the amount of mass that can flow through the ports.

The test program presented in this publication was unable to identify the maximum acceptable feed rate due to constraints of the circuit, which limited the volumetric capacity to about 6.7 kL/min.

Table IV. Metallurgical results obtained for the +37 μm particle size material showing the ability to achieve efficient separations at high mass throughput values.

Flotation Comparison

It is well known that enhanced gravity concentrators are ineffective in the treatment of slimes, i.e., -37 μm material (Luttrell et al., 1995). Thus, froth flotation remains to be needed for recovering the coal in the slimes fraction. In addition, it is possible that, for coals having a small amount of middling type particles, froth flotation may be more efficient for treating particles with a size greater than 37 μm. To evaluate this possibility, traditional release analyses were conducted on the nominal –600 μm particle size fractions. The release data were combined with the C40 Falcon results to simulate treatment of the total sample.

As shown in Figure 2(a), the most effective separation achieved on the basis of product ash content involved the treatment of the –75 µm particle size fractions using a froth flotation process while the +75 µm fractions were better treated by the Falcon Concentrator. On the other hand, the ultimate separation efficiency on the basis of total sulfur reductions was realized by the treatment of the +37 µm size fractions by the Falcon unit while treating the –37 µm fraction with a flotation process (Figure 2b). The use of froth flotation to treat the entire –600 µm Pittsburgh No. 8 coal sample provided a much inferior separation performance.

(a)

(b)

Figure 2. A comparison of the metallurgical separation performances from the treatment of the Pittsburgh No. 8 coal sample using different combinations of treatment strategies with the C40 Falcon Concentrator and a froth flotation process on the basis of (a) ash and (b) total sulfur reductions.

The results indicate that, for he Pittsburgh No. 8 coal sample, the Falcon was more effective in reducing the total sulfur content in the 75 x 37 µm particle size fraction whereas ash rejection was more efficiently achieved by froth flotation. This finding is due to the differences in solid density and floatability between the ash-forming components (average sp. Gr. + 2.7) and coal pyrite (average sp. Gr. + 4.8). In other words, as the particle size decreases, the heavier and floatable pyrite particles are more readily rejected in the Falcon Concentrator until the particle mass becomes too small to allow transport to the heavy stream within the corresponding residence time. Below this particle size, separation based on differential flotation kinetics is more effective. Since the ash-forming components are lighter, the transition particle size occurs at a larger value. However, it should be noted that this effect could be counteracted with a increase in centrifugal force a the sacrifice of lost coarse coal.

The transitional particle size in the above discussion is a function of the amount of middling type particles in the coal ad the floatability of the coal pyrite. As shown in Table II, the Pittsburgh No. 8 coal sample has a relatively low middlings content. Thus, the Falcon Concentrator may be more efficient over a larger particle size range for a coal having a greater quantity of middling particles.

Process Efficiency

Based on the parametric steady, a set of operating conditions was identified, which provided the optimum separation performance. Under these conditions, the C40 Falcon Concentrator reduced the ash content in the +37 μm particle size fractions from 14.1% to 6.3% while recovering 92.4% of the coal. The total sulfur content was simultaneously decreased from 3.49% to 1.94%. To evaluate the efficiency of the process, centrifugal washability analyses were conducted on the various particle size fractions in the feed and product samples. The partition curves generated from the analyses are shown in Figure 3. It is clear that more efficient separations were achieved on the coarsest particle size fractions. In addition, lower, separation density values are also realized for the coarsest size fractions. This trend is more evident by the results shown is Figure 4.

Figure 3. Partition curves obtained on a particle size-by-size basis by the C40 Falcon Concentrator under optimum operating conditions.

Figure 4. The effect of particle size on the probable error and separation density achieved from the C40 Falcon Concentrator.

Probable error values for the coarsest size fractions were around 0.12 with separation density (D_{50}) values of approximately 1.50. These values are in agreement with those obtained from the smaller C10 Falcon Concentrator (Honaker et al., 1995). An explanation for this trend may be associated with particle mass. As the particle mass decreases with decreasing size, the effect of the centrifugal force reduces, which results in higher D_{50} values and lower efficiencies. Alternatively, it may be the presence of the larger particles that causes the reduced efficiency due to the movement of coarse material toward the bowl wall and the resulting increase in water velocity moving away from the wall. The inward water velocity reduces the ability of the finest particles to report to the underflow during the corresponding retention time. Thus, the efficiency of and D_{50} values are negatively effected.

SUMMARY AND CONCLUSIONS

A full scale C40 Falcon concentrator has been successfully evaluated for the treatment of fine coal. The experimental program was conducted using a closed-loop circuit, which provided a maximum volumetric feed rate of 6.7 kL/min. Efficient separation performances were achieved at mass throughput capacity values as high as 78 tonnes/hr. Other significant findings include:

1. The metallurgical performances achieved by the C40 Falcon Concentrator were near those obtained from washability analysis of the 600 x 37 μm particle size fraction of a Pittsburgh No. 8 coal. Organic efficiency values greater than 95% were obtained while recovering 80% of the total mass to the product.

2. For a nominal –600 μm Pittsburgh No. 8 seam coal sample, ash reduction for the –75 μm particle size fraction was more efficiently achieved by a froth flotation process. However, the falcon Concentrator provided a better sulfur reduction performance for particle sizes as low as 37 μm.

3. Under optimum operating conditions probable error values of nearly 0.12 were achieved for particle size fractions greater than 150 μm and exponentially increased as the particle size decreased. Likewise, the separation density (D50) increased from a value of around 1.50 at 400 μm to a relatively constant value of 1.85 at about 250 μm.

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