APPLICATION OF THE FALCON CONCENTRATOR FOR FINE COAL CLEANING

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ABSTRACT

An enhanced gravity separator (EGS) commercially known as the Falcon Concentrator has been evaluated for its ability to treat fine coal. From a comparison with other EGS technologies, the magnitude of the applied centrifugal force was found to determine the overall separation performance and throughput capacity. Using the relatively high g-forces supplied by a continuous 25-cm diameter Falcon unit, a low density cut point of 1.6 was achieved for the 210 x 37 µm size fraction of a fine coal sample which is significantly lower than that achieved by other EGS units. As a result, ash rejection values between 60% to 75% have been obtained from the treatment of several fine coal samples while recovering greater than 85% of the combustibles, which corresponds to an organic efficiency of about 90%. In addition, the sulfur rejection values achieved on various particle size fractions comprising a -1 mm coal sample were superior to that achieved by a spiral concentrator and a flotation column. Due to an insufficient centrifugal force, the metallurgical performances achieved on the basis of ash rejection for the -37 µm size fraction of all coal samples were insignificant. The ability to achieve efficient, low gravity cut points on fine coal and the operational simplicity of the Falcon Concentrator indicate potential for near term application in coal processing plants.

Key Words:
Fine particle processing; gravity concentration; coal

INTRODUCTION

The need to treat the fine coal streams in today's coal preparation plants is the result of two important trends that have occurred world wide dealing with the production and utilization of coal. The increased use of highly mechanized mining techniques has resulted in the production of larger amounts of fine coal (i.e., - 600 µm), which presently accounts for as much as 20% of the total plant feed. Since clean coal is a low-valued product, production costs must be minimized by maximizing plant yield, which requires the recovery of the fine coal fraction. In addition, more stringent environmental controls are expected to be placed on coal combustion emissions throughout the world. Therefore, the ability of pre-combustion cleaning technologies to reject coal pyrite as well as other toxic elements may decide the fate of many mines extracting medium-to-high sulfur coal.Presently, physical cleaning methods are considered to be the only economical means by which fine coal can be treated. Due to improved liberation, the rejection of sulfur and ash is more easily achieved for the fine coal fraction. Based on the aforementioned trends, it is evident that a highly efficient physical coal cleaning technology is needed to recover the fine coal present in today's coal preparation plants.

Flotation, which is a physico-chemical process, is the most commonly used cleaning technique for fine coal. During the flotation process, the naturally hydrophobic coal particles attach on the surface of the air bubbles and are collected at the top of the cell as concentrate while the hydrophilic particles, such as pyrite and mineral matter, are not attracted by the rising air bubbles and report as underflow tailings. Unfortunately, it has been noted that middling particles containing as little as 5% coal on their surface could be responsible for their floatability as observed in past studies [1]. In fact, Honaker and Reed [2] found that nearly 30% of the heavy middling particles (i.e., sp.gr. between 2.1 and 2.7) reporting in the feed to a flotation column was floated into the froth concentrate. Other studies have found that coal pyrite surfaces are hydrophobic under certain flotation conditions, thereby, reducing the effectiveness of the flotation process in reducing the total sulfur content [3 - 6]. Therefore, it is evident that the froth flotation process as a single cleaning unit does not have the ability to efficiently treat fine coal containing significant amounts of middling and/or coal pyrite particles.

The cleaning of fine coal using processes which rely on bulk property differences, such as density differences, has been found to be more efficient than the separation achieved by froth flotation. By comparing gravity-based washability curves to flotation results, it was found that gravity-based processes were always more efficient at treating coals containing a significant amount of middlings [7, 8]. Therefore, to achieve efficient fine particle cleaning using a continuous process, extensive research efforts have been provided to increase the inertia of fine particles by application of an enhanced gravitational force. These efforts have led to the development of various enhanced gravity concentrators.

The enhanced gravity concentrators that operate continuously and are commercially available include the Multi-Gravity Separator (MGS), the Kelsey Jig, the Knelson Concentrator, and the Falcon Concentrator. Highly efficient rejections of both ash and sulfur from fine coal have been reported for the Knelson Concentrator [9] and the Kelsey Jig [10, 11]. In comparison with single stage treatment using column flotation, Venkatraman et al. [12] found significantly larger reductions in both ash and total sulfur contents by combining column flotation with the MGS unit. However, each of these studies reported relatively high gravity cut points of 1.9 to 2.1 and low throughput capacities, which were most likely due to their inability to provide a centrifugal force greater than 60 times the natural gravitation force [13]. On the other hand, the Falcon Concentrator has the ability to apply a centrifugal force of 300 *g*'s, thereby, allowing lower gravity cut points at relatively high throughput capacities. As a result, Honaker et al. [14] obtained high ash and total sulfur rejections from a semi-continuous Falcon Concentrator on particle sizes down to 10 μm while recovering greater than 90% of the coal.

This publication will present the results from a study which was performed to evaluate the feasibility of the Falcon Concentrator to effectively treat fine coal. The study involved the comparison of the metallurgical performances and throughput capacities obtained from a continuous C10 Falcon unit with that obtained from a continuous 30 cm diameter Knelson unit. In addition, the findings of a comparison with the size-by-size metallurgical results obtained from a spiral concentrator and a flotation column are presented.

EXPERIMENTAL

Falcon Concentrator

The essential feature of a continuous Falcon Concentrator used in this investigation is a 25 cm (10-in) diameter, vertically-aligned, open-topped cylindrical bowl which is mounted on a revolvable shaft as shown in Figure 1. The bowl speed can be adjusted so that up to 300 *g*'s of centrifugal force can be produced to cause deposition and stratification of the fine particles against the inside wall of a smooth centrifugal bowl. The coal slurry is continuously introduced at the bottom of the spinning bowl by means of a conduit extending downwards along the axis of rotation. The slurry is then impelled to the wall of the bowl by an impeller, thereby causing stratification along the inclined lower section of the bowl, called the migration zone, due to differential acceleration. In this zone, the enhanced gravity field generated by the spinning bowl is resolved into two force components. The strong force component normal to the wall is the concentrating gravity force that allows the hindered settling processes and stratification of the particles in the feed according to, primarily, density and, secondarily, particle size. The weak driving component parallel to the wall of the bowl pushes the stratified solids up toward the top of the bowl. During the upward movement, heavy particles and coarse, light particles continue to form a bed on the bowl surface with the heavy particles forming a layer nearest the bowl wall, while the clean coal and coal-rich middling particles form the particle layers the farthest from the bowl wall. The friction between settled particles and the wall of the bowl results in different vertical velocities for the particles in different layers.

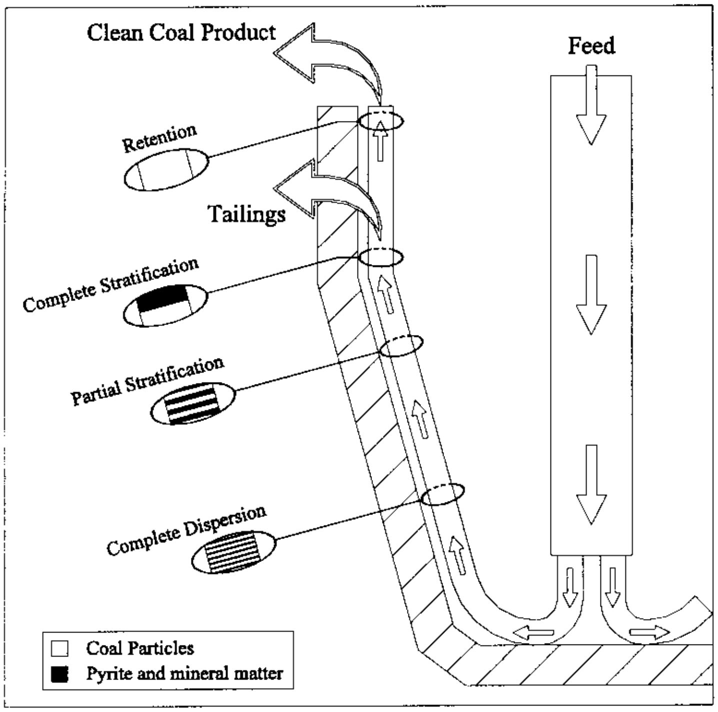

Fig. 1 A schematic illustration of the operating principles of the continuous Falcon Concentrator.

The upper part of the bowl, called the retention zone, is parallel to the axis of rotation. As a result, there is no weak driving force component to push particles upward toward the top of the bowl. Also, an overflow lip that has an internal diameter less than the bowl diameter restricts the particle bed from reporting to the overflow. The combination of the lack of a vertical force component and the presence of an overflow lip causes the heavy pyrite and ash-bearing particles to come to rest while the centrifugal force that is normal to the bowl wall assists the heavy particles into a slot that exists around the circumference of the bowl. Mass transport chutes and 12 pinch valve-nozzle assemblies placed at equal distances in the slot allow discharge of the heavy particles into an underflow launder. The underflow rate through the nozzles can be controlled by fluctuating the air supply to the pinch valves on an on-off basis through a central control unit. At the same time, light particles forming the particle bed furthest from the bowl wall move upward and over the overflow lip of the bowl using the momentum accumulated in the migration zone and the force of the upward flowing water film. These light particles report as final product with other particles that are too fine to be effected by the enhanced gravitational force.

Test Sample

The coal sample used in the majority of the tests was collected from the fine circuit feed stream (i.e., -1 mm) of a coal preparation plant treating the Illinois (Herrin) No. 5 seam coal. To prevent plugging of the Falcon underflow nozzles, the sample was fed through a 600 µm screen. Size-by-size and washability analysis data for the screen underflow material is provided in Table 1. As shown, the coal sample can be classified as an "easy" to "moderately difficult" coal to clean as indicated by the 8.6% mass weight existing in the intermediate gravity fractions (i.e., 1.6 x 2.0). The product ash and total sulfur content of the sample was found to be 36.45% and 2.97%, respectively.

The feed, product and tailing samples were wet-screened to obtain the size-by-size data presented in this publication. Ash and total sulfur analyses were conducted using ASTM procedures. Due to the fine particle sizes, the centrifugal washability procedure was used on all size fractions [8].

TABLE 1. Size-by-size and washability analyses data obtained for the Illinois No. 5 fine coal sample.

Size Fraction (µm)	Weight (%)	Ash (%)	Total Sulfur (%)	Gravity Fraction	Weight (%)
+600	3.49	20.03	3.18	-1.30	43.55
600 x 300	19.90	21.67	3.20	1.30 x 1.40	18.26
300 x 210	9.71	22.70	3.27	1.40 x 1.50	8.74
210 x 150	6.51	20.65	3.85	1.50 x 1.60	4.94
150 x 37	25.89	21.40	4.20	1.60 x 1.75	3.91
-37	34.50	64.78	1.64	1.75 x 1.90	2.94
				1.90 x 2.00	1.71
				+2.00	15.95
Total	100.00	36.45	2.97		100.00

Experimental Procedure

Prior to each test, four 210 liter (55 gallon) drums of coal slurry were placed in the feed sump where the feed solids content was adjusted to the desired value, which was typically 16% by weight. During the tests, the Falcon unit was fed from a split stream on a recirculation loop that transported material from the bottom of the feed sump to its top. The feed rate was adjusted using valves located on the recirculation line. The Falcon unit was mounted slightly above the feed sump so that the overflow (product) and underflow (tailings) streams could return to the feed sump by gravity. Due to the closed-loop system, particle size degradation was monitored by periodic screening of a feed sample. If significant particle size reductions were realized, a fresh sample was added to the sump and the test(s) repeated. After allowing sufficient time for the process to reach steady-state, samples of the feed, product, and tailing streams were collected in short incremental time periods for approximately 5 minutes.

The metallurgical performance achieved by the Falcon Concentrator was compared to that obtained from a 30-cm (12 in.) diameter continuous Knelson Concentrator, which is also an enhanced gravity concentrator [15]. The Knelson unit utilizes rinse water that is forced through perforations in a spinning bowl to create a fluidized bed. Particles that settle through the fluidized bed under a maximum centrifugal force of 60 *g* are withdrawn through underflow valves while the remaining particles report to the overflow. The Knelson Concentrator was operated in the same closed-loop system as the Falcon. However, due to the addition of fluidization water, a 10-cm diameter Krebs cyclone was used to remove an equivalent amount of water from the recirculating feed stream.

Additional metallurgical performance comparisons were performed using an MDL LD-9 spiral and a Packed-flotation column. The spiral was fed at a mass rate of 3.3 tonne/hr using a solids concentration of 35% by weight. The Packed-Column was 10 cm in diameter and 5 m tall. Froth washing and a relatively deep froth depth of 2 m were used to prevent hydraulic entrainment. The operating conditions providing the maximum separation efficiency, which was determined through a series of tests, were used for both the spiral and flotation column to obtain the metallurgical performances used for comparison with those achieved from the Falcon unit.

RESULTS AND DISCUSSION

Metallurgical Performance

Experimental programs based on a statistical design were conducted on both the Falcon and Knelson Concentrators to evaluate the effect of the operating parameters and to identify the optimum separation performances. A total of 27 experiments were conducted on both units over a range of feed volumetric flow rates, feed solid contents, opening and closing times of the underflow discharge valves, and fluidization water flow rates. A comparison of the metallurgical results obtained as a function of ash rejection are provided in Figures 2 (a) and (b). For the 600 x 210 μm size fraction, the Knelson unit provided a slightly superior separation performance. A 75% rejection in ash content by the Knelson resulted in a reduction in ash content from about 21% to 8% while recovering 85% of the combustible material. This performance equates to a 90% organic efficiency when compared to the theoretical performance predicted from feed washability data. However, for the 210 x 37 μm size fraction, the Falcon unit provided a better separation performance as shown in Figure 2 (b). This finding is likely due to the significantly higher centrifugal forces applied by the Falcon unit (i.e., 300 versus 60 *g*). In fact, an approximately equal separation was achieved by the Falcon on the 210 x 37 μm fraction as was obtained by the Knelson on the 600 x 210 μm fraction. On the other hand, the ash rejection achieved on the -37 μm size fraction was negligible for both units due to an insufficient centrifugal force.

Both the Falcon and Knelson units were found to achieve nearly perfect separations in terms of total sulfur rejection when compared to the theoretical washability curve. However, as shown in Figures 3 (a) and (b), the Falcon unit provided a slightly superior rejection of sulfur, especially for the 210 x 37 μm size fraction. As shown in Table 2, the pyritic sulfur content for the 210 x 37 μm size fraction was reduced in a test from 3.04% to 0.66%, which equates to a rejection of nearly 85%, while achieving a combustible recovery of about 84%. Almost 100% of the pyritic sulfur was removed from the 210 x 37 μm size fraction by increasing the underflow rate to relatively large values which produced a 1.31% total sulfur content in the concentrate; however, the combustible recovery was a relatively low 44%. The ability to effectively reject coal pyrite in the fine size fractions represents an improvement over current plant practices which utilize mostly froth flotation to treat the fine coal. The nearly ideal rejection of total sulfur was expected due to the large density difference between the coal (i.e., 1.3) and the coal pyrite (i.e., 4.5) particles.

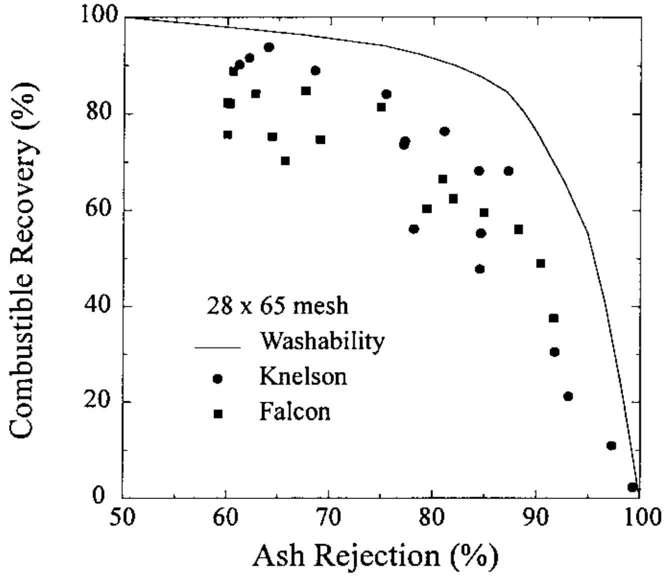

Fig. 2a Comparison of the metallurgical performance results achieved on the basis of ash rejection by the Falcon and Knelson concentrators from the treatment of the 600 x 210 μm size fractions of the Illinois No. 5 fine coal sample

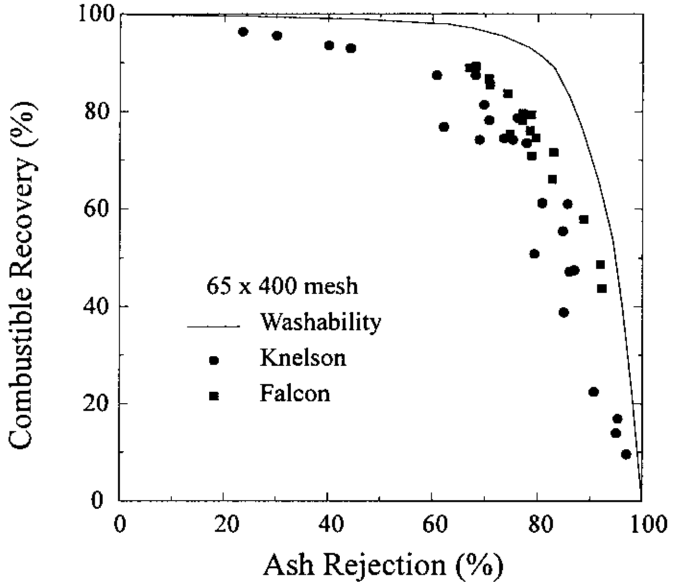

Fig. 2a Comparison of the metallurgical performance results achieved on the basis of ash rejection by the Falcon and Knelson concentrators from the treatment of the 210 x 37 μm size fractions of the Illinois No. 5 fine coal sample

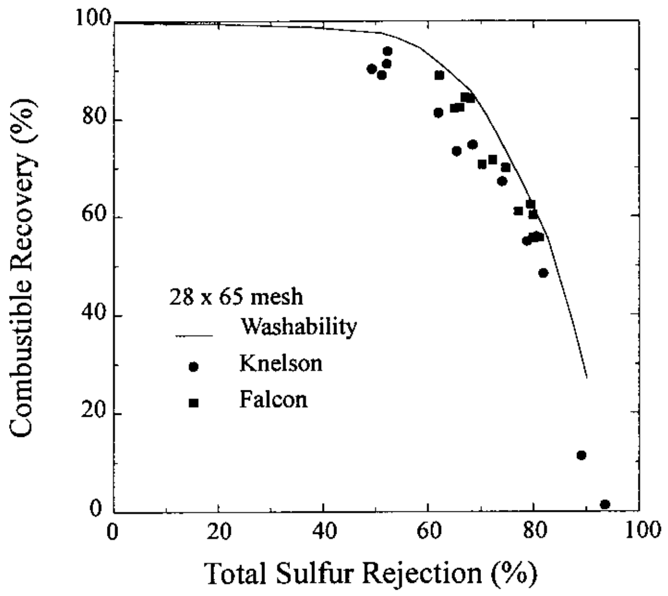

Fig. 3a Comparison of the metallurgical performance results achieved on the basis of total sulfur rejection by the Falcon and Knelson concentrators from the treatment of the 600 x 210 μm size fractions of the Illinois No. 5 fine coal sample

Although the Knelson Concentrator achieved comparable metallurgical performances, its ability to sustain the high separation performance is limited to relatively low volumetric feed flow rates. Figure 4 shows a comparison between the separation efficiency values achieved as a function of volumetric feed flow rate by the Falcon and Knelson units. In this case, separation efficiency is equal to the difference between the recovery of combustibles and ash-forming material to the product. For both size fractions, the separation performance provided by the Knelson unit improves when the feed rate is increased from 0.2 L/s to 0.6 L/s, which is due to an improvement in the recovery of the coarse coal particles. However, a further increase in feed flow rate sharply reduces the separation performance as a result of a reduced particle retention time which causes a significant amount of high-ash content particles to by-pass to the overflow (product) stream. On the other hand, the separation performance achieved by the Falcon reached a maximum value at 1.2 L/s and remained relatively constant with further increases in the feed flow rate for both size fractions. It should be noted that the Falcon unit effectively treated higher feed flow rates despite the fact that the Falcon unit was smaller in diameter (i.e., 25 cm versus 30 cm) than the Knelson concentrator.

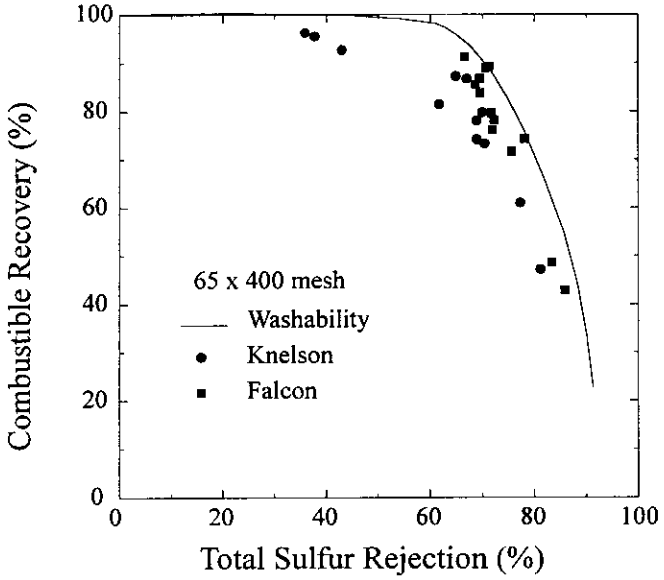

Fig. 3b Comparison of the metallurgical performance results achieved on the basis of total sulfur rejection by the Falcon and Knelson concentrators from the treatment of the 210 x 37 μm size fractions of the Illinois No. 5 fine coal sample

TABLE 2 Results obtained from the treatment of a pyrite-rich 210 x 37 μm size fraction of an Illinois No. 5 coal sample using the Falcon Concentrator; feed ash content = 21.7 % and feed pyritic sulfur content = 3.04%.

Test Number	Ash		Pyritic Sulfur		Ash Rejection (%)	Pyritic Sulfur Rej. (%)	Combustible Recovery (%)
	Product (%)	Tailings (%)	Product (%)	Tailings (%)			
1	8.99	63.6	0.74	9.18	68.2	82.3	89.2
2	7.84	55.8	0.66	8.60	74.3	84.8	83.7
3	6.91	51.3	0.52	7.46	78.7	89.1	79.3
4	6.17	44.7	0.30	6.31	83.0	94.6	71.6
5	4.69	31.2	0.29	3.73	92.2	98.1	43.7

The ability of the Falcon to treat substantially higher feed flow rates is due in part to the significant difference in the applied centrifugal force. Since both devices utilize a rotating truncated cone, their separation performance is limited by the ability of the heavy particles to settle to the bowl wall during the provided retention time. Increasing the feed rate reduces the particle settling time and, thus, to maintain a high separation performance, a higher centrifugal force is needed to increase the settling kinetics. As shown in Figure 5, increasing the centrifugal field beyond a value of 70 *g* in the Falcon unit has a negative impact on the 600 x 210 μm size fraction but a positive impact on 210 x 37 μm fraction. In fact, an optimum centrifugal force of 50 *g* was found for the 600 x 210 μm fraction whereas a higher optimum value of 125 *g* was realized for the 210 x 37 μm fraction. Below the optimum value, a portion of the ash-forming particles report to the overflow product and the recovery of combustibles is high. On the other hand, coarse coal particles are lost to the underflow tailings stream when the centrifugal force is increased beyond the optimum value. Thus, volumetric feed flow rate and the magnitude of the applied centrifugal force are dependent operating variables which combine to control the overall separation performance.

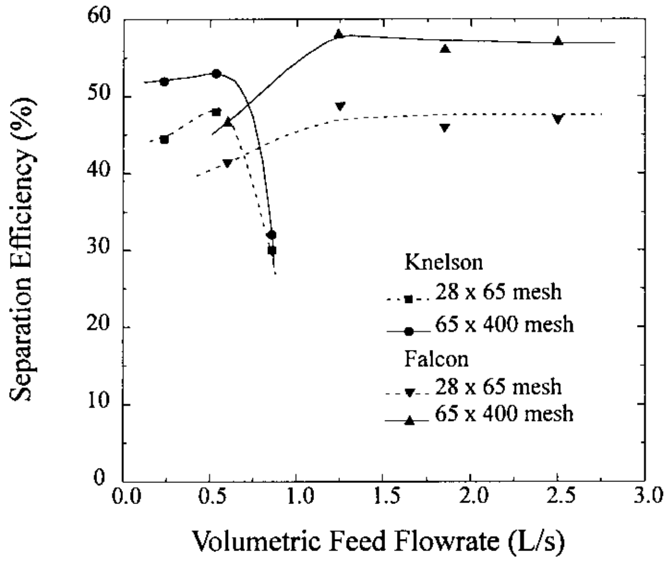

Fig. 4 Experimental results obtained from the Falcon and Knelson concentrators showing the effect of volumetric feed flow rate on separation efficiency (= combustible recovery - ash recovery); Falcon *g*-force = 130.

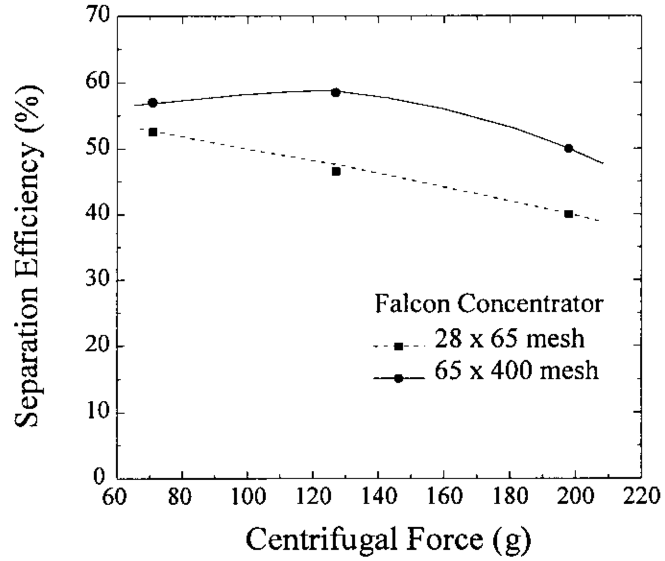

Fig. 5 Experimental results obtained from the Falcon Concentrator showing the effect of the applied *g*-force on separation efficiency (= combustible recovery - ash recovery); feed solids = 16% by weight, volumetric feed flow rate = 1.26 L/s.

Figure 6 shows a comparison of the separation efficiency values obtained as a function of particle size from the Falcon Concentrator, a MDL LD-9 spiral, and a Packed-Column. The nominally -1 mm Illinois No. 5 coal sample that was fed to the three units was pre-treated in a hindered-bed hydrosizer to scalp out the coarse, heavy particles. The spiral was found to provide 5% to 10% greater recovery of the coarse coal particles (i.e., > 600 μm) while the Falcon provided a better reduction in the product ash content by 2 to 3 weight units or percentage points. However, the larger centrifugal field provided by the Falcon unit, which was 70 *g* in this test, allowed effective treatment over a relatively large particle size range of 12:1 as compared to the 6:1 for the spiral. In fact, the effective particle size range for the Falcon bridges the gap between the separation performance provided by the spiral and the Packed-Column. Tests have indicated that the particle size range effectively treated by the Falcon unit can be shifted to lower particle sizes by increasing the centrifugal field which will allow an increased cleaning efficiency for particle sizes in the flotation range. However, this action would result in the loss of coarse coal particles, e.g., > 210 μm, to the tailings stream.

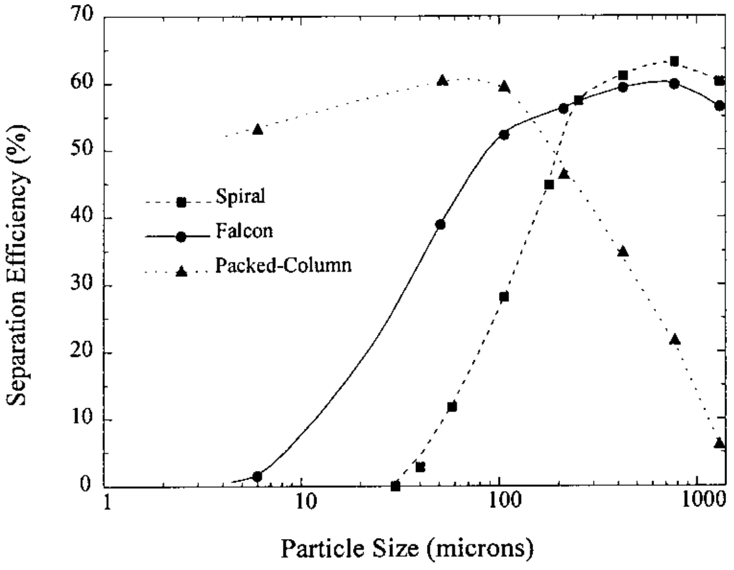

Fig. 6 A comparison of the size-by-size separation efficiency values achieved by the Falcon, MDL spiral, and Packed-Column.

The Falcon Concentrator was found to generate the lowest product sulfur contents over the entire range of particle sizes studied although the values were nearly equivalent to the spiral results obtained for particle sizes greater than 300 μm. As shown in Figure 7, a gradual increase in the product sulfur content was obtained with decreasing particle sizes due to the declining effect of the centrifugal force. Due to the inefficiency of the froth flotation process to treat middling particles and the fact that coal pyrite tends to be hydrophobic, the product sulfur contents achieved by the Packed-Column remained higher than those from the Falcon, even in the finest particle size fractions.

The test results shown in Table 3 summarize some of the typical separation performances achieved from the treatment of various coal samples using the C10 Falcon Concentrator. The results indicate that the Falcon concentrator has the ability to significantly reduce the ash content of the 600 x 37 μm size fraction while achieving very high combustible recovery values of greater than 90%. These results were obtained at relatively high mass throughput values ranging from 16 to 43 tonne/hr/m^2 (1.7 - 4.4 stph/ft^2). The high recovery values achieved for the 600 x 150 μm size fraction indicate the ability of the Falcon unit to selectively withdraw ash-bearing particles from the inner portion of the solids bed through the underflow valves while allowing the outer portion containing the coarse and fine coal particles to by-pass to the overflow. Significant ash rejection values were achieved on the 600 x 150 μm size fraction by the Falcon unit while recovering nearly 90% of the combustibles. However, applied centrifugal forces as high as 300 *g* were insufficient for rejecting the ash-bearing material having a particle size less than 37 μm as shown by the low ash rejection values in Table 3. This indicates that either a desliming device or a flotation column would be needed to reject the sub-micron clay particles from the Falcon overflow, thereby, producing a final -600 μm clean coal product.

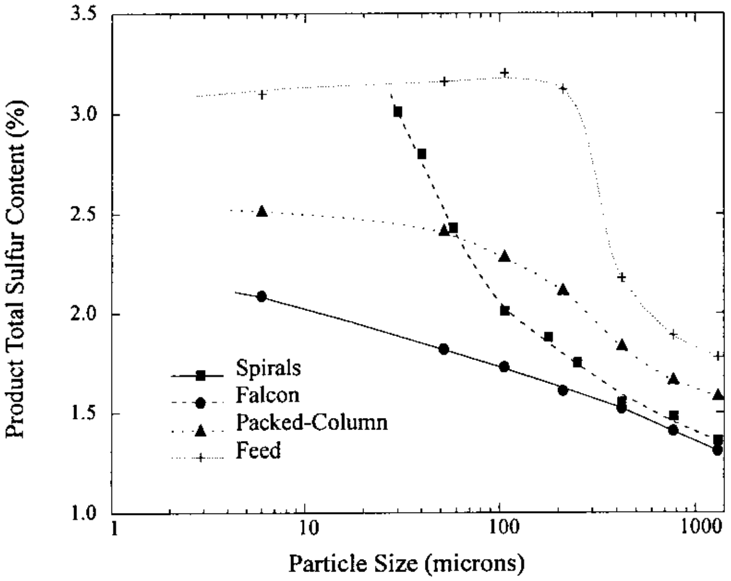

Fig. 7 A comparison of the size-by-size product total sulfur contents obtained from the treatment of the Illinois No. 5 coal sample by the Falcon, MDL spiral, and Packed-Column.

TABLE 3 Metallurgical performance results obtained on a size-by-size basis from the treatment of various coal samples by the continuous Falcon concentrator using an applied centrifugal force of about 130 *g*.

Sample	Size (μm)	Ash (%)			Ash Rej. (%)	Recovery (%)	Throughput (tonne/hr)
		Feed	Product	Tailings			
Illinois No.5 (S1)	600 x 150	9.88	7.05	54.7	32.9	97.0	1.90
Flotation Feed	150 x 44	17.6	8.30	79.3	59.1	96.7	
	-44	53.7	53.3	80.9	2.13	99.4	
Illinois No.6	600 x 150	4.47	3.66	11.5	26.6	90.4	1.15
Flotation Feed	150 x 44	8.48	3.97	38.8	59.2	91.3	
	-44	62.4	61.3	89.0	5.59	98.9	
Illinois No.5 (S2)	600 x 150	7.92	6.21	52.4	24.5	98.1	0.83
Flotation Feed	150 x 44	12.8	7.33	66.3	48.1	96.4	
	-44	54.3	52.7	76.2	4.04	98.6	
Illinois No. 6	600 x 150	22.3	13.7	58.0	50.6	89.5	1.90
Refuse Pond	150 x 37	34.1	24.6	74.9	41.5	92.8	
	-37	55.6	54.5	81.8	5.93	98.3	
Pittsburgh No. 8	1000 x 210	13.7	7.35	58.8	53.0	94.1	2.20
Flotation Feed	210 x 37	15.5	5.02	68.8	72.9	93.9	
	-37	47.6	46.1	76.8	7.89	97.8	
Pittsburgh No.8	1000 x 210	19.1	8.70	67.5	62.5	92.9	2.00
W-O-C Feed	210 x 37	18.4	11.0	64.2	48.5	93.9	
	-37	59.9	59.1	67.5	10.7	92.3	

Process Efficiency

The efficiency of a gravity-based process is typically measured by the partition curve which, for fine particles, is generated from the data obtained from centrifugal washability analysis [8] of samples collected from the process streams. Figure 8 shows the size-by-size partition curves generated from the treatment of the Illinois No. 5 coal sample using the Falcon Concentrator. At a relatively low centrifugal force of 72 *g*, the specific gravity cut point (D_{50}) decreases from about 1.8 for the 210 x 37 μm size fraction to 1.6 for the +300 μm size fraction. Over the same particle size range, the probable error (E_p) value increases from 0.15 to 0.20, which equates to a decline in process efficiency with an increase in particle size. These trends indicate the method by which the particles of varying size and density form the particle bed located adjacent to the bowl wall in the Falcon unit. Coarse particles are distributed throughout the bed with nearly all of the heaviest particles reporting to the bowl wall and the underflow discharge ports. Although a majority of the coarse, light particles report to the overflow product, a significant portion is trapped inside the bed and reports to the underflow tailings stream. On the other hand, particles in the 210 x 37 µm size fraction that are significantly affected by the applied centrifugal field tend to segregate according to density in a more efficient manner. However, heavy ultrafine particles tend to be by-passed to the overflow stream due to an insufficient centrifugal force as indicated by the near 10% recovery value for the 2.3 specific gravity particles (Figure 8).

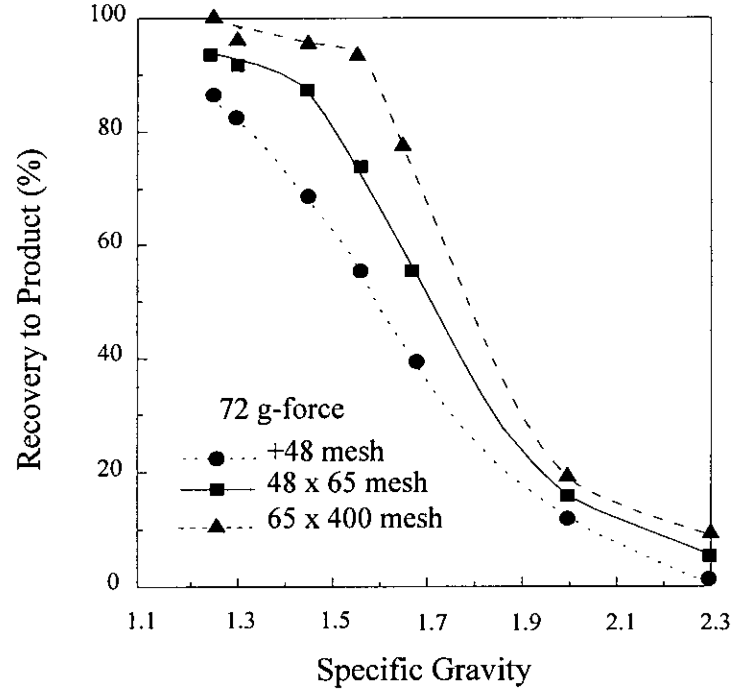

Fig 8. Size-by-size partition curves produced from the treatment of a nominally -600 µm Illinois No. 5 fine circuit feed sample using the Falcon Concentrator; feed flow rate = 1.26 L/s, feed solids content = 16% by weight.

From the partition curves in Figure 9, increasing the applied centrifugal field improves the ability of the Falcon Concentrator to treat the ultrafine particles as indicated by the decrease in the by-pass of heavy particles. The magnitude of the centrifugal field also has a significant effect on the D_{50} and E_p values achieved from the treatment of 210 x 37 µm size fraction. The D_{50} decreased from 1.8 under a 72 *g*-field to a relatively low 1.50 for a 199 *g*-field. A minimum E_p value of 0.10 and, thus the maximum process efficiency was achieved using a centrifugal force of 127 *g*, which is equivalent to the value corresponding to the maximum separation efficiency value previously shown in Figure 4.

CONCLUSIONS

The C10 Falcon Concentrator was found to efficiently reduce the ash and total sulfur contents of fine coal. Maximum separation performance was achieved for 210 x 37 μm size fraction from which 70% of the ash and total sulfur were removed while recovering nearly 90% of the combustibles from an Illinois No. 5 coal sample. Similar results were obtained from the treatment of several coal samples originating from the Illinois No. 5, Illinois No. 6 and Pittsburgh No. 8 coal seams.

The excellent metallurgical performances achieved on 210 x 37 μm coal at relatively high throughput capacities up to 2.2 tonne/hr were due to the ability of the Falcon Concentrator to provide relatively high centrifugal forces. A comparison of the separation performances obtained from the Falcon and Knelson concentrators revealed that the separation efficiency provided by the Knelson was comparable to the Falcon at volumetric feed flow rates less than or equal to 0.6 L/sec. However, the separation performance achieved by the Falcon unit was superior for feed flow rates greater than 0.6 L/sec. In fact, the separation efficiency obtained for the particle size fractions between 600 and 37 microns by the Falcon Concentrator remained relatively constant through a feed flow rate of 2.5 L/sec. This finding is due to the fact that the higher centrifugal force supplied by the Falcon unit: 1) enhances the settling kinetics of the particles thereby counteracting the reduction in particle residence time caused by the increase in volumetric feed flow rate and 2) provides a lower specific gravity cut point for the ultrafine particle sizes.

The high centrifugal forces resulted in gravity-cut points (D_{50}) as low as 1.5 for the 210 x 37 μm size fraction. The low gravity-cut points combined with E_p values between 0.10 and 0.15 explain the high efficiency separations achieved from the treatment of the 210 x 37 μm size fraction. A comparison with the results obtained from an MDL-LD9 spiral revealed that the efficiency of the Falcon was slightly inferior for the treatment of particle sizes greater than 300 μm. However, the Falcon provided effective treatment over a much broader range of particle sizes (i.e. 12:1 versus 6:1) and at smaller particle sizes (i.e., down to 37 μm) . In fact, the Falcon Concentrator appears to bridge a particle size gap in separation performance that exists between the decline in the performance of the spiral and the increase in the efficiency of a froth flotation device, such as the Packed-Column, when the particle size is decreased.

Although the Falcon Concentrator has the ability to provide a centrifugal field as high as 300 *g*'s, the ash rejection values achieved on the -37 μm size fraction were insignificant. These findings indicate that a desliming device or a flotation technology will be needed to produce a final clean coal concentrate from the Falcon product.

The excellent separation performances achieved on the 600 x 37 μm size fraction by the Falcon Concentrator and its operational simplicity indicate potential for near term industrial application for the treatment of fine coal. Coal preparation plants processing high sulfur coal may find the Falcon unit to be more effective and cost efficient than currently used technologies, such as conventional flotation, for rejecting the coal pyrite and ash-bearing particles. Fine coal containing significant amounts of finely-disseminated ash-bearing material, such as the Gondwana coal in the southern hemisphere, may be more effectively treated by the Falcon Concentrator. In addition, treatment using an enhanced gravity concentrator may be the only method by which fine oxidized coal can be economically recovered. The results from a test program being conducted on an industrial-size Falcon unit having a capacity of about 100 tonne/hr will be reported in a future publication.

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