ABSTRACT

Physical cleaning processes utilized in fine coal cleaning circuits are effective only over a specific particle size range. Beyond the optimum particle size range, the separation efficiency of these processes is significantly reduced, causing poor product quality and the loss of valuable clean coal to slurry ponds. Classifying cyclones are traditionally used to achieve fine particle size separation at particle size of 150 micron and finer primarily due to their high throughput capacity. However, their size separation inefficiency due to significant undersize misplacement and density effect on particle size classification is widely known. Thus, the main objective of this study was to demonstrate the size separation performance of the Pansep fine screening technology in an operating coal preparation plant in parallel with the plant cyclones. A slip-stream with a maximum flow rate of 350 L/min, obtained from the feed stream of the plant’s classifying cyclones, was sized using a Pansep screen having a projected surface area of 0.5 m².

An optimization test program conducted with the Pansep screen not only confirmed previous findings obtained in a pilot-scale study (Mohanty, 2001), but also generated new technical information. Spray water pressure utilized for fluidizing and stratifying the solid material bed on the screen surface was found to play an important role in the size separation performance obtained from the Pansep screen. Samples taken while running the Pansep screen over one week showed minimal variability in the size separation performance of the Pansep screen. An average screening imperfection of 0.14 and undersize-bypass of 4.3% obtained from the Pansep screen compared favorably with the corresponding values of 0.43 and 33% for the 38-cm (15-inch) diameter classifying cyclones. The inferior size separation performance of the classifying cyclone was further compounded by the density effect on its classification process. More than 90% of the sulfur bearing minerals (pyrites) of ultrafine particle size (10 micron) and ash bearing minerals of 100 micron mean particle size were found to be concentrating in the cyclone underflow. No such density effect was apparent in the samples classified using the Pansep screen.

An economic analysis indicates an average size coal preparation plant in Illinois could recover an additional $2 million of fine coal by switching from classifying cyclones to Pansep screens. The revenue generated from recovery of fine coal would far offset the higher capital and operating costs required for the Pansep equipment.
EXECUTIVE SUMMARY

Generally, when considering how to improve the performance of a fine coal cleaning circuit, replacing conventional coal cleaning technologies with advanced flotation or enhanced gravity technologies is usually recommended. However, it must be realized that it is also possible to achieve considerable improvement in the performance of a plant’s fine coal cleaning circuit by merely improving the performance of fine size separation devices for the simple reason that a significant inefficiency in conventional fine size separation processes is a commonly observed phenomenon. For example, it is well established that the conventional flotation process achieves an effective separation of clean coal from ash bearing minerals in the 250 x 45 micron (48 x 325 mesh) particle size range. However, it is almost impossible to eliminate all ultrafine (finer than 45 micron) material present in the flotation feed due to the inefficiency of the de-sliming cyclones typically used in the coal preparation plants in Illinois. The presence of ultrafine ash bearing minerals in the flotation feed slurry affects the separation process and results in a lower product quality due to the well-known problem of hydraulic entrainment and also increases the reagent consumption of the process. Another example relates to the spiral concentrators that are known to achieve an efficient coal cleaning performance in a particle size range of 1 mm x 150 microns (16 x 100 mesh). However, a significant amount of minus 150 micron size particles is often misplaced to the spiral feed stream due to the inefficiency of the primary raw coal classification process in the plant. A majority of these finer particles are entrained in the product stream of the spiral concentrators along with most of the feed water and are ultimately rejected to the thickener as the sieve-bend underflow. This phenomenon causes a significant loss of recoverable fine coal.

The major goal of this project was to demonstrate the Pansep screening technology at a coal preparation plant in Illinois for a smooth transfer of this technology from the pilot-scale research phase to its commercialization in the state of Illinois. This linear screen technology was originally invented in South Africa in 1998 for possible application in the South African platinum industry. Its possible application in coal preparation plants was investigated for the first time in the U.S. through a previous ICCI/DCEO project (Mohanty, 2001) at Southern Illinois University Carbondale (SIUC). In this project, the Pansep screening process was further developed and optimized using a Pansep screen with a maximum capacity of 5 tph. Knight-Hawk Coal Company’s Creek Paum Mine was selected as the host-site for this project. A Pansep screen was installed inside the plant on the same floor as the 15-inch diameter cyclone bank and a slip stream obtained from the feed stream of plant cyclones was used as the feed to the Pansep screen.

The pressure of spray water utilized from both the top and bottom of the screen mesh for fluidizing the solid material bed was found to play an important role in affecting the size separation performance obtained from the Pansep screen. The screening imperfection may decrease from 0.15 to 0.07 and the separation size may increase from nearly 150 micron to 170 micron by increasing the spray pressure from 20 psi to 40 psi. Long-term testing conducted over a period of one week confirmed the excellent suitability of the Pansep fine coal screening technology for plant application. The average screening
efficiency determined from 20 different sets of samples collected during the test program was nearly 90% with a standard deviation of only 2%. This high efficiency value was the result of an average imperfection value of 0.14 and average undersize bypass to the screen overflow of 4.3%. Parallel sets of test samples collected from the plant cyclone bank during the same time period indicate a significantly inferior average efficiency of 65% with a standard deviation of 5%. The low classification efficiency resulted from an average imperfection value of 0.43 and undersize bypass of 33% to the plant cyclone underflow.

The present comparative study allowed the quantification of the density effects on cyclone classification and Pansep screening technology. Predictably, the Pansep size separation was found to be almost completely devoid of any density effect. On the other hand, a significant density effect on the size separation achieved by classifying cyclones was clearly evident. While only 27% of the cyclone feed material having a mean particle size of 10 micron was recovered in the cyclone underflow, 78% and 95% of the sulfur bearing minerals (pyrites) of the same size class were recovered in the underflow in two separate tests. The concentration of ash bearing minerals in the cyclone underflow at a mean particle size of 10 micron was very minimal; however it was quite significant up to a mean particle size of 106 micron. These density effects from the cyclone classification process along with the inefficiency in particle size separation typically causes high sulfur and high ash contents in the spiral feed stream and the deslimed flotation feed stream in coal preparation plants. The poor quality of feed coal is reflected in the relatively poor grade of the final clean coal product. Understandably, this problem may be eliminated in the coal preparation plants in Illinois by the use of Pansep screens in place of classifying cyclones.

A comparative economic analysis conducted indicates that the largest coal preparation plant operating in Illinois, which treats nearly 2,100 tph of raw coal (370 tph of raw fine coal), may require an additional $136,000 per year over the current cost of operating 15-inch diameter cyclones to operate industrial size Pansep screens. However, due to the higher recovery of clean coal, the Pansep screen may result in an increased annual revenue of more than $6 million. For an average size plant this increase may be nearly $2 million, which would far offset the costs of switching to the Pansep screening technology.

An open demonstration of the Pansep screening operation was conducted at the KnightHawk Creek Paum mine preparation plant to inform and educate industry personnel about Pansep screening operations including their advantages and disadvantages. It was well attended by personnel from several equipment manufacturers, coal mining companies, and state agencies in Illinois. It is believed the successful completion of this year’s project may bring the Pansep screening technology a step closer to commercialization in Illinois coal preparation plants.
OBJECTIVES

The overall goal of the proposed project was to demonstrate the excellent size separation performance of the Pansep screen in an operating preparation plant site to facilitate the transfer of this technology from the pilot-scale research phase to full-scale commercialization in coal preparation plants in Illinois:

To accomplish this overall goal, the specific research objectives are:

- To document and demonstrate the excellent performance of the Pansep screen over a relatively long period (a few months) of time.
- Establish the maximum volumetric throughput capacity on a gallons/min-m² basis for a given solids content in the plant streams.
- Develop a confidence band for the size-classification performance achievable from the Pansep screen in a continuously fluctuating plant environment.
- Disseminate the results of using the Pansep technology to the coal preparation community and related state agencies through an “open demonstration” at the plant test site.

INTRODUCTION AND BACKGROUND

Coal in the particle size range of minus 1 mm (16 mesh) is typically cleaned in the fine coal cleaning circuit of a coal preparation plant. A typical fine coal circuit is illustrated in Figure 1, which indicates that the first unit operation that the fine coal goes through is a bank of classifying cyclones. The minus 1 mm particle size coal is classified into coarse (1 mm x 150 micron) and fine (minus 150 micron) particle size streams to be separately cleaned by spiral concentrators and flotation cells, respectively. However, in many cases, the minus 150 micron (100 mesh) particle size stream is subjected to another stage of classification (often known as secondary classification or de-sliming) to prepare a 150 x 45 micron particle size feed stream for flotation cells. The minus 45 micron (325 mesh) particle size stream, usually concentrated with ultrafine ash-bearing minerals, is discarded to the plant slurry thickener.

Size classification in the fine particle size range of 150 micron and finer is typically achieved using classifying cyclones due to their high throughput capacity. However, classifying cyclones are known to cause a significant amount of misplacement of fine particles in the coarse particle stream. In addition, due to the density effect in the cyclone classification process, the heavier particles in the feed stream are often concentrated in the coarse particle stream irrespective of their particle size. In case of high or medium sulfur coal, the undesirable concentration of coal pyrite particles in the coarse particle stream renders the subsequent beneficiation step more difficult. Due to these problems,
the spiral feed stream in a preparation plant is usually contaminated with a lot of misplaced fine particles, which are difficult to clean with spirals. Similarly, the flotation feed stream is contaminated with ultrafine particles, rendering the flotation process less efficient.

The detrimental effects of fine particle classification on coal cleaning performance in the fine coal circuit have been discussed in detail (Firth et al., 1995, 1997 and 1998). Several studies (Dahlstorm, 1954; Kelsall and Holmes, 1960; Firth et al., 1997; Patil and Rao, 1999; Honaker et al., 2001 a, b; Mohanty et al., 2002) have been conducted in the past to improve the size separation performance obtained by classifying cyclones. These studies indicate that significant reduction in undersize misplacement is achievable by the injection of a sufficient amount of elutriation water at the apex of a cyclone. However, it has also been found that the effective separation size ($d_{50}$) is increased by the addition of apex-elutriation water. No improvement in the undesired density effect on the cyclone classification process has been reported in any of these studies.

A relatively new linear screening technology, known as the Pansep screen, has been investigated for its suitability for fine coal and mineral size separations by a few researchers (Buisman and Reyneke, 2000; Brown et al., 2000, 2001a, b; Mohanty, 2001). After completing a successful optimization study (Mohanty, 2001) of the Pansep screen at the pilot-scale research facility of the Illinois Coal Development Park, the authors have studied the performance of the Pansep screen in a coal preparation plant environment as a part of the present study. The sensitivity of the Pansep screen to the continuously fluctuating feed characteristics has been studied through long-term tests conducted over a
period of one week. Head-to-head comparison of size classification and density effect has been conducted between the Pansep screen and raw coal classifying cyclones operating in the plant. An economic analysis has been conducted to determine the profitability and the pay-back period for replacing the classifying cyclones by Pansep screens in coal preparation plants in Illinois.

EXPERIMENTAL PROCEDURE

The Pansep screen used in the present study had a projected screen surface area of 0.5 m². A slip-stream obtained from the feed stream to the raw coal classifying cyclones operating in the host preparation plant was used to feed coal slurry to the Pansep screen as shown in Figure 2. The screening of particles in the Pansep screen is achieved under the action of water sprays both from the top and bottom of the mesh pans as shown in the Pansep schematic in Figure 2. Since rectangular mesh screen openings are typically used for fine particle screening applications, it was desired to conduct a factorial experimental program to study the effect of spray water pressure on both screening efficiency and the effective size of separation (d₅₀c). After the optimum set of experimental conditions was identified for the Pansep screening operation, a long-term test was conducted over a period of one week by setting the Pansep screen at its optimum operating point. Hourly samples were collected from the Pansep screen and also from the raw coal cyclones operating in parallel in the plant to not only compare their size separation performance but also study the density effect on size separation achieved by both unit operations. In total, 40 hourly sample sets were collected from both the Pansep screen and the plant cyclone and analyzed for particle size distribution. Selected samples were analyzed for ash and sulfur contents on a size-by-size basis.

Figure 2. A schematic diagram of the experimental layout used during the in-plant testing.
RESULTS AND DISCUSSIONS

Task 1: Pansep Circuit Installation at a Plant Site

The Creek Paum Mine of the Knight Hawk Coal Company served as the host mine site for this project. During the initial project months, the Pansep unit was mounted and carried to the host plant site along with its ancillary equipment. A new entrance door (shown in Figure 3) had to be built on the third floor of the host plant to raise and install the Pansep screen at the same level as the bank of raw coal classifying cyclones operating in the plant. A 2-inch diameter slip-stream was tapped from the feed distribution box of the classifying cyclone bank to gravity feed the Pansep screen as shown in Figure 3. A new electrical circuit-breaker box had to be installed for the sole use of the Pansep screen during this entire test program. The screen opening size for the set of mesh panels that was installed in the Pansep screen was 100 x 400 microns to produce a $d_{50}$ separation size of nearly 150 micron.

![Figure 3: The Pansep screen operating in parallel to the classifying cyclones at the host plant of the Knight Hawk Coal Company](image)

Task 2: Pansep Testing

Coal Sample Characterization:

A majority of the coal treated by the host preparation plant originates from the Murphysboro No. 2 seam. A size-by-size distribution of weight, ash and sulfur in the Pansep feed stream (which is the same as the cyclone feed stream) is provided in Table 1. The mean sizes, shown in Table 1, refer to +16 mesh, 16x60 mesh, 60x80 mesh, 80x100 mesh, 100x200 mesh and –200 mesh size fractions. As indicated, sulfur bearing minerals
are fairly uniformly distributed in all size classes, whereas there is a concentration of ash bearing minerals in the finest size fraction of the Pansep feed stream.

Table 1: Size-by-size distribution of mass, ash and sulfur in the feed slurry treated by the Pansep screen.

<table>
<thead>
<tr>
<th>Mean Size (micron)</th>
<th>Weight (%)</th>
<th>Ash (%)</th>
<th>Total Sulfur (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1414</td>
<td>25.1</td>
<td>26.6</td>
<td>3.01</td>
</tr>
<tr>
<td>500</td>
<td>25.6</td>
<td>28.6</td>
<td>2.65</td>
</tr>
<tr>
<td>212</td>
<td>4.61</td>
<td>30.5</td>
<td>3.10</td>
</tr>
<tr>
<td>164</td>
<td>2.92</td>
<td>31.2</td>
<td>3.26</td>
</tr>
<tr>
<td>106</td>
<td>8.62</td>
<td>30.3</td>
<td>3.36</td>
</tr>
<tr>
<td>10</td>
<td>33.1</td>
<td>52.0</td>
<td>2.36</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>36.2</td>
<td>2.74</td>
</tr>
</tbody>
</table>

Parametric Study:

A detailed parametric study conducted to investigate the main effects and interaction effects of various Pansep process parameters was reported in an earlier final technical report (Mohanty, 2001). However, the main effects of spray water pressure and the corresponding interaction effects were not studied previously due to the non-availability of high-pressure water sprays. Therefore, it was desired to study the effects of spray water on the screening performance of the Pansep screen in a dynamic process environment during this in-plant study. The solid content of the Pansep feed slurry varied slightly around an average level of 15% during the entire experimental program. Based on the previous test data (Mohanty, 2001), the spray angle was maintained perpendicular to the screen surface. The process parameters that were set at different levels according to a Central-Composite design test matrix included feed flow rate, screen speed and spray water pressure. Table 2 summarizes the experimental condition and test results obtained from each experiment conducted during the optimization test program. As indicated, the spray water pressure was varied in the range of 3 to 6 kPa, which is equivalent to the range of nearly 20 to 40 psi. Based on the exploratory tests conducted prior to the optimization test program, the maximum feed flow rate tested was 300 liters per minute (L/min), beyond which, significant spillage of feed slurry from the mesh pans was noted.

The screening performance shown in Table 2 is indicative of the excellent size separation achievable by the Pansep screening technology. Excluding the results obtained from Tests 16 and 20, which appear to be clear outliers, an average imperfection value of 0.11, ultrafine bypass of 3.76% at a d50c separation size of nearly 160 micron can be considered as excellent fine size separation performance by any standard. A statistical software package, known as Design Expert, was utilized to analyze the experimental results and
develop empirical models for various performance parameters as functions of the key Pansep process parameters, such as screen speed (A), feed rate (B) and spray water pressure (C). The software provided Equations 1, 2 and 3 to calculate the efficiency of the Pansep screen.

Imperfection = 0.11+0.00085A+0.008B-0.028C-0.016A² -0.014AB-0.012AC  [1]

d₅₀c (micron) =167.66-0.72A-1.28B+5.50C  [2]

Ultrafine Bypass (%) = 3.85+1.70B-1.15C-1.38BC  [3]

where screen speed (A), feed rate (B), and spray water pressure (C) are all in coded terms varying between -1 and +1.

Table 2: Summary of operating parameters and test results obtained during the optimization test program.

<table>
<thead>
<tr>
<th>Experimental Design Run Order</th>
<th>Pansep Operating Parameters</th>
<th>Screening Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Screen Speed (M/Min)</td>
<td>Feed Rate (L/Min.)</td>
</tr>
<tr>
<td>1</td>
<td>20.0</td>
<td>140</td>
</tr>
<tr>
<td>2</td>
<td>12.5</td>
<td>220</td>
</tr>
<tr>
<td>3</td>
<td>20.0</td>
<td>140</td>
</tr>
<tr>
<td>4</td>
<td>12.5</td>
<td>220</td>
</tr>
<tr>
<td>5</td>
<td>12.5</td>
<td>140</td>
</tr>
<tr>
<td>6</td>
<td>12.5</td>
<td>220</td>
</tr>
<tr>
<td>7</td>
<td>12.5</td>
<td>220</td>
</tr>
<tr>
<td>8</td>
<td>12.5</td>
<td>140</td>
</tr>
<tr>
<td>9</td>
<td>5.0</td>
<td>140</td>
</tr>
<tr>
<td>10</td>
<td>20.0</td>
<td>300</td>
</tr>
<tr>
<td>11</td>
<td>12.5</td>
<td>220</td>
</tr>
<tr>
<td>12</td>
<td>12.5</td>
<td>300</td>
</tr>
<tr>
<td>13</td>
<td>20.0</td>
<td>300</td>
</tr>
<tr>
<td>14</td>
<td>5.0</td>
<td>140</td>
</tr>
<tr>
<td>15</td>
<td>12.5</td>
<td>220</td>
</tr>
<tr>
<td>16</td>
<td>5.0</td>
<td>300</td>
</tr>
<tr>
<td>17</td>
<td>12.5</td>
<td>220</td>
</tr>
<tr>
<td>18</td>
<td>20.0</td>
<td>220</td>
</tr>
<tr>
<td>19</td>
<td>5.0</td>
<td>220</td>
</tr>
<tr>
<td>20</td>
<td>5.0</td>
<td>300</td>
</tr>
</tbody>
</table>
The plot shown in Figure 4 illustrates the effect of spray water pressure on the screening imperfection for the entire range of feed flow rate and screen speed tested during this investigation. Imperfection was found to be independent of feed flow rate in the range of 140 to 300 L/min tested during this experimental program. Its dependence on water pressure and screen speed is clearly evident from the response surface contours shown in Figure 4. The screening operation becomes increasingly imperfect (less efficient) with the increase in screen speed due to the commensurate decrease in the residence time of the solid material on the screen surface. Conversely, increasing spray water pressure renders the screening process more and more efficient indicated by decreasing imperfection values in the contour diagram. Higher spray pressure facilitates better stratification on the screen surface and also better passage of near size particles through the screen openings. This is why the effective separation size increases to some extent with the increase in spray water pressure as illustrated in Figures 5 a-c. Clearly, there is a trade-off as to where to set the spray water pressure since higher spray pressure results in a more efficient size separation at one hand but a coarser separation size at the other.

Figure 4. Effect of spray water pressure on imperfection, which is an important measure of screening efficiency.
Figure 5. Effect of spray water pressure on the effective particle size of separation ($d_{50}$ in micron) in a dynamic test environment.
Task 3: Continuous Testing and Demonstration

Task 3.1 Continuous Pansep Testing:

After optimizing the operating parameters of the Pansep screen it was desired to investigate the sensitivity of this screening technology to the continuously fluctuating feed characteristics in a plant environment. With a change in the characteristics of run-of-mine coal, the amount of near-size material in the Pansep feed may alter. Larger amounts of near-size particles may render the screening process less efficient. To observe this effect on the screening efficiency of the Pansep screen, the operating parameters were set at an optimum level and the screen was operated for five to six hours every day over a period of one week. Hourly samples were collected from the Pansep screen to evaluate its screening performance. A similar exercise was also conducted to evaluate and compare the size separation performance obtained from the bank of raw coal classifying cyclones operating in parallel to the Pansep screen in the plant. In total, 40 sets of samples were collected from the Pansep screen and classifying cyclones at nearly the same time over a period of one week. Partition curves were drawn for each test to determine performance indicators such as imperfection, separation size ($d_{50}$), undersize bypass for both the Pansep screen and plant cyclones. In addition, screening efficiency, defined as the product of recovery of oversize particles to Pansep overflow (cyclone underflow) and recovery of undersize particles to Pansep underflow (cyclone overflow), was calculated for each test.

As shown in Figure 6(a), screening efficiency for the Pansep screen was maintained at nearly 0.90 (90%) and imperfection at an average of 0.14. The average separation size was nearly 160 micron. With the exception of just one data point for imperfection (Test 5), the relatively small fluctuations in performance indicators are indicative of the excellent suitability of the Pansep screening technology in the plant environment. In contrast, the results shown in Figure 6(b) indicate a much inferior size separation performance obtained from classifying cyclones with an average efficiency of 65% and imperfection of 0.43. It should be noted that the poor classification efficiency obtained from the plant cyclones is not only a reflection of poor imperfection values, which are calculated from the respective corrected partition curves but also due to high under-size bypass occurring at the cyclones. As shown in Figure 6(c), the average ultrafine bypass for the plant-cyclones is as high as 33% in contrast to a meager 4.3% for the Pansep screen.

The aforementioned poor size separation performance of classifying cyclones is compounded by a significant density effect on size separation. Selected test samples collected from the Pansep screen and the plant cyclones during the long-term test program were analyzed for their ash and sulfur contents to determine the size-by-size recovery of sulfur and ash bearing minerals. It may be noted that pyritic sulfur constitutes more than 70% of the total sulfur in the coal treated at the host plant. As illustrated in Figure 7(a), for the Pansep screen, the superior partition of the total quantity (mass) of coal particles in each size fraction is accompanied by similar partitions of ash and sulfur bearing mineral particles present in the respective size fractions.
Figure 6: Effect of the continuous fluctuation in the plant feed characteristics on the size separation performance of the Pansep screen in comparison to classifying cyclone.
Figure 7: Effect of Pansep screening and cyclone classification on ash and sulfur partition.
However, as shown in Figure 7(b), a significant concentration of higher density particles such as ash and sulfur bearing mineral particles is noticed in the cyclone underflow irrespective of their particle size. For example, nearly 60% of the total quantity belonging to a mean particle size of 106 micron is recovered to the cyclone underflow; however the corresponding recovery of both ash and sulfur bearing minerals present in this size class is nearly 100%. A simple calculation indicates that recovery of clean coal particles (the lighter materials) present in this size fraction to the cyclone underflow is less than 50%. The recovery of sulfur-bearing minerals (of specific gravity 5.0) continue to remain at a high level of 78% and 95% (in two different tests) for even the finest particle size fraction having a recovery (of total quantity) of only 27% to the cyclone underflow. As shown, the recovery of ash-bearing minerals (of specific gravity in the range of 2.4 to 2.8) in the finest size fraction having a mean particle size of 10 micron is nearly the same as the recovery of total quantity (mass). Such preferential separation of heavier and lighter materials during a size separation process, which results in a higher sulfur concentration in the cyclone underflow, is clearly undesirable. However, it is the size separation mechanism of the classifying cyclone, which causes this discrepancy. Therefore, a fine particle screening alternative such as the Pansep screen, which eliminates the density effect from size-based separation, may help improve the overall performance of a fine coal cleaning circuit.

Task 3.2 Open Demonstration:

An invitation was extended to the Illinois Coal Preparation Society, several coal slurry pond operators, and state agencies, such as SIU Coal Research Center, ICCI and DCEO, to visit the plant site at the Creek Paum mine to participate in an open demonstration of the Pansep operation. This demonstration included a poster presentation followed by a show of the actual Pansep operation inside the plant as revealed by the pictures in Figure 8. It was attended by personnel from several equipment manufacturers, coal mining companies and state agencies in Illinois.

Task 4: Economic Analysis

The improved particle size separation efficiency of the Pansep screen will result in reduced misplacement of particles to the overflow and underflow streams. In other words, more fine coal will be recovered from the sieve bend underflow and cyclone overflow as well as more coarse coal recovered from the oversize material from the screen overflow or cyclone underflow. To determine the economic benefit that could be realized due to this improvement, a comparative economic analysis has been conducted for the 100 mesh size separation achieved at an Illinois coal preparation plant. For showing the maximum extent of possible benefits, the fine coal circuit of the largest coal preparation plant operating in Illinois has been used for the present analysis.

As indicated in the comparative cost analysis in Table 3, the fine coal cleaning circuit of the example plant treats 370 tph (nearly 11,000 gallons per minute), which is classified at 100 mesh using banks of 15-inch diameter classifying cyclones.
Considering the rated mass and volumetric throughput capacity of an industrial sized Pansep screen, eight units would be required to treat the same volume of fine coal. At a cost of $12,000 per cyclone (including the pump, piping, and sump assembly for 2 banks of cyclones having eight cyclones in each bank) and $75,000 per Pansep screen (to be gravity-fed), the capital costs for both options will be $192,000 and $600,000, respectively. The annualized capital costs for both options would be $28,186 and $88,080, respectively, at a discounting rate of 12% over a period of 15 years. The total operating cost for two banks of cyclones including the pumps has been estimated at $20,000, based on discussions with a cyclone manufacturer. Similarly, the total operating cost for eight Pansep screens has been estimated at $96,000. A major portion of the Pansep operating cost is the replacement the screen mesh panels on an estimated quarterly basis. A summary of the capital and operating costs is provided in Table 3. As described in the follow paragraph, the higher capital and operating costs of the Pansep screens are offset by the recovery of fine coal that would normally report to the plant thickener.
Table 3: Summary of the comparative cost-analysis of Pansep screens and classifying cyclones

<table>
<thead>
<tr>
<th>Feed Rate to the Fine Coal Circuit: 370 tph; 11,000 gpm</th>
<th>Annualized Capital Cost ($)</th>
<th>Annual Operating Cost ($)</th>
<th>Total Annual Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of 15-inch diameter cyclones</td>
<td>16</td>
<td>28,186</td>
<td>20,100</td>
</tr>
<tr>
<td>No. of 9 m² Pansep screens</td>
<td>8</td>
<td>88,080</td>
<td>96,000</td>
</tr>
</tbody>
</table>

The preparation plant used for this economic analysis rejects the underflow of the sieve bends, which screen the spiral product to remove relatively high ash fine material. Any minus 100 mesh fine coal misplaced to the cyclone underflow, bypasses the spiral cleaning process and is ultimately rejected to the plant thickener. This is a significant loss of valuable fine coal. A simple analysis indicates that nearly 40% of the minus 100 mesh material is misplaced to the cyclone underflow. Using the 370 tons per hour fine coal feed rate, nearly 57 tph of fine coal are misplaced to the plant thickener. This fine coal has an ash content of approximately 39%. This loss could be reduced to only 5 tph by switching to Pansep screens in place of the two banks of 15-inch diameter cyclones in the plant, resulting in the recovery of an additional 52 tph of fine coal. If the fine coal circuit was operated 7,000 hours per year, based on a price of $1.05 per million BTU and 8,000 BTU/lb for the high ash coals on a dry basis, nearly $6.45 million of additional revenue could be generated every year by the Pansep screens. Understandably, this will far offset the increased annual cost of $136,000 incurred from the installation and operation of the Pansep screens. The additional annual revenue of more than $6 million per year from the largest coal preparation plant translates to nearly $2 million per year for an average size (700 tph of raw coal) plant in Illinois.

The above economic analysis is somewhat simplistic since it does not consider the installation cost of the equipment, which may be 2 to 3 times the capital cost for the Pansep screens. Additionally, it does not consider the cost of extra space for the Pansep screens. The detrimental density effect of the cyclone classification process, which significantly increases the sulfur content of the feed slurry reporting to plant spirals, has also not been considered in this economic analysis.

CONCLUSIONS

- The Pansep fine screening technology provided an excellent size separation performance while treating a slip-stream of the raw coal cyclone feed slurry in an operating coal preparation plant. The spray water pressure utilized from both the top and bottom of the screen mesh for fluidizing the solid material bed plays an important role in affecting the size separation performance obtained from the Pansep screen. The screening imperfection may decrease from 0.15 to 0.07 and the separation size may increase from nearly 150 micron to 170 micron by increasing the spray pressure from 3 kPa to 6 kPa.
Long-term tests conducted over a period of one week confirmed the excellent suitability of the Pansep fine coal screening technology for plant application. The average screening efficiency determined from 20 different sets of samples collected during the long-term test program was nearly 90% with a standard deviation of only 2%. This high efficiency value was a result of an average imperfection value of 0.14 and average undersize bypass to the screen overflow of 4.3%. Parallel sets of test samples collected from the plant cyclone bank during the same time period indicate a significantly inferior average efficiency of 65% with a standard deviation of 5%. The low classification efficiency resulted from an average imperfection value of 0.43 and undersize bypass of 33% to the underflow of the plant cyclone.

The density effects on cyclone classification and Pansep screening have been duly quantified. Predictably, the Pansep size separation was found to be almost completely devoid of any density effect. On the other hand, a significant density effect on the size separation achieved by classifying cyclones was clearly evident. When only 27% of the feed materials having a mean particle size of 10 micron were recovered in the cyclone underflow, 78% and 95% of the sulfur-bearing minerals (pyrites) of the same size class were found to be recovered in the underflow in two separate tests. The concentration of ash bearing minerals in the cyclone underflow at a mean particle size of 10 micron was very minimal; however it was quite significant up to a particle mean size of 106 micron. These density effects on the cyclone classification process along with the inefficiency in particle size separation typically cause high-sulfur and high-ash contents in spiral feed streams and deslimed flotation feed streams in coal preparation plants.

A comparative economic analysis conducted indicates that the largest coal preparation plant operating in Illinois, which treats nearly 2,100 tph of raw coal (370 tph of raw fine coal) may require an additional $136,000 annually to replace the banks of 15-inch diameter cyclones with industrial size Pansep screens. However, due to the higher recovery of clean coal, the Pansep screen may result in an increased annual revenue of more than $6 million. For an average size plant, this increase may be nearly $2 million per year, which far offsets the extra cost of commercializing the Pansep screening technology and further improves the profitability from coal preparation plants in Illinois.

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