

TESTING OF THE HYDROFLOAT SEPARATOR FOR COAL CLEANING APPLICATIONS

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ABSTRACT

Hindered-bed separators are commonly used for upgrading particles based on differences in specific gravity. Unfortunately, these separators are inefficient when treating a wide particle size distribution. The poor efficiency is normally attributed to the contamination of the high-density underflow by large, low-density particles that are misplaced to the separator underflow. In light of this shortcoming, a novel device known as the Eriez HydroFloat separator was developed. This process combines the many advantages of density-based separators with the flexibility and selectivity of a flotation process. This article describes the theoretical basis for the development of the HydroFloat separator and provides an overview of performance data obtained from recent field trials.

INTRODUCTION

Water-based separators, such as coal spirals and water-only cyclones, have been widely used in the coal preparation industry to upgrade coal feeds in the intermediate particle size range (e.g., 2 x 0.15 mm). Particles of this size are generally too small to be handled in conventional dense medium circuits and too coarse to be efficiently recovered by froth flotation circuits. Unfortunately, water-based separators often provide a lower separation efficiency when compared to other plant circuits. For example, water-only cyclones tend to misplace significant amounts of larger, low-ash coal particles to the reject stream due to the size classification within the cyclone. Spirals are capable of minimizing the rejection of these coarser, low-ash particles due to the buffering action of the flowing film on particle classification. However, spiral circuits generally suffer from high specific gravity cut-points and often misplace larger, high ash material into the clean coal product. As a result, water-based separators are often used in multi-stage circuits in an attempt to deal with misplaced coal or rock.

Another water-based device that is gaining popularity for coal cleaning is the hindered-bed separator. A hindered-bed separator is a vessel in which water is evenly introduced across the base of the separator and rises upward. Solids are typically introduced in the upper portion of the vessel and begin to settle at a rate defined by the particle size and density. The coarse, higher density particles settle against the rising flow of water and build a bed of teetering solids. This bed of high-density solids has an apparent density much higher than the teetering fluid (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. As a result, the low-density component of the feed resists penetrating the bed and remains in the upper portion of the separator where it is transported to the overflow launder by the rising teeter water. Likewise, the high-density component of the feed passes down through the teeter bed and is eventually rejected through an automatic control valve.

Hindered-bed separators, which have traditionally been used for classification, work reasonably well for upgrading coal provided the particle size range and density difference are within acceptable limits (Bethel, 1988; Mankosa et al., 1995; Reed et al., 1995). The major shortcoming of hindered-bed separators is that coarse, low-density particles tend to gather at the interface between the high and low density particles because the teeter water velocity is not sufficient to transport this material to the overflow launder. These particles continue to gather at the bed interface and eventually migrate into the teeter bed, thus reporting with the high-density product. This inherent inefficiency can be partially corrected by increasing the teeter water velocity to convey the coarse, low-density solids to the overflow. Unfortunately, this approach will also cause the fine, high-density solids to be misplaced to the overflow launder resulting in a loss of efficiency. As a result, conventional hindered-bed separators are inherently inefficient when treating feed streams with a wide particle size distribution and/or a narrow density distribution.

To overcome the shortcomings of traditional hindered-bed separators, a novel device known as the *Eriez HydroFloat Separator* was developed. As shown in Figure 1, the HydroFloat unit consists of a rectangular tank

subdivided into an upper separation chamber and a lower dewatering cone. The device operates much like a traditional hindered-bed separator with the feed settling against an upward current of fluidization water. The fluidization (teeter) water is supplied through a network of pipes that extend across the bottom of the entire cross-sectional area of the separation chamber. However, in the case of the HydroFloat separator, the teeter bed is continuously aerated by injecting compressed air and a small amount of frothing agent into the fluidization water. The air is dispersed into small bubbles by circulating the water through a closed-loop configuration with a centrifugal pump. The air bubbles become attached to the hydrophobic particles within the teeter bed, thereby reducing their effective density. The particles may be naturally hydrophobic (e.g. coal) or made hydrophobic through the addition of flotation collectors. The lighter bubble-particle aggregates rise to the top of the denser teeter bed and overflow the top of the separation chamber. Unlike flotation, the bubble-particle agglomerates do not need to have sufficient buoyancy to rise to the top of the cell. Instead, the teetering effect of the hindered bed forces the low-density agglomerates to overflow into the product launder. Hydrophilic particles that do not attach to the air bubbles continue to move down through the teeter bed and eventually settle into the dewatering cone. These particles are discharged as a high solids stream (e.g., 75% solids) through a control valve at the bottom of the separator. The valve is actuated in response to a control signal provided by a pressure transducer mounted to the side of the separation chamber. This configuration allows a constant effective density to be maintained within the teeter bed. In coal applications, the selective attachment of air bubbles makes it possible to recover very coarse, low-ash particles that would otherwise report to the reject stream of traditional hindered-bed separators.

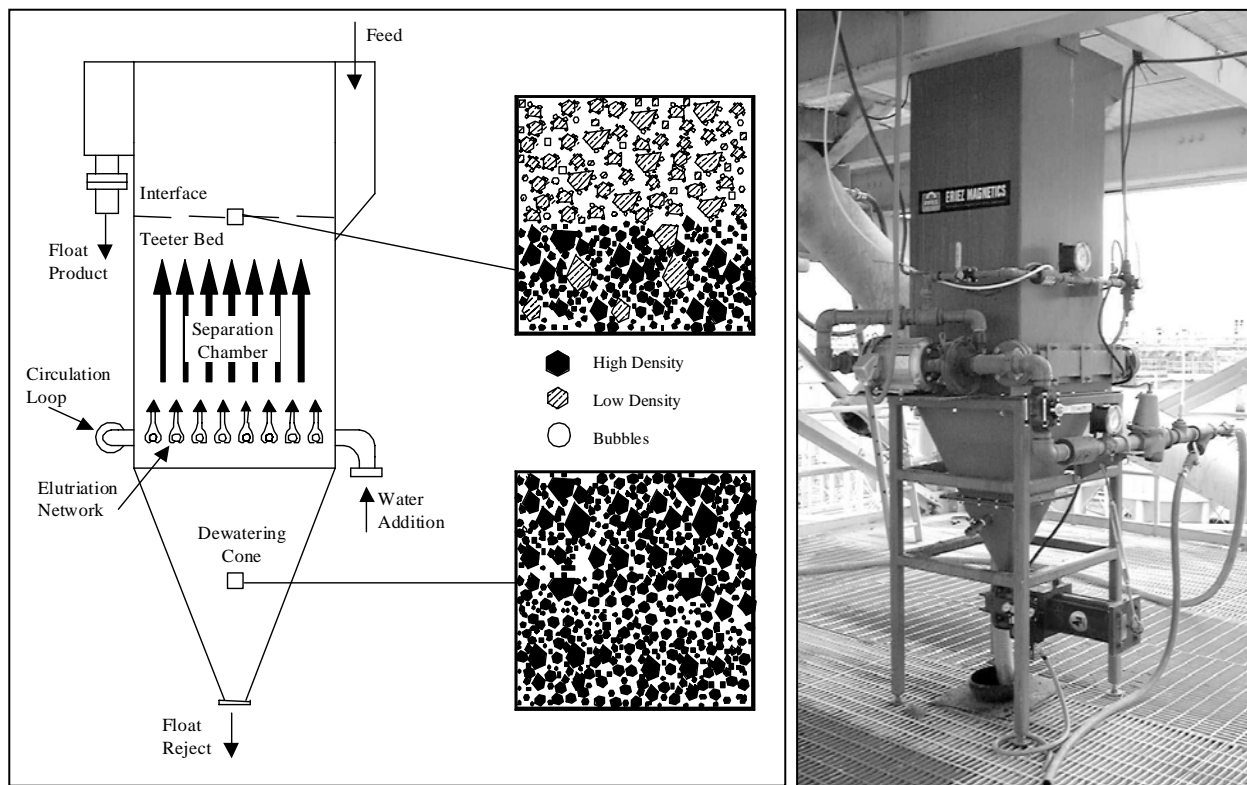


Figure 1. Schematic of the Eriez HydroFloat separator.

HYDROFLOAT ADVANTAGES

Unlike traditional coal cleaning processes, the HydroFloat separator is both a flotation device and a density separator. This unique combination provides several advantages for the upgrading of fine coal. These include:

- **No Buoyancy Limitation:** The use of a teeter bed makes it possible to achieve separations based on small differences between the density of free suspended particles and the density of bubble-particle aggregates. As a result, separations can be achieved even if the buoyancy of the bubble-particle aggregate is too small to lift the aggregate from the surface of the teeter bed. This capability eliminates the buoyancy limitation that often prevents particles coarser than about 0.3-0.5 mm from being recovered in conventional flotation processes.
- **Plug-Flow Conditions:** The HydroFloat cell operates under nearly plug-flow conditions because of the low degree of axial mixing afforded by the uniform distribution of particles across the teeter bed. Consequently, the

cell operates as if it were comprised of a large number of cells in series. Provided that all other conditions are equal, this characteristic allows a single unit to achieve the same recovery as a multi-cell bank of conventional cells (Arbiter and Harris, 1962; Mankosa et al., 1992). In other words, the HydroFloat cell makes more effective use of the available cell volume than conventional processes.

- **Increased Retention Time:** In most processes, feed particles move with the fluid flow towards the discharge point (co-current mode). In contrast, particles move in the opposite direction to the fluid flow in the HydroFloat cell (counter-current mode). The counter-current mode has obvious advantages since the effective settling velocity of the particles is reduced by the upward flow of liquid. In addition, the hindered settling conditions within the teeter bed never allow the particles to achieve their terminal free-fall velocity. Therefore, the fluidization water provides a significant increase in the particle retention time. The longer retention time allows good recoveries to be maintained in a relatively small cell volume.
- **Reduced Turbulence:** According to Barbery (1984), the optimum conditions for coarse particle flotation occur when cell agitation intensity is reduced to a point just sufficient to maintain the particles in suspension. Woodburn (1971) and Schultz (1984) have also shown that reduced cell turbulence significantly increases the maximum particle size limit for effective flotation. The use of fluidization water in the HydroFloat separator makes it possible to keep particles dispersed and in suspension without the intense random agitation required by mechanical flotation machines.
- **Improved Attachment:** The differential velocity between bubbles and particles is greatly reduced by the hindered settling/rise conditions within the teeter bed of the HydroFloat separator. Consequently, the reduced velocity increases the contact time between bubbles and particles, thereby promoting the probability of adhesion and enhancing flotation recovery. This phenomenon is particularly important for coarse particles. The high solids concentration within the teeter bed will also improve recovery by increasing the collision probability between bubbles and particles (Yoon and Luttrell, 198).

PROOF-OF-CONCEPT TESTING

Several proof-of-concept tests were conducted to evaluate the potential of the HydroFloat separator for upgrading various coals. The test unit was fabricated from Plexiglas and had an open area of approximately 0.1 m². The unit was operated with an uninterrupted flow of feed slurry provided by a constant volume feeder. If necessary, the feed ore was reagentized with predefined addition rates of diesel fuel or kerosene collector. An automatic control valve in closed loop with a pressure transmitter was used to adjust the rate of the underflow stream so as to maintain a constant teeter bed level.

Central Appalachian Coal

A sample of run-of-mine coal from central Appalachia was used to evaluate the effectiveness of the HydroFloat separator in treating 2 mm x 0.15 mm coal from an existing spiral circuit. The feed coal was classified to remove the minus 100 mesh fines and conditioned with approximately 0.25 kg/t of diesel fuel to enhance particle hydrophobicity. In the first series of comparison tests, the HydroFloat separator was operated without the addition of air. The separation performance achieved in this mode of operation was identical to that obtained using a traditional hindered-bed separator. In the second series of tests, the HydroFloat was operated with air bubbles added to the teeter bed. In this case, approximately 0.1 kg/t of polyglycol frother was injected into the teeter water to improve air dispersion and minimize bubble coalescence.

Figure 2(a) shows the recovery-ash curves comparing the performance of the HydroFloat and hindered bed separators. For convenience, the data have been reported for both the coarse (plus 50 mesh) and fine (minus 50 mesh) size fractions. As expected, both devices achieved good recoveries (>90%) of the minus 50 mesh material. The HydroFloat separator also produced good recoveries of the plus 50 mesh material. Combustible recoveries in the range of 87-97% were readily attainable over a wide range of operating conditions. In contrast, the hindered-bed separator was not able to achieve recoveries greater than about 75% for the plus 50 mesh material. Attempts were made to improve the recovery of the plus 50 mesh particles by increasing the flow rate of the fluidization water or by raising the level of the teeter bed. However, these attempts generally produced unacceptably high ash products due to (i) short-circuiting of mineral matter into the product launder and (ii) excessive turbulence within the teeter bed. Since more of the feed mass resided in the plus 50 mesh fraction (approximately 60%), the overall performance of the HydroFloat was far superior to that of the hindered-bed separator in treating the overall 2 x 0.15 mm sample. As shown in Figure 2(b), the recoveries obtained for the overall feed with the addition of air were approximately 20 percentage points higher than those obtained without air injection.

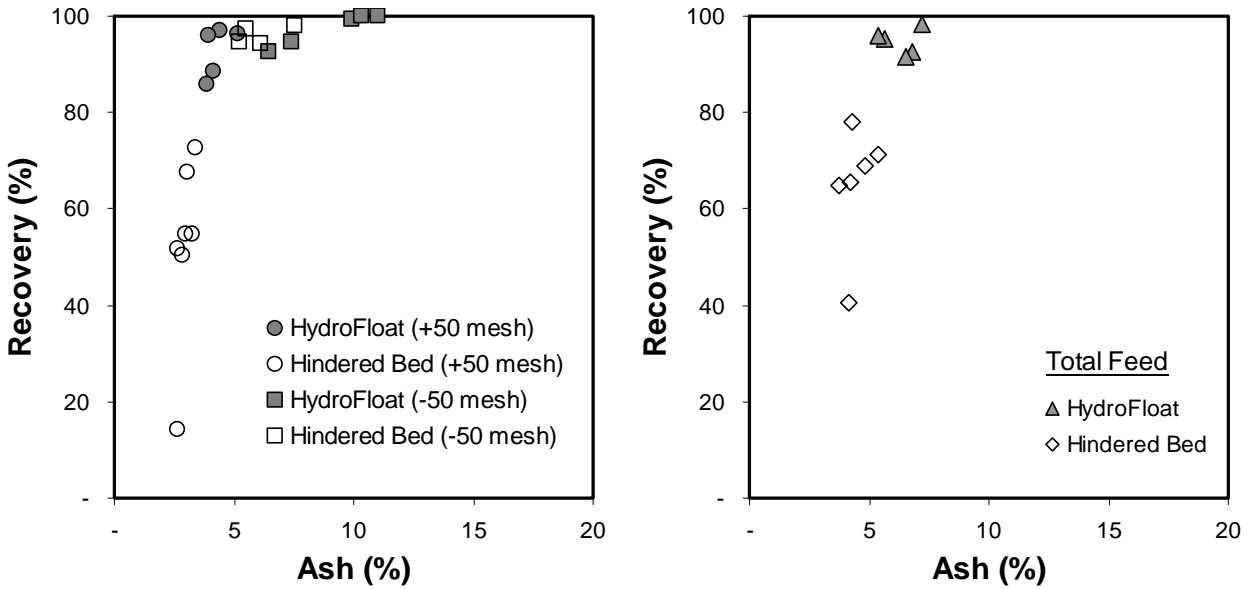


Figure 2. Test results obtained using 2 x 0.15 mm spiral feed from Central Appalachia.

Australian Coal

A tailings sample from a froth flotation circuit in an operating Australian coal plant was obtained for testing in the HydroFloat separator. This circuit currently processes -16 mesh coal and, as a result of flotation inefficiencies when processing coarse material, the tailings contain a great deal of high quality coal in the 16x48 mesh fraction. Traditionally, coal flotation suffers from low recovery above 48 mesh. It was expected that the HydroFloat could recover the coarse material that was currently being lost in the froth flotation tailings. The test objective was to recover as much of the +48-mesh coal as possible. Product contamination by the -48-mesh ash material present in this sample was neglected since the overflow product was to be screened and the resulting screen underflow discarded.

Table 1 provides a summary of the size-by-size weight recoveries and qualities obtained using the HydroFloat separator. As shown, the preliminary data indicate the plus 48 mesh material can be cleaned to an acceptable ash content with a product mass yield approaching 30%. As expected, the ash content of the finer size fractions (below 48 mesh) increased sharply due to the carryover of fine mineral matter. This corresponds to a combustible recovery of greater than 90%. By comparison, tests conducted with a standard teeter-bed separator (without air) provided an average recovery of only 83%

Table 1. Size-by-size HydroFloat results obtained using an Australian coal.

Sample Mesh	Yield (%)		Product Ash (%)
	Per Size Class	Cumulative	
+16	85.0	0.5	8.4
16 x 20	80.4	8.0	13.8
20 x 48	75.8	28.2	16.5
48 x 65	61.4	61.6	21.2
-65	63.3	70.3	25.8

Anthracite Slag

A sample of +20 mesh slag was supplied for testing from a Canadian processing company. This sample, which contained approximately 12% fixed carbon in the form of anthracite coal, was ideally suited for HydroFloat treatment due to the inherent hydrophobicity of the low-density component (anthracite). The slag also contained approximately 30% Fe₂O₃ and 26% TiO₂. The as-received sample was screened at 1/4 inch to remove oversize tramp material prior to testing. The objective of these tests was to recover the remaining fixed carbon at a product quality greater than 80%.

Due to the small amount of available material, only seven tests were conducted on this sample. Four tests were conducted utilizing the lab-scale Hydrofloat with full teeter-bed aeration. The remaining three tests were conducted with the Hydrofloat operating as a traditional hindered-bed separator (i.e., teeter-bed air was turned off). A summary of the operating conditions are shown in Table 2.

Table 2. Conditions used in the testing of anthracite slag.

Test No.	Feed Rate (kg/hr)	Feed Water (lpm)	Teeter Water (lpm)	Aeration (lpm)	Frother (kg/ton)	Diesel (kg/ton)
1	32.7	1.1	7.0	3.0	0.25	0.25
2	32.7	1.1	7.5	n/a	n/a	n/a
3	32.7	1.1	7.0	2.5	0.25	0.25
4	32.7	1.1	7.0	3.0	0.25	0.25
5	32.7	1.1	7.0	n/a	n/a	n/a
6	32.7	1.1	6.5	n/a	n/a	n/a
7	32.7	1.1	7.0	3.5	0.25	0.25

Figure 3 shows the product grade and recovery plot for the 1/4-inch by 28-mesh anthracite slag. Without aeration, the hindered-bed separator was able to make a separation, although a product quality of over 71% fixed carbon could not be achieved. In contrast, a quality of over 80% could be achieved when the teeter-bed was aerated. Aeration allowed the product recovery to be increased by an average of 10-15%, while simultaneously improving the fixed carbon content of the product.

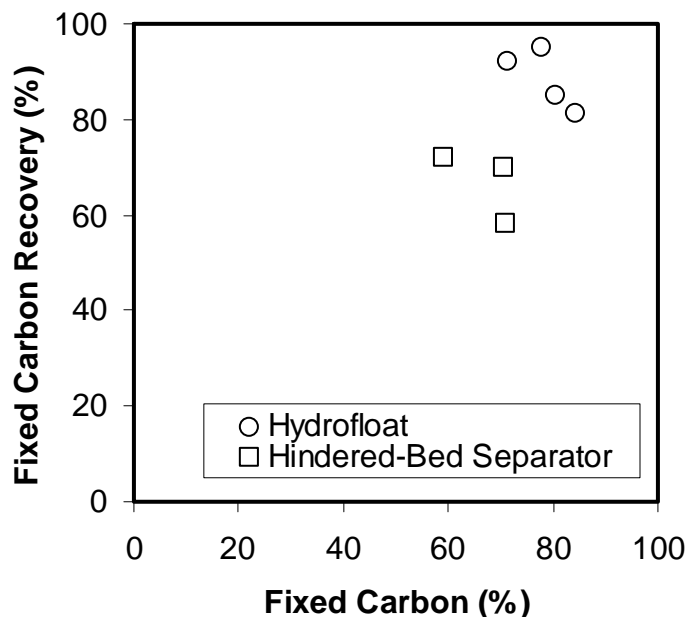


Figure 3. Performance of the Hydrofloat separator for the upgrading of anthracite slag.

SUMMARY

A new concentrator, known as the Hydrofloat separator, has been developed to overcome some of the shortcomings associated with traditional water-based separators. The novel characteristic of this separator is the formation of a hindered "teeter" bed of fluidized solids into which small air bubbles are introduced. The bubbles attach to hydrophobic particles and create light bubble-particle aggregates that can be separated from hydrophilic particles based on the principal of differential density. Benefits of this new separator include enhanced bubble-particle contacting, better control of particle residence time, lower axial mixing/cell turbulence, and reduced air consumption.

Demonstration tests were conducted with a small-scale continuous Hydrofloat unit in order to evaluate the potential of this new technology for the upgrading of different feed coal streams. Samples evaluated to date include coal feeds from central Appalachia and western Australia, as well as a Canadian anthracite slag. The test results indicate that the Hydrofloat cell is capable of increasing coal recoveries by nearly 20% over conventional separation processes. In particular, the HydroFloat separator was capable of substantially improving the recoveries of the coarser particles (+65 mesh) present in the feed streams.

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