# APPLICATIONS OF THE CROSSFLOW TEETER-BED SEPARATOR IN THE U.S. COAL INDUSTRY

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## ABSTRACT

Hindered-bed separators are recognized as low-cost, high-capacity devices for both classification and density separation; however, since their inception, there have been few significant advances in the fundamental technology. Recently, Eriez has shown through modeling and pilot-scale testing that the innovative approach to feed presentation offered in the CrossFlow teeter-bed separator provides improved metallurgy when compared to traditional hindered-bed classifiers or single-stage coal spirals. This design feature prevents excess water from entering the separation chamber and disrupting the overall fluidization flow rate within the teeter zone. Most recently, a side-by-side industrial scale evaluation has verified that this technology improves overall efficiency and simultaneously reduces the separation cut-point. With regards to coal processing, data from full-scale units indicate that the CrossFlow offers good separation efficiency, high unit capacity, and metallurgical results consistent with laboratory- and pilot-scale separators.

## INTRODUCTION

### TEETER-BED SEPARATORS: GENERAL

Hydraulic separators are frequently used in the minerals processing industry to classify fine particles according to size, shape or density (Wills, 1997). Although many types of equipment exist, a device that has been gaining popularity in recent years is the teeter-bed or hindered-bed separator. The traditional design consists of an open top vessel into which elutriation water is introduced through a series of distribution pipes evenly spaced across the base of the cell. During operation, feed solids are injected into the upper section of the separator and are permitted to settle. The upward flow of elutriation water creates a fluidized "teeter-bed" of suspended particles. The small interstices within the bed create high interstitial liquid velocities that resist the penetration of the slow settling particles. As a result, small/light particles accumulate in the upper section of the separator and are eventually carried over the top of the device into a collection launder. Large/heavy particles, which settle at a rate faster than the upward current of rising water, eventually pass through the fluidized bed and are discharged out one or more restricted ports through the bottom of the separator.

Hydrodynamic studies indicate that quiescent flow/non-turbulent conditions must exist in a teeter-bed separator to maintain a high efficiency (Heiskanen, 1993). Excessive turbulence or changes in flow conditions can result in the unwanted misplacement of particles and a corresponding reduction in separation efficiency. Unfortunately, hydraulic separators typically utilize a feed injection system that discharges directly into the main separation chamber. These simplistic feed systems consist of a vertical pipe that terminates approximately one-third of the way into the main separator body. The pipe discharge is usually equipped with a distribution plate to reduce the flow velocity and disperse the feed slurry, but this approach creates turbulence within the separator that is detrimental to an efficient separation.

Another problem with the feed injection system is the discontinuity in flow velocity created by the additional water that enters with the feed solids and reports to the overflow launder. Below the feed point, the flow rate of water is dictated only by the fluidization water rate. This situation is desirable since it allows the operator to accurately control the separation size by adjusting the fluidization flow rate. However, above the feed injection point, the flow rate is the sum of both the feed water and fluidization water flow rates. As a result, the total upward velocity of water is higher above the feed injection point. In fact, at higher feed rates, the volume of water entering with the feed slurry may be greater than the volume flow of fluidization water. The discontinuity created by the feed water often results in a secondary interface of fluidized solids, which varies uncontrollably as the solids content of the feed varies. The increased/variable flow severely impacts the separation performance by increasing cut size, reducing efficiency (greater particle misplacement), and limiting throughput capacity.

Equipment maintenance is also an important issue in the design of a hydraulic separator. Conventional teeter-bed designs use a series of lateral pipes or a steel plate located at the base of the separation zone. These pipes and plates are perforated at regular intervals with large numbers of small diameter holes. Elutriation water is injected through these holes over the entire cross-section of the separator. The large water flow rates combined with the small injection hole diameters leave the device susceptible to blockage/plugging due to contaminants in the process water. When several orifices become blocked, a dead zone occurs in the fluidization chamber resulting in a loss of performance in this area. As a result, conventional teeter-bed separators have an inherent design flaw that limits both the capacity and efficiency of the unit.

## PARTICLE SETTLING THEORY

Several expressions have been developed to describe the characteristics of particles settling within a hindered state. In this work, the settling velocity of particles is described using the expression advocated by Masliyah (1979):

$$U_t = \frac{gd^2(\rho_s - \rho_f)}{18\eta(1 + 0.15\mathrm{Re}^{0.687})} F(\phi) \qquad [1]$$

in which g is the acceleration due to gravity, d is the particle size, $\rho_s$ is the density of the solid particles, $\rho_f$ is the density of the fluidized suspension, and $\eta$ is the apparent viscosity of the fluid. The term $F(\phi)$, which corrects for the effects of particle concentration (i.e., hindered effect), was estimated in the present work using:

$$F(\phi) = (\phi_{\max} - \phi)^{\beta} \qquad [2]$$

where $\phi$ is the volumetric concentration of solids, $\phi_{\max}$ is the maximum concentration of solids obtainable for a given material, and $\beta$ is a function of the Reynolds number (Re). Note that Equation [2] is equivalent to the expression advocated by Richardson and Zaki (1954) when $\phi_{\max} = 1$. Furthermore, these investigators showed that:

$$\text{For } \mathrm{Re}_s < 1 \quad \beta = 4.36/\mathrm{Re}^{0.03} \qquad [3]$$

$$\text{For } \mathrm{Re}_s \geq 1 \quad \beta = 4.4/\mathrm{Re}^{0.1} \qquad [4]$$

Likewise, the Reynolds number was calculated using:

$$\mathrm{Re} = \frac{d\rho_f |v_t| (\phi_{\max} - \phi)}{\eta} \qquad [5]$$

The apparent viscosity ($\eta$) was estimated using a semi-empirical expression suggested by Swanson (1989) where:

$$\eta = \eta_w \frac{2\phi_{\max} + \phi}{2(\phi_{\max} - \phi)} \qquad [6]$$

Empirical methods are normally used to estimate $\phi_{\max}$ (Swanson 1999). In fact, tests conducted using the CrossFlow separator suggested that changes to the cut point ($d_{50}$) had a large impact on the maximum particle concentration ($\phi_{\max}$) of the underflow. This should be expected since fine particles tend to fill voids that occur between coarser particles; however, as more fines report to the overflow (i.e., higher cut point), these voids remain proportionally empty. To quantify this effect, tests were conducted in which the cut point and maximum packing were determined experimentally. Test data indicate that there is a linear fit between $\phi_{\max}$ and $d_{50}$.

Combining the above expressions, the overall hindered-settling equation can be derived as follows:

$$U_t = \frac{gd^2(\phi_{\max} - \phi)^{\beta}(\rho_s - \rho_f)}{18\eta(1 + 0.15\mathrm{Re}^{0.687})} \qquad [7]$$

## TEETER-BED SEPARATORS: GRAVITY CONCENTRATION

As described by Equation 7, the settling rate of any particle within a hindered state is a function of both particle size and density. Because of this inherent interdependency, these devices are typically used for the classification of a like species (i.e., silica sand). However, if the feed size distribution is within acceptable limits, hindered-bed separators can be used for the concentration of particles based on differences in density. Typical density applications include the concentration of heavy minerals or coal. While heavy minerals have a naturally tight size distribution, it is generally accepted for coal applications that the treated size range should have a top to bottom size ratio of no more

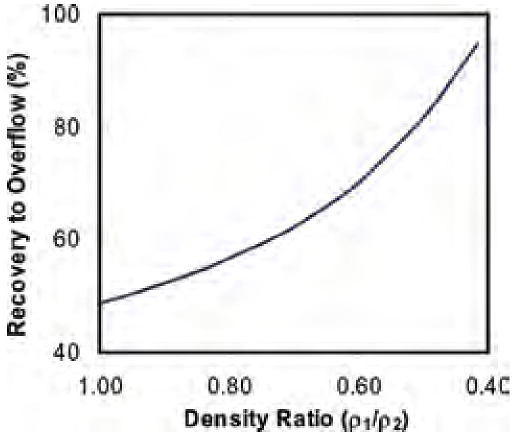

**FIGURE 1**
Recovery vs. density of components

than 6:1 in order to minimize the classification effects (Bethell 1988). Plant data suggests that efficient concentration can only be achieved if the particles are in the size range of 75 microns (200 mesh) to several millimeters in diameter.

For density separations, the high-density particles settle against the rising flow of water and build a bed of teetering solids segregated according to mass. This bed of solids has an apparent density much higher than the elutriation water. Since particle settling velocity is driven by the density difference between the solid and liquid phase, the settling velocity of the particles is reduced by the increase in apparent density of the teetering bed. This artificial density forces low-density particles to report to the overflow of the separator, and high-density particles to report to the underflow.

A population balance model was developed to evaluate the operating behavior of the CrossFlow teeter-bed separator using Equations 1-7. The model is used to predict overflow and underflow partitions, particle size distributions, and the recovery of various density components. Input data to the model include feed rate, percent feed solids by mass, feed size distribution, fluidization water rate, and up to two density components. The discrete model is constructed using a series of well-mixed zones. Three different sections are employed to represent regions in the separator with similar mixing patterns and flow regimes (i.e., feed section, teeter-bed section, and underflow section). Due to interdependencies between the various equations, an iterative process is required to calculate the hindered settling velocities using this approach. The development and validation of this model has been described elsewhere (Kohmuench et al., 2002).

To illustrate the separation characteristics of a hindered bed for density applications, the population balance model was used to investigate the effect of density difference with regards to recovery. In this effort, a feed, having two density components, was investigated. Simulations were conducted while varying the density ratio of the two components. Component 1 was varied from an SG of 3.0 to 1.25 while maintaining the density of the second component constant at 3.0 SG. For the purpose of this exercise, the density distribution of the feed was maintained equivalent for nine size classes between 1.20 and 0.100-mm (12:1 top to bottom size ratio).

Given a constant set of operating parameters, both component 1 and 2 have an equal chance (~50%) of reporting to the separator overflow when the density ($\rho$) of both components are identical as seen in Figure 1. As the SG of component 1 decreases relative to component 2, the recovery of component 1 increases substantially. For instance, in a coal cleaning application, combustible material (1.40 SG) is being separated from rock (2.65 SG) resulting in a $\rho 1:\rho 2$ ratio of 0.52. Utilizing the size distribution of this simulation, it can be expected that approximately 82% of component 1 will report to the overflow as product. The portion of component 1 that does not report to product is essentially the coarser material whose size effect offsets its density effect. Naturally, additional improvements in overall recovery can be realized if a tighter feed size distribution is utilized or the operating parameters of the separator are altered.

# CROSSFLOW SEPARATOR

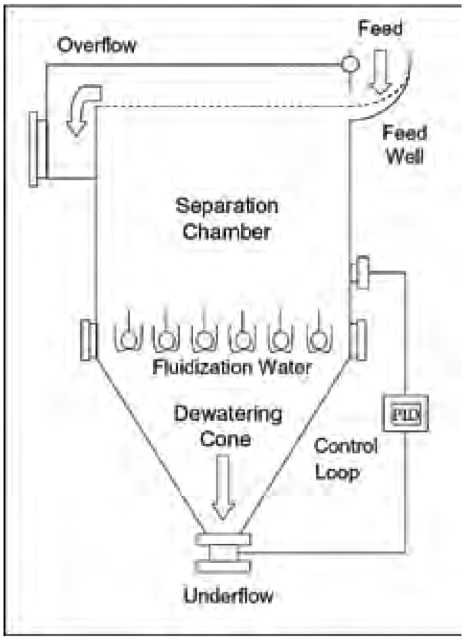

***FIGURE 2***
Schematic of the CrossFlow classifier

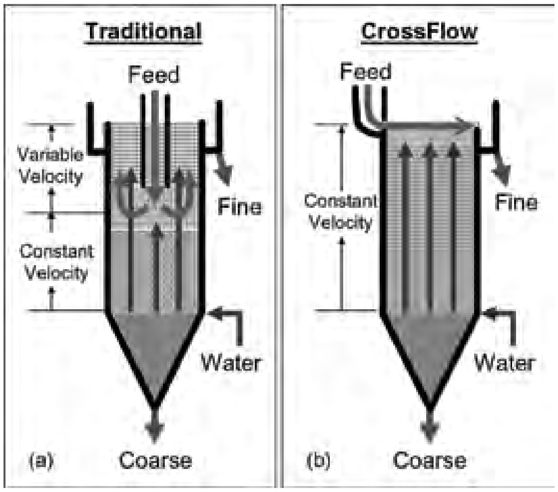

***FIGURE 3***
Water flow velocities in classifiers

The CrossFlow separator has been developed as a new generation of teeter-bed separator. It incorporates several novel design features to improve process performance (separation efficiency and capacity) and reduce operating costs (power consumption and water usage). A schematic of the CrossFlow is provided in Figure 2.

Compared to a conventional hydraulic classifier, the CrossFlow design uses an improved feed delivery system that gently introduces the feed slurry across the top of the separator as opposed to injecting the slurry at a high velocity directly into the teeter-bed. As previously stated, high slurry feed volumes create turbulent mixing that has a detrimental impact on separator performance. In the new feed delivery system, the feed velocity is reduced using a transition box. The purpose of this box is two-fold. First, the feed transition box increases the flow area to the full width of the separator so that the slurry velocity, and any associated turbulence, is minimized.

The second unique feature is its ability to tangentially feed the separator. This stilling-well, which is located at the top of the separator, smoothly passes the feed slurry horizontally across the top of the cell and into the overflow launder. Compared to conventional systems, the tangential feed introduction system ensures that variations in feed slurry characteristics (e.g., solids content) do not impact separator performance. In the CrossFlow, the teeter-water velocity remains constant throughout the separation chamber at all times, while the velocity in a conventional classifier generally increases above the feed addition point (Figure 3). A baffle plate is also located at the discharge end of the feed well to prevent short-circuiting of solids directly to the overflow launder.

Another design feature incorporated into the CrossFlow classifier is the improved water distribution system. A novel approach has been developed that incorporates a slotted plate to disperse the elutriation water across the base of the separator. In this design, a horizontal slotted plate is located at the base of the separation chamber. Water is introduced beneath the plate through a series of large diameter holes (>1.25 cm). However, unlike existing separators, these orifices are located at distant intervals (typically >15 cm) and serve simply to introduce the water, while water dispersion is achieved by the baffle plate. This modification essentially eliminates problems associated with plugging of distributor plates or pipes. The combined use of the improved feed injection system and simplified water distribution system makes it possible to increase both the separation efficiency and throughput capacity while eliminating mechanical problems associated with traditional designs. Because of the higher throughput capacity, the operating demands in terms of power, water consumption and maintenance are lower for the CrossFlow when reported on a per ton of concentrate basis.

| Test Variable | Conventional | CrossFlow |
|---|---|---|
| Feed Rate (tph/m²) Feed | 20-90 | 10-70 |
| Solids (%) | 15-40 | 15-50 |
| Water Rate (m³/hr) | 43 | 9-20 |

***TABLE 1***
CrossFlow pilot-scale test conditions

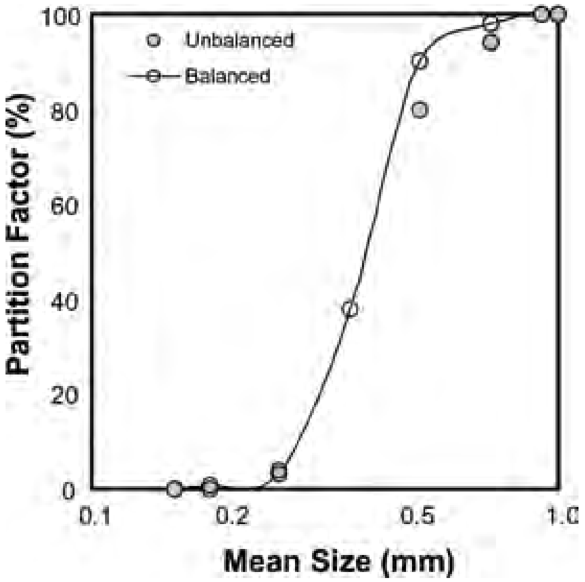

***FIGURE 4***
Example of a CrossFlow partition curve

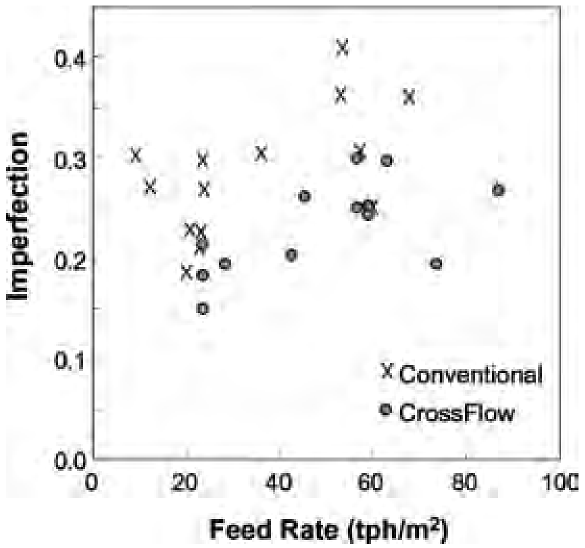

***FIGURE 5***
Imperfection vs. solids feed rate

## CLASSIFICATION PERFORMANCE VERIFICATION: PILOT-SCALE

An on-site test program was conducted at an industrial phosphate plant to evaluate the potential benefits of the CrossFlow separator for particle classification. The 0.6x0.6-m (2x2-ft) pilot-scale unit was installed to partition the 1.0x0.1-mm (16x150 mesh) plant feed for the existing flotation circuits into narrowly-sized fractions. Comparison tests were also performed using a pilot-scale conventional classifier so that any improvements in sizing performance could be accurately quantified. Table 1 provides a summary of the operating conditions examined for each classifier. For each test, representative samples were collected from the feed, overflow, and underflow streams. The samples were subjected to sieve analysis and the results were mass balanced using a sum-of-least-squares method to assess the reliability of the experimental data. Data that mass balanced poorly were deemed unreliable and eliminated from the analysis.

The mass-balanced data were used to construct partition curves for each test run performed for the two classifiers. Figure 4 shows an example of a partition curve obtained using the CrossFlow separator. The partition factor represents the recovery of dry solids from the feed to the underflow (oversize) product for each size class. The partition curves were used to determine the imperfection (I) for each test. The imperfection is a dimensionless number commonly used to quantify the efficiency of sizing units. A lower number represents a steeper curve and thus a better separation. A vertical line represents a perfect separation. The imperfection (I) is determined by:

$$I = (d_{75} - d_{25})/2d_{50} \qquad [8]$$

Using this approach, the test results were analyzed to compare the performance of each separator. These results, which are compared in Figure 5, show the imperfection of each unit as a function of dry feed rate. The test results indicate the CrossFlow unit consistently performed at a higher level of efficiency (i.e., lower imperfection). Close examination of the test results indicated that the lower efficiency associated with the conventional classifier was due to misplacement of coarse material to the overflow product created by the higher flow rate and greater turbulence within the upper section of the conventional sizer. On the other hand, the CrossFlow hindered-bed separator maintained a uniform (laminar) flow pattern and thus the amount of misplaced material was minimized.

It is also important to note that the unique design of the CrossFlow makes it possible to accurately control the particle cut size. The cut size is defined as the particle size corresponding to the 50% recovery point on the partition curve, and is considered to be the separation size for a given test. As stated previously, variations in the characteristics of the feed (such as solids content) do not significantly impact the cut size since the teeter water velocity remains constant throughout the unit. As a result, the particle cut size is controlled predominantly by the teeter water flow rate. In fact, the data in Figure 6 show that an approximately linear relationship exists between flow rate and particle cut size. As a result, on-line adjustment of size of the overflow and underflow products can be achieved through simple water flow control for the CrossFlow classifier.

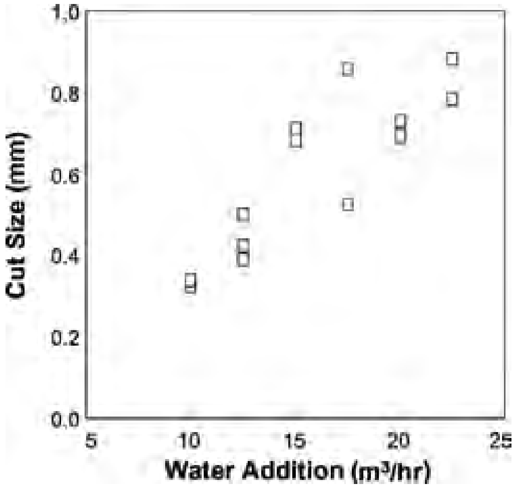

**FIGURE 6**
Cut size vs. fluidization water rate

| Test Variable | Conventional | CrossFlow |
|---|---|---|
| Particle Cut Size | 729 µm | 362 µm |
| Alpha Value | 3.4 | 8.1 |
| Misplaced +0.425-mm | 9.0% | 1.7% |

**TABLE 2**
Comparison of full-scale classifiers

| Test Variable | Conventional | CrossFlow |
|---|---|---|
| Particle Cut Size | 490 µm | 420 µm |
| Alpha Value | 3.2 | 7.2 |
| Imprefection | 0.162 | 0.109 |

**TABLE 3**
Comparison of full-scale classifiers

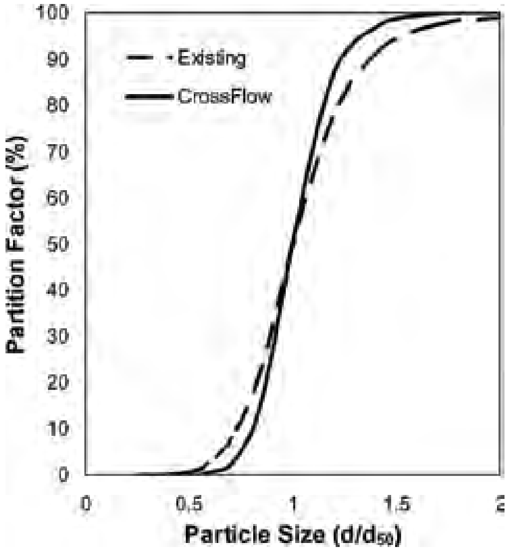

**FIGURE 7**
Separation curves for industrial sizers

## CLASSIFICATION PERFORMANCE VERIFICATION: FULL-SCALE

In light of the promising results obtained using the pilot-scale CrossFlow unit, a full-scale classifier at an industrial phosphate beneficiation plant was retrofit using the CrossFlow feed introduction system. The data obtained from the retrofitted unit were then compared to those obtained from the conventional full-scale classifiers operating in parallel. Due to fluctuations in the plant feed tonnage, the test results are reported as an average of seven sets of experiments conducted over a range of circuit feed rates from 1400 to 1980 tph (1270 to 1800 stph). In each test, representative samples of feed, oversize and undersize solids were collected and subjected to sieve analysis. The resulting size data were used to construct partition curves for both the conventional and CrossFlow units. The data points were then fit using an empirical partition function given by:

$$P = (\exp\{\alpha(d/d_{50})\} - 1)/(\exp\{\alpha(d/d_{50}) - \exp\{\alpha\} - 2) \qquad [9]$$

in which P is the partition factor, d is the particle size, $d_{50}$ is the particle size cut point (defined at P=50%), and $\alpha$ is a parameter that reflects the sharpness of the size separation (defined as the slope at P=50%). Note that a larger value of $\alpha$ indicates a sharper (more efficient) particle size separation.

The results of the side-by-side comparison of the conventional and CrossFlow classifiers are provided in Table 2. The test data show that the CrossFlow reduced the particle cut size from 729 to 362 microns while maintaining the same feed throughput. At the same time, the CrossFlow substantially improved the efficiency of sizing (alpha was increased from 3.4 to 8.1). In fact, the amount of misplaced coarse (+0.425-mm) solids in the fine product overflow was reduced by more than five-fold (from 9.0% to 1.7%). These impressive results illustrate the superior performance of the CrossFlow separator for industrial classification applications.

A second round of testing was completed in order to compare the two classifiers at a similar particle size cut point. Since the particle cut size had been reduced simply by changing the feed arrangement, the teeter water and effective density of the retrofitted unit were adjusted until the cut size between the two units were similar. Presented in Table 3 are the results of this comparison. In addition, Figure 7 shows the separation curves for the two units normalized to their respective cut points. It is easily seen that the retrofitted classifier offers a much sharper separation curve when compared to the existing unit. A comparison of the separation curves indicates that the retrofitted separator operated with a 33% higher efficiency.

## GRAVITY PERFORMANCE VERIFICATION

The use of hindered-bed separators for density concentration has long been examined. Dunn et al., 2000, reported that the Allflux® separator has been tested successfully in concentration applications including quartz sands, iron ore, and heavy minerals. Also, several coal cleaning applications have been successfully tested (Reed et al., 1995). Successful use of the Floatex Density Separator to recover zircon from previously rejected mill tailings was also demonstrated (McKnight et al., 1996).

Further investigation by Dunn et al., 2000, indicated that hindered-bed separators offer heavy mineral recovery in excess of 95% while rejecting approximately 90% of the quartz contaminants from a wet mill concentrate. In these studies, the product grade averaged 33% $TiO_2$ and 95% heavy mineral. Furthermore, it was reported that the CrossFlow feed presentation system offered a significant capacity advantage over other teeter-bed technologies.

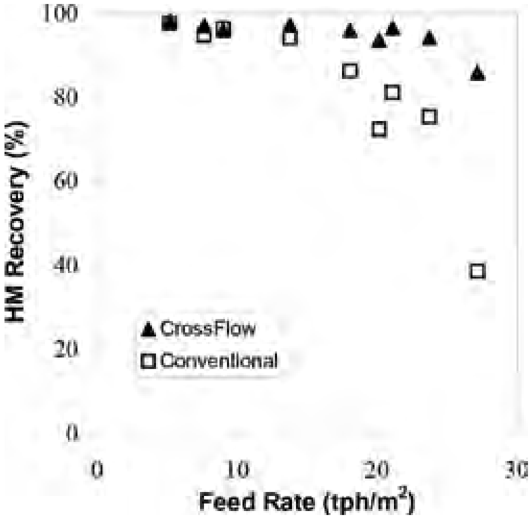

**FIGURE 8**
Capacity tests (after Dunn et al., 2000)

Figure 8 shows the results from capacity tests undertaken in this work. Specifically, the CrossFlow was shown to have a clear capacity advantage. At a target heavy mineral recovery of 95%, the CrossFlow was shown to have a capacity 1.8 times that of a conventional unit. It was concluded that this increase in capacity was a result of the elimination of the high velocity zone in the upper section of the teeter-bed. In addition, as a direct result of the higher capacity, the overall teeter water requirement for the CrossFlow system was 60% of the conventional system.

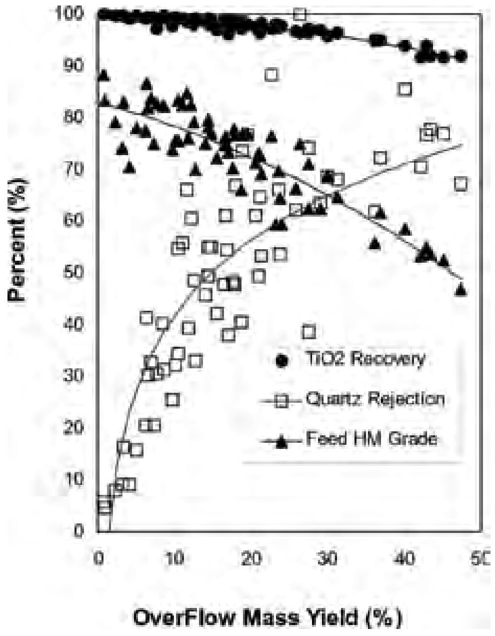

**FIGURE 9**
CrossFlow testing of heavy mineral concentrate (after Eisenmann, 2001)

Follow-up testing conducted by Eisenmann (2001) evaluated the performance of the CrossFlow separator over a wider range of operating parameters. The overall performance curves for all tests are presented in Figure 9. As shown in this figure, heavy mineral recovery ranged between 90% and 100% with quartz rejection up to 75%. The benefits of rejecting the quartz contaminants from the wet mill concentrate include reduced transportation, scrubbing, and drying costs. It is also anticipated that the subsequent dry mill and zircon upgrade processes will be improved (i.e., more efficient) due to the higher grade of the feed for each of the downstream unit operations. Based on these findings, a full-scale CrossFlow has been purchased and installed.

Other density evaluations included work on a South American barite sample. Laboratory test work indicated that the CrossFlow separator was able to achieve a $BaSO_4$ (SG 4.5) recovery greater than 90% while simultaneously rejecting, on average, over 90% of the $SiO_2$ (SG 2.65) contaminant. In fact, due to the success of the initial test work, a second round of testing was implemented to confirm the metallurgy. The final underflow product was assayed at better than 98% $BaSO_4$ with a silica content of less than 1%.

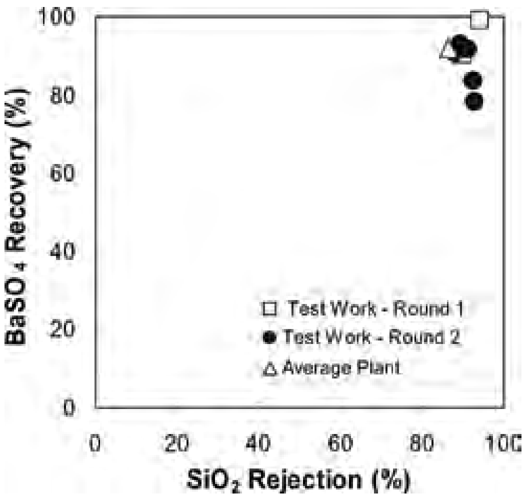

**FIGURE 10**
Pilot and full-scale results for barite

Based on these results, a full-scale separator was installed and commissioned in 2002. Figure 10 shows the average plant metallurgy with respect to the two sets of pilot-scale test runs. This figure indicates that a good correlation was achieved between the pilot and full-scale units. As shown, the plant averaged approximately 90% barite recovery at a silica rejection of 90%. In general, scale-up for teeter-bed separators is straightforward provided that the flow per unit area of the separator is maintained relatively constant. This ensures that the velocity and hindered-settling profiles under both the pilot and full-scale approaches are consistent.

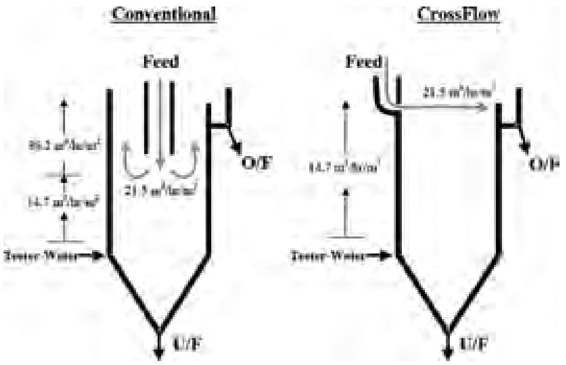

**FIGURE 11**
Comparison of a conventional and CrossFlow separator treating 50 t/hr coal at 50% solids

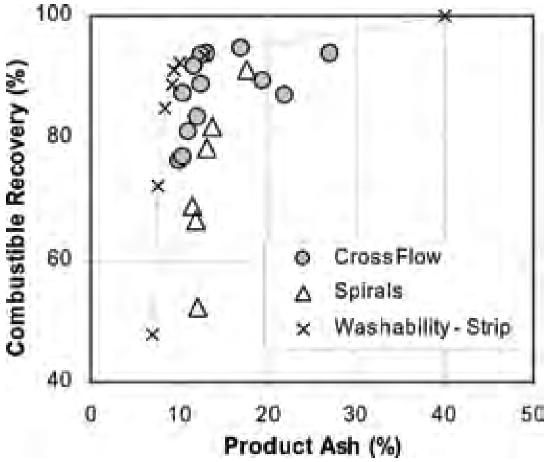

**FIGURE 12**
Pilot-Scale results versus washability

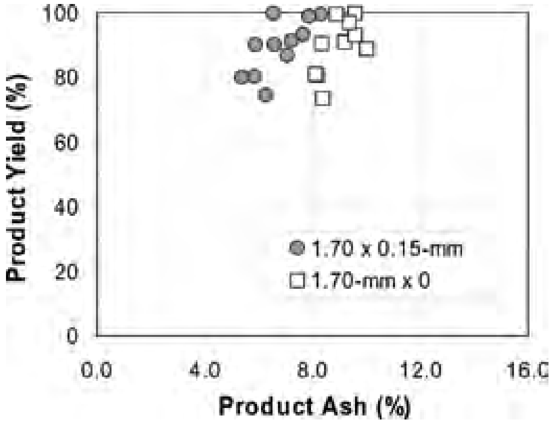

**FIGURE 13**
CrossFlow performance on central Appalachia low-middling coal

# COAL APPLICATIONS

The advantage of this system is most obvious in applications using relatively small amounts of fluidization water. For instance, in a coal application treating 50 t/hr at 50% solids, the influx of feed water is equivalent to 50 t/hr or 13.9 L/s, by volume. This influx has a large impact on separators using a traditional downcomer feed system where the net upward flow of water within the separation chamber is substantially increased. Treating this material in a 1.5x1.5-m separator requires approximately 14.7 $m^3/hr/m^2$ of teeter water for fluidization; however, the water associated with the feed substantially increases the fluidization rate by 21.5 $m^3/hr/m^2$ to a total of 36.2 $m^3/hr/m^2$. Consequently, the fluidization rate is more than doubled at, and above, the point of feed entry. Using the new tangential feed presentation system, the entire separation chamber is left virtually undisturbed, allowing for a constant flow regime. This example is illustrated in Figure 11.

## PILOT-SCALE DATA

**Central Appalachia Strip Coal** - Test work was completed using a pilot-scale CrossFlow separator to treat coal from a U.S. strip operation. The material treated was relatively high in rock with a feed grade of approximately 40% ash. Operating in parallel to the CrossFlow was a single re-pulping test spiral. Feed was supplied to both units from an existing slurry distributor. The feed percent solids was adjusted to approximately 35% and 25% for the CrossFlow and spiral, respectively. Sufficient tests were run to create grade/recovery curves. This data is presented in Figure 12. As shown, the CrossFlow separator operates very close to the washability curve. At maximum separation efficiency, a product containing 12% ash was produced at a mass yield of 78% and combustible recovery of 92%. In contrast, the spiral operated further from the washability data, providing a higher ash product for the same combustible recovery.

While spirals offer many advantages, including high combustible recovery, they suffer from misplacement of coarse rock to the clean coal product as illustrated by the higher spiral product ash values presented in Figure 12. Additionally, coal spirals operate at a high specific gravity cut point. Overall, more efficient plant circuits must operate at reduced gravities to compensate for the higher ash products generated by coal spirals.

**Central Appalachia Deep Mine Coal** - Additional pilot-scale test work was completed on a U.S. low-middling coal. The ash content of the feed material ranged between 10% and 13%. During the on-site test work, feed was obtained from the underflow of an existing dewatering cyclone. An adjustable splitter was arranged directly beneath the cyclone spray, which allowed for full adjustment of the feed flow to the pilot unit. Feed percent solids for all tests averaged 45%, by weight. The results from this test work are presented in Figure 13. It can be seen that the CrossFlow separator was able to upgrade this material by reducing the overall ash content to less than 8% while maintaining product yields in excess of 90%. This is possible due to the rejection of the high ash particles from the underflow of the separator. The average reject from the CrossFlow was measured at 77% ash.

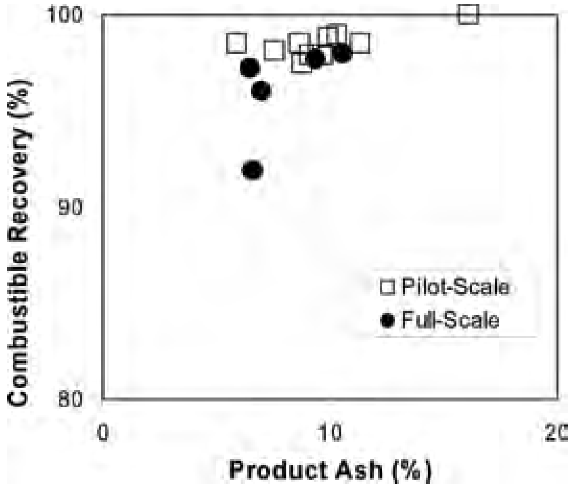

***FIGURE 14***
Full-scale commissioning results versus pilot-scale performance

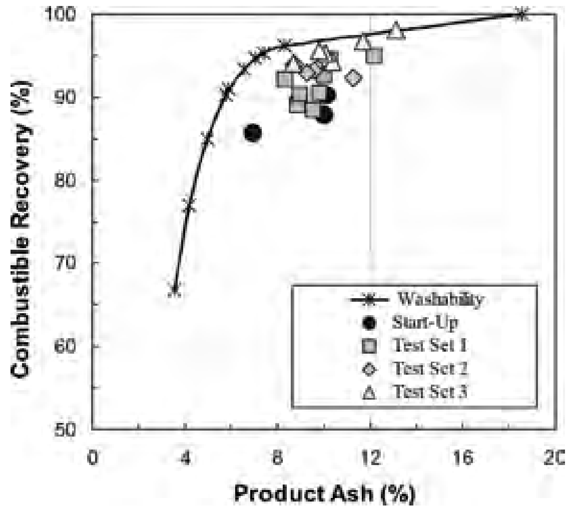

***FIGURE 15***
Results of full-scale evaluations versus washability data

## FULL-SCALE DATA

**Central Appalachian Coal** – The pilot-scale testing of a low-middling, central Appalachian coal led to the installation of a full-scale CrossFlow separator. This unit, 2.75x2.75-m, was engineered to treat over 200 tph of coal. Performance results produced during start-up are shown in Figure 14. The data indicate that the separation performance achieved at full scale is consistent with the performance demonstrated during the pilot-scale work. In fact, when optimized, this unit achieved a product ash content of 9.5% at a combustible recovery of 97.5%.

This full-scale CrossFlow was installed as a replacement for existing coal spirals. The teeter-bed unit offers many advantages, including a low separation cut point in a single stage, high-tonnage throughput per unit area of plant floor space, and automatic control of the separation cut point. In contrast, coal spirals are manually controlled (i.e., splitters), which make them extremely sensitive to changes in volumetric feed rate (Walsh and Kelly 1992). During normal plant fluctuations, the static spiral splitters cannot automatically compensate as the coal and rock interface moves up and down on the spiral trough.

**Southeast Appalachian Coal** – A full-scale CrossFlow was installed and commissioned at a Kentucky coal preparation plant. Performance data is presented in Figure 15. Start-up of this unit proved uneventful. The unit worked well and produced a clean coal product with an ash content of approximately 10%. This was achieved at a combustible recovery of better than 90%. To further evaluate the performance of the CrossFlow separator, on-site testing was conducted by personnel from Virginia Tech and the University of Kentucky with support from the U.S. Department of Energy Industries of the Future Program (DE-FC26-03NT41789).

Three site evaluations were conducted in this effort. During the initial test (Set 1), the separator was simply sampled throughout the test period. Figure 15 shows that the combustible recovery regularly exceeded 90% with product ash values ranging between 8% and 10%. During the follow-up effort (Set 2), the objective was to improve recovery while maintaining product grade. As such, evaluations were conducted while running the unit at the highest available bed pressure (i.e., level) while varying the elutriation water rate. The maximum level was limited by the calibration of the existing pressure transducer.

This effort resulted in an incremental improvement in combustible recovery as presented in Figure 15. In fact, the average combustible recovery and yield improved by nearly 2%. The data set generated during this follow-up testing suggested that further performance improvement could be realized by further increasing the bed pressure. Generally, an increase in teeter-bed level will increase the effective gravity cut-point of the separator, thereby increasing combustible recovery.

This approach was investigated in a second set of follow-up tests (Set 3). In an effort to carry out these evaluations, the existing pressure sensor was recalibrated. Again, as seen in Figure 15, the increase in bed density further improved the combustible recovery by an additional 2%. In total, this systematic approach resulted in an average increase in product mass yield of over 4% (or 5.9 tph). For this installation, this process improvement results in a revenue increase of better than $2.0 million per year (5.9 tph x 7000 hr/yr x $50/ton).

# SUMMARY

Laboratory, pilot, and full-scale evaluations have shown that the novative feed presentation system utilized in the CrossFlow separator has several benefits which are a direct result of preventing excess water from entering the separation chamber and disrupting the fluidization rate within the teeter-zone. These benefits include an overall improvement in separation efficiency, a reduction in the separation cut size, and an increase in throughput capacity.

**In General:**

1. Pilot-scale testing has shown that the CrossFlow feed presentation system offers improved separation efficiency in comparison to conventional hindered-bed classifiers.
2. A full-scale retrofit of an existing hydrosizer with a CrossFlow feed system verified that at equivalent cut points, the classification efficiency is improved by more than 33%.
3. Teeter-bed separators provide an efficient density separation between valuable heavy mineral and silica gangue in a heavy mineral wet mill concentrate. In addition, data indicate that the CrossFlow feed presentation system offers a higher unit capacity and lower water requirement when compared to conventional units.
4. A full-scale CrossFlow separator was installed for a barite application that showed good correlation between laboratory data and the full-scale unit. Typical results show that over 90% of the available barite can be recovered at a silica rejection of greater than 90%.
5. Test data indicate that the CrossFlow separator provides separation results superior to that of single-stage coal spiral circuit. In general, hindered-bed separators provide low specific gravity cut points, high solids throughput, and are less sensitive to changes in operating conditions, such as volumetric feed flow rate, when compared to coal spirals. While teeter-bed separators can often operate at maximum separation efficiency, plant operators are often forced to choose between grade or recovery when operating coal spiral circuits due to the make-up of material found in the middling stream.
6. All lab-, pilot-, and full-scale data have demonstrated that the CrossFlow separator provides a low ash product at a high combustible recovery when upgrading coal. These evaluations show that the results from the CrossFlow separator tests are in good agreement with washability data, and provide a high organic efficiency.
7. Comparison of data from both pilot- and full-scale CrossFlow separators show that pilot-scale evaluations are an acceptable indication of full-scale results (i.e., scale-up criteria). In fact, during commissioning, full-scale separators achieved a separation consistent with the pilot-scale test work.
8. A structured and scientific approach was utilized to improve the performance of an existing CrossFlow separator at a Kentucky coal preparation plant. By increasing the effective density within the teeter zone, the combustible recovery and product mass yield of the separator were improved. The increase in product tonnage has resulted in a revenue increase estimated at over $2.0 million per year.

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