A Comeback for Fine Coal Recovery

Dr M. Mankosa, Dr J. Kohmuench, Eriez, US, and J. Furey, Canadian Process Technologies, Canada, describe the debut of the Coalpro column in the US coal industry.

Traditionally, coal fines have been considered a nuisance in coal processing. In fact, in many operations the minus 100 mesh material is discarded due to high processing costs, poor flotation performance and high final product moisture. However, with the increasingly competitive nature of the industry, a resurgence has occurred with regard to fine coal recovery. As a result, Eriez and Canadian Process Technologies (CPT) have worked with various engineering companies to supply and commission three new column installations in the US coal industry.

In 2000, Eriez and CPT introduced the CoalPro column flotation cell. Most noted for magnetic separation, Eriez has extended its product line to include column flotation. The CoalPro, developed specifically for coal applications, is a joint development project with CPT that draws upon its experience in column flotation over the past two decades.

Figure 1. 3m CoalPro columns treating nominal 100x325 mesh feed.

A total of nine columns were installed over the past year ranging in size from two 3m diameter columns at TECO's Clintwood-Elkhorn No. 3 facility in Virginia (Figure 1) to five 4.25m diameter columns at Coastal's White Tail facility in central West Virginia. The latter is currently the largest column flotation plant in the US coal industry. This paper will discuss development and application of column cells in the US coal industry and will present comparative test data from laboratory-, pilot-, and full-scale installations.

Conventional flotation technology

Fine coal (<0.2mm) flotation has traditionally been achieved using conventional flotation cells. These low-profile tanks-in-series are a well-proven technology and are used extensively throughout the minerals industry. Unlike mineral applications, however, the economics of coal processing do not allow for multi-stage cleaning. Therefore, final product grade and recovery must be achieved in a single pass. This is

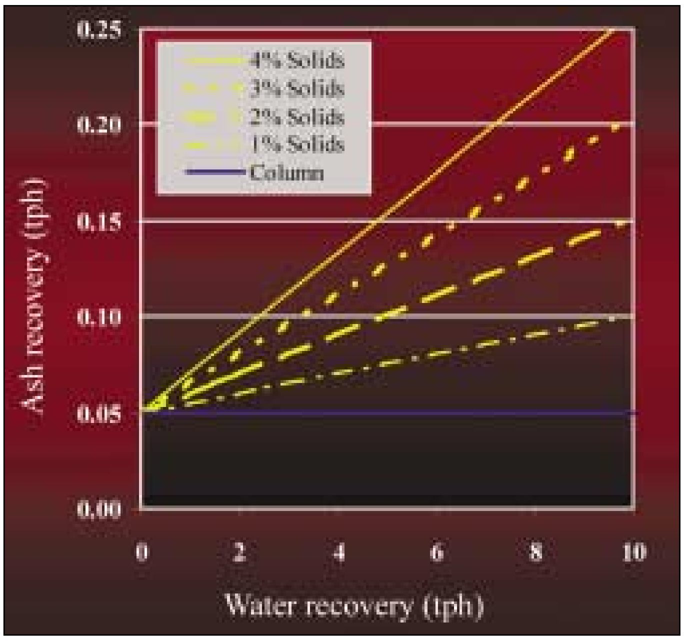

Figure 2. Water vs. ash recovery for conventional flotation cells.

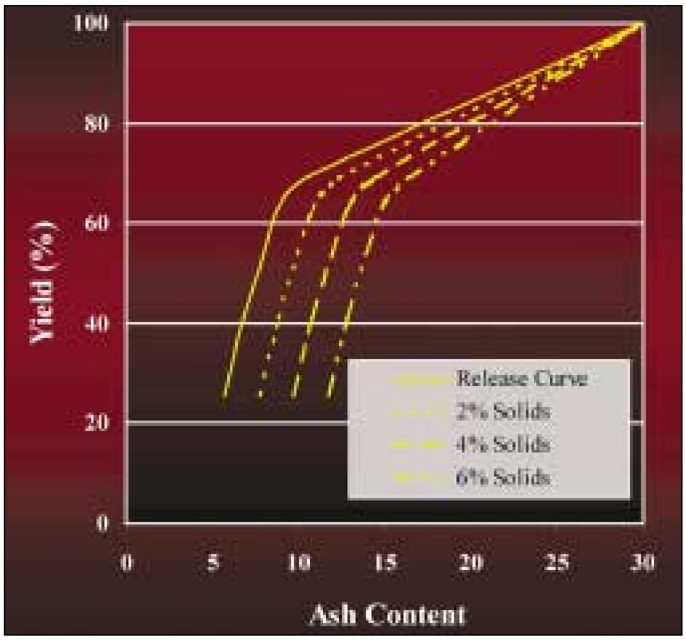

Figure 3. Product yield vs. ash content for various feed solids content.

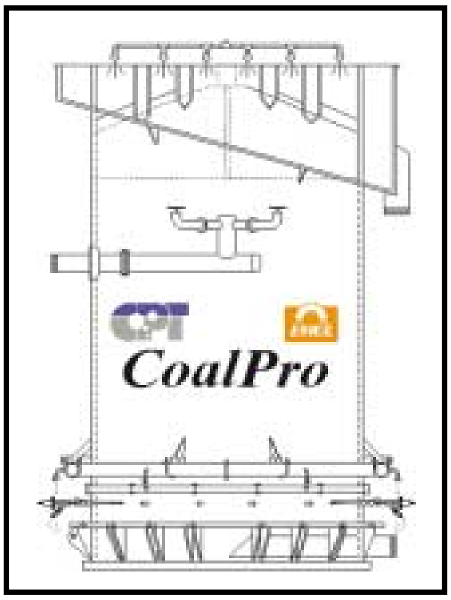

Figure 4. A CoalPro column.

Figure 5. 4.25m CoalPro overflow launder and wash water addition system.

Figure 6. SlamJet Air Sparger.

often a difficult task for conventional cells due to the high ash content of flotation feed stocks. Typical minus 0.15mm (100 mesh) flotation feeds can range from 20-30% ash and, in some instances, can exceed 50%. The high ash content results from the presence of excessive ultra-fine clays. In these applications, conventional cells struggle to maintain an acceptable product grade due to entrainment of fine clays into the froth product.

Two mechanisms are responsible for solids reporting to the flotation concentrate: bubble/particle attachment and entrainment. Bubble/particle attachment is a selective process resulting from the hydrophobic attraction of one particle type (coal) to a bubble surface. Other non-coal gangue components such as quartz, shale and clay fines do not exhibit a natural hydrophobicity and, therefore, are not attracted to the bubble surface. Bubble/particle attachment is the desired separation phenomenon and is responsible for concentration of the coal particles in the flotation product.

Entrainment, on the other hand, is a non-selective process resulting from the recovery of water into the froth concentrate. Fine particles (<0.025mm) that are not collected through bubble/particle attachment will report to the froth concentrate in direct proportion to the amount of product water. This fact is clearly illustrated in Figure 2 which shows tonnes per hour of gangue (ash) reporting to the froth product as a function of water recovery. In this case, every tonne of water reporting to the froth concentrate results in a corresponding contribution of ash due to entrainment. As a result, in coal applications, it is often difficult to 'pull hard' on the flotation cells to maintain product yield since the associated entrainment of slimes will result in an unacceptable product quality. The ash content at zero water recovery provides an indication of the concentrate quality in the absence of non-selective entrainment. This 'baseline' ash content is a function of the liberation characteristics of the material and is attributed to either locked particles or the inherent ash of the coal.

The influence of pulp percent solids on entrainment is shown in Figure 3. It can be seen that the influence of entrainment on final product quality is less significant at lower pulp percent solids due to dilution. In fact, in the absence of entrainment, the release analysis curve is obtained. The release analysis curve represents the best separation that can be achieved using flotation and is often used to determine the organic efficiency of coal flotation circuits. This approach parallels the use of washability to evaluate heavy media circuits. As shown, conventional flotation performance approaches the release curve with increased dilution. Unfortunately, a reduction in percent solids results in a greater volume flow of slurry and, likewise, more (or larger) cells to maintain the same retention time. This is not an economical solution.

The CoalPro column

Column flotation cells are an alternative approach to flotation that offers a solution to mechanical entrainment problems. Column cells were first introduced in the Canadian iron ore industry in the early 1960s. From a metallurgical point of view, the columns were extremely successful. Column cells differ from conventional cells in that they have a high aspect ratio (height to diameter). As discussed below, adequate column height is essential to provide sufficient slurry retention time. This geometry also allows for operation with a deep froth bed. In coal applications, froth depth typically approaches 1m. The deep froth allows for the use of wash water to rinse entrained material back into the cell, thus preventing entrained gangue from entering the froth product. Froth washing is not possible in conventional flotation since there is insufficient cell height to allow operation with a deep froth. Additionally, the large volume of wash water required to adequately rinse the froth product will have a detrimental impact on cell retention time.

A schematic diagram of the CoalPro column flotation cell is shown in Figure 4. This cell, developed specifically for coal applications, offers several novel design features that are critical for fine coal flotation, including the following.

- An adjustable, gravity-flow wash water system.
- Multi-point feed distribution.
- Internal product launders.
- A removable, self-closing sparging system.

Proper design of the wash water system is important for efficient column operation. In addition to eliminating entrainment, wash water also helps maintain a 'wet' and 'mobile' froth structure. This is particularly important in large diameter cells used for coal flotation since the froth must travel a significant distance before reaching a launder. The natural hydrophobicity of coal combined with fuel-oil collectors tends to depress the froth structure and can lead to collapse of the froth with subsequent loss of product. Proper distribution of wash water over the entire cell cross-sectional area replenishes drained water and maintains froth mobility. Additionally, the gravity-fed system (Figure 5) minimises wash water injection velocity. This is an important design feature since pressurised systems can actually rupture and collapse the froth structure.

Feed distribution and launder design

must also be properly addressed in coal columns. Unlike mineral flotation, coal feed slurry density typically ranges from 3-6% solids (by weight) for a minus 100 mesh application. As a result, slurry feed flow rate is quite high. For example, a 4.25m diameter column cell may have a slurry feed rate approaching 450m^3/hr. This requires a multi-point feed distribution system to minimise turbulence and ensure proper distribution over the column cross-sectional area.

Likewise, coal applications have a high mass recovery rate (50-70%). This fact, combined with a low solids density (s.g.<1.5) and low froth solids content (12-15% w/w), results in a large volume of froth product. From a design point of view, sufficient launder length must be available to ensure that the froth is adequately removed from the top of the cell with a minimal travel distance. This is accomplished through the use of external and internal launders. The 4.25m diameter column shown in Figure 5 has a launder lip length approaching 35m. Additionally, the launders are designed with sufficient volume to properly convey the froth product. This approach minimises froth breakage and/or collapse that can result in a loss in product recovery.

Air sparging is by far the most important aspect of proper column design. Floatable particles are only removed by attachment to a bubble surface. Therefore, a properly designed air sparging system must maximise the rate of bubble surface area through the column to provide sufficient capacity. In addition, this system must be reliable and maintenance free. Early problems with bubble generation systems delayed industrial acceptance of column flotation cells. The first practical solution to bubble generation was developed by the US Bureau of Mines in Salt Lake City. This design incorporated multiple injection tubes with a number of small diameter (2-3mm) orifices along the tube body. Although this approach worked well, persistent maintenance problems existed with regard to plugging of the orifices.

Canadian Process Technologies (formerly Cominco Engineering Services Limited) solved the plugging problem with the introduction of the SparJet aeration system. This removable, single-orifice nozzle utilised high velocity air injection to create finely dispersed bubbles in the column. Considered a breakthrough in column sparging technology, this design has been accepted internationally and has eliminated maintenance problems associated with previous systems. The current design, known as the SlamJet (Figure 6), has furthered development by incorporating a self-closing mechanism that eliminates problems associated with back-flow of slurry into the sparging system.

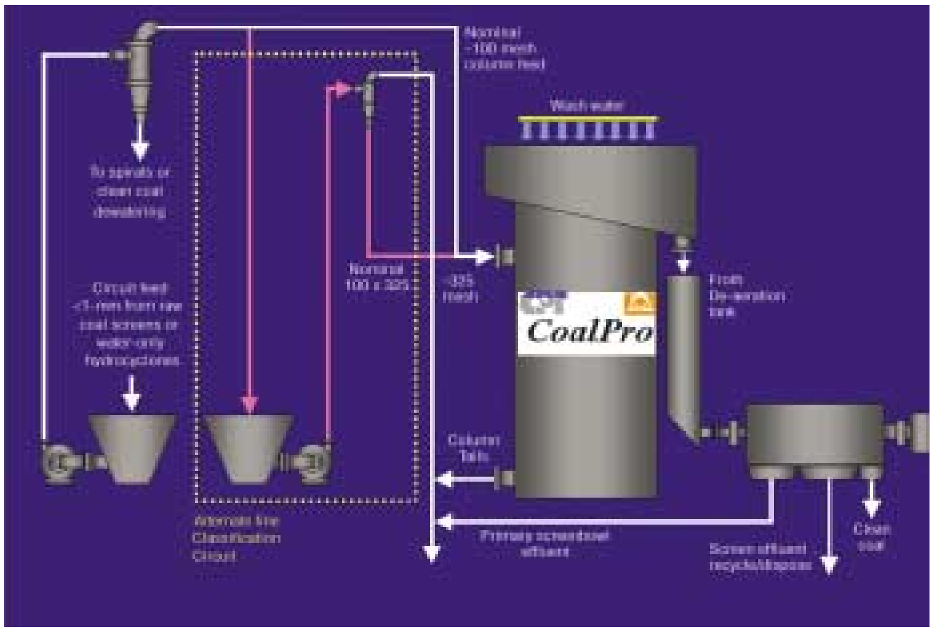

Figure 7. Typical -100 mesh and 100 x 325 mesh flotation circuits.

In addition to the mechanical design requirements described above, research and development efforts by CPT and Eriez over the past decade have clearly defined the important parameters that must be addressed to achieve accurate scale-up predictions. Of these, retention time and carrying capacity are clearly the most important. Retention time can be characterised by the cell volume (corrected for air hold-up) divided by the volume flow through the tank. Carrying capacity is defined as the tonnes per hour of flotation concentrate per cell cross-sectional area. Carrying capacity has been well defined by numerous researchers with extensive data available for coal and mineral applications. Proper application of these, and other, design parameters is essential to ensure a successful column flotation installation.

Circuit applications

Two flotation circuits are currently used for column applications in the US coal industry. The traditional approach (Figure 7) is to send the minus 1mm feed fraction to classifying hydrocyclones. The hydrocyclones are configured to achieve a d_{50} (cut-point) of approximately 100/150 mesh. The underflow stream is processed using spiral concentrators and the overflow stream is sent to flotation. Alternatively, the classifying hydrocyclone underflow may go directly to dewatering if this material has been pre-concentrated using water-only cyclones. The columns are typically installed at the proper elevation to allow for gravity flow of the tailings directly to the thickener with the clean coal concentrate reporting to either centrifuges or filters for dewatering. It should be noted that columns produce a very stable froth structure due to the use of glycol-based frothers that are required to maintain a deep froth bed that will withstand vigorous washing. This created problems in early column installations that resulted in difficulty handling froth transfer from the column launder to the dewatering equipment. As a result, precautions must be taken to ensure that the froth has sufficient time to de-aerate. More recent installations incorporate froth de-aeration/transfer tanks that provide sufficient time and hydrostatic head for the froth to de-aerate.

A more recent departure from this approach has been the use of fine classification in advance of flotation. In this approach, shown in Figure 7, small-diameter hydrocyclones (150-250mm) are used to classify the flotation feed in advance of the columns with a desired cut-point of 35-45 microns. The objective of this circuit is to remove the majority of the ultra-fine clay and/or coal particles prior to flotation. This desliming step benefits flotation by providing a higher carrying capacity. As previously mentioned, carrying capacity is a critical factor with regard to column design and is highly dependent on the size distribution of the clean coal product. Research has shown that coarser and/or higher density solids provide a higher froth carrying capacity. Therefore, removing the ultra-fine coal prior to flotation increases column capacity and, correspondingly, decreases the required number of columns. A coarser froth concentrate will also provide lower product moisture from associated dewatering equipment. The disadvantage of pre-classification is that a portion of the fine, recoverable coal is discarded. The decision as to which circuit best applies is case specific and should be based on final product specifications and total capital cost.

Operating results

Results from an operating minus 100-mesh fine coal flotation circuit are shown in Figure 8. In this application, a maximum product yield of approximately 65-70% is achieved at an average ash content of 7%. Results from two release analysis tests conducted on composite circuit feeds are also shown. These findings clearly illustrate the ability of a properly designed column to eliminate non-selective entrainment. As a result, the column data is in agreement with the release curves. The variation between column performance and the release curve is a result of changing plant feed characteristics. In this application, the column feed ash content varies from 35-47% due to truck haulage from various coal sources. As a result, the maximum product yield and quality can vary. It should be noted that field testing was not possible for this application since it was a green field installation. The final flotation circuit design was based on laboratory testing of core samples and historical data from similar applications.

The current performance of two 4m diameter columns processing a nominal 100 x 325 mesh feed is shown in Figure 9. In this case, pilot tests were conducted using a 0.5m diameter column in combination with a single 15cm diameter Krebs hydrocyclone. A portion of the current thickener feed stream (minus 100 mesh) was diverted to the hydrocyclone and the corresponding underflow was fed directly to the test column. Tests were conducted over a one-week period as a function of solids feed rate and chemical dosage. Samples were collected and analysed to determine a complete material balance for the hydrocyclone / column circuit. The full-scale columns were designed based on these data. The results from the pilot-scale tests and current plant performance are shown in comparison to the release analysis curve in Figure 9. As expected, both the pilot- and full-scale results are in agreement with the release curve. A maximum product yield of nearly 60% is achieved at an average product ash content of 8%.

Conclusion

The information presented in this article clearly illustrates that a successful flotation circuit can be designed using the CoalPro column in combination with proper application of testing and scale-up procedures. Over the past year, three column flotation circuits were commissioned by Eriez and Canadian Process Technologies. In each case, plant performance is in agreement with that predicted using release analysis.

Additionally, this article has highlighted the superior metallurgical performance of column cells as compared to conventional flotation. It should be noted, however, that several other benefits also result from the use of column cells. As previously described, conventional flotation cells suffer from non-selective recovery of fine clays due to entrainment. The ash content of this clay fraction typically exceeds 90%. As a result, every tonne of clay reporting to the froth product contributes nearly an identical amount of ash to the final plant product. Rejection of this material by means of column cells will allow for an increase in ash contribution from other sources. Ideally, this can be achieved by increasing the gravity in heavy media circuits and / or changing splitter settings on spirals. Using this approach, an incremental fraction containing less ash (30-40%) can be added to the final product as opposed to the pure clay component. This approach results in a 2.5 to 3-fold increase in product tonnage at the same ash content.

Rejection of fine clays from flotation products also has a positive impact on dewatering since clays reduce filtration rates. Additionally, the column cells can be configured to provide the maximum yield since product quality is more consistent; i.e., flotation yield does not need to be sacrificed to control product quality. ■

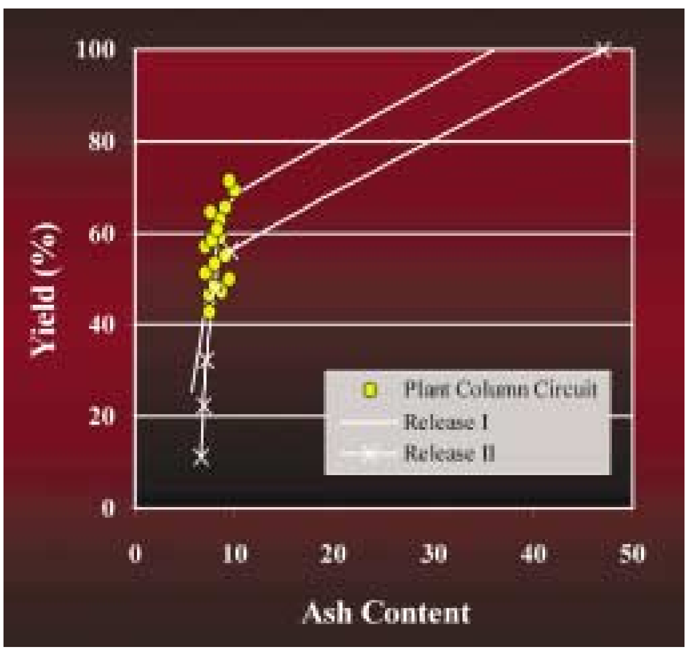

Figure 8. Plant column performance and release analysis for -100 mesh flotation circuit.

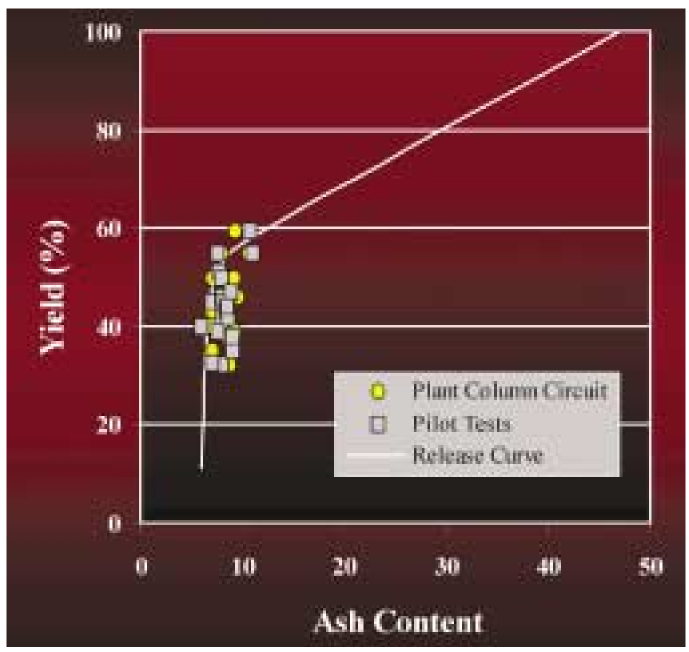

Figure 10. Plant column performance, pilot test results and release analysis for -100 x 325 mesh flotation circuit.