Coal Preparation, 22: 323–341, 2002
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0734-9343/02 $12.00 + .00
DOI:10.1080/07349340290018983

An Evaluation of the Alpha Prototype MagMill™ for Dry Coal Cleaning

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This paper describes the construction and performance of an alpha prototype MagMill™ processing bituminous coal at 90 kg/hr. The prototype consists of an air-swept hammermill, which has been modified for withdrawal of a continuous stream of hard material separated from its internal circulation. The mineral-rich stream is sent to an attached ParaMag™ magnetic separator for rejection of paramagnetic minerals. The magnetically cleaned stream is returned to the pulverizer for grinding to specification, thus lowering the ash and sulfur of the mill product. Raw Upper Freeport, Clarion, and Lower Kittanning seam coals from North Central Pennsylvania were used for calibration and illustration of performance. Reductions in sulfur concentration (kgSulfur/MJ) ranged from greater than 22.5% to 40%, with heat recoveries ranging from 89.9% to greater than 99% for the series of test runs.

Keywords Magnetic separation; Grinding; Trace elements; Sulfur

There have been many attempts [1, 2] to apply the technology of magnetic separation to the separation of mineral impurities from coals of various ranks. However, with the exception of recovery of magnetite in dense medium wet cleaning of coal, there have been no commercial

Received 15 July 2002; accepted 1 November 2002.

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applications. The primary driving force behind these efforts has been the paramagnetism of ferruginous minerals and especially iron pyrite, which accounts for typically one-half of the sulfur in bituminous coals of the United States. The hydrocarbon components of coal are basically diamagnetic with specific susceptibility about -0.6×10^{-9} m^3/kg, while the paramagnetic susceptibility of neat iron pyrite is nominally $+ 0.33 \times 10^{-9}$ m^3/kg. This value is small when compared to that of a mineral such as siderite, Fe_2CO_3, which has a susceptibility about 150×10^{-9} m^3/kg and which is easily separated from coal and other minerals using conventional magnetic separation technology. Nonetheless, it is easy to demonstrate on a laboratory scale that modern magnetic separators can separate iron pyrite, but it is considerably more of a challenge to demonstrate the commercial feasibility of application because of the large range of magnetism of minerals in coal and the high cost of magnets.

The benefits of efficient separation of minerals from coal are many. Out-of-seam rock is removed at the mine to lower transportation costs. The in-seam minerals, which are more difficult to separate because of the very broad particle size distribution in which they occur in coal, carry a significant portion of the sulfur in coal and almost all of the trace metals, including mercury and arsenic. Efficient precombustion cleaning delivers more heat to the burner per kilogram of coal and lessens slagging and fouling problems, all of which is of great value to the coal-fired power generating station. The high cost to the Tennessee Valley Authority (TVA) of burning raw coal was pointed out by Phillips and Cole [3] in 1980 and played a large role in causing utilities to switch to cleaned coal in the years since. Cole made a compelling argument for burning cleaned coals by developing statistical relationships between such factors as forced-outage-ratio and the ash and sulfur levels in the coals which TVA was burning. This was prior to the onset of sulfur and nitrogen oxide emission controls, which have further exacerbated the effects of coal minerals on power plant operation. The hazardous air pollution precursor, mercury, is closely associated with the iron pyrites in coal [4–6]. The cost for an 1100 MW plant to remove 90% of the mercury supplied to the burner using activated carbon will be about $15 million per year when burning a coal containing 4.3 kg mercury per kJ, a level typically found in bituminous coals of Northern Appalachia. Practical precombustion separation of iron pyrites more effectively than can be achieved with wet coal cleaning at the mine is a very attractive opportunity. The place to do this is at the coal-fired power plant where the coal is pulverized to 70–80% finer than 74 microns to improve coal combustion characteristics. Here, the mineral liberation is much more complete than can be practically achieved at the mine because of the high cost of dewatering the fine coal.

THE MAGMILL^{TM}

Recently, a new effort has been undertaken to apply magnetic methods to cleaning coal [7]. This method, called a MagMill^{TM}, attaches a dry magnetic separator to the pulverizer at the front end of a coal-fired power station. In this approach, a stream of highly concentrated minerals is withdrawn from the pulverizer and sent to the magnetic separator for rejection of the mineral gangue and for recovery of the carbon, which is inadvertently withdrawn from the mill. The magnetic separator separates the coal-rich fractions from the minerals on the basis of their magnetism. The "cleaned coal fractions" recovered by the magnetic separator are returned to the pulverizer for grinding to specification.

This method has several advantages over previous attempts at applying magnets to coal cleaning. First, in the MagMill^{TM} approach, the pulverizer is an integral part of the coal cleaning operation. The pulverizer selectively classifies the material inside on the basis of density and grindability. The minerals iron pyrite and quartz, for example, are much harder than the hydrocarbon fractions of the coal and do not grind as rapidly. Consequently, they are concentrated in selective streams circulating inside the pulverizer. Secondly, in the MagMill^{TM} approach, the concentrated material is withdrawn from this stream and sent to the magnetic separator. Because of the mineral concentration in this stream, it contains less heat content per pound compared to the feed to the pulverizer. Additionally, the rate of withdrawal of this stream is typically one-third to one-half the rate of feed to the pulverizer. Consequently, the size of the magnet needed to achieve the same effect as a magnet treating the full stream, either on the input to the pulverizer or on its output, is smaller, leading to a softening of the effect of the high capital cost of magnets on the cleaning process. This technology offers a very efficient way to apply magnetic separation to cleaning of coal. It cleans coal at finer sizes than are possible at the mine, is dry, has no transportation or storage problems, reduces abrasive wear in the pulverizer by removing hard and abrasive minerals from the pulverizer before they are overground, and, lastly, uses no additives.

Several papers [8] have been published showing the results of processing coals with a 1360 kg/hr prototype MagMill^{TM} and of feasibility testing of in-plant pulverizers at several coal-fired plants in the Midwest and the Eastern United States [9]. This paper provides design and operational information on the first MagMill^{TM} prototype, a modified 90 kg/hr hammer mill.

ALPHA PROTOTYPE MAGMILL^{TM} (PATENT PENDING)

The first of its kind alpha prototype MagMill^{TM} was built and used to demonstrate the concept. This unit, which combined a hammer mill and EXPORTech's 90 kg/hr ParaTrap^{TM} magnetic separator, was instrumented with the original intention of continuously producing nominal minus 74 micron coal. It was blanketed with nitrogen gas for safety. The following operating parameters are monitored and controlled: MagMill^{TM} feed rate, MagMill^{TM} coarse reject withdrawal rate, ParaMag^{TM} Magnetic Separator reject rate, MagMill^{TM} product rate, oxygen content in the gas stream, nitrogen purge rate, and air stream pressures at several key points.

Mill Modifications

A hammer mill has been modified to accommodate air-swept operation and continuous withdrawal of the internal circulation material from the mill. The modified hammer mill is shown schematically in Figure 1.

In the unmodified hammer mill, the ground coal particles are discharged through a screen extending along a nominal 120° arc from the bottom on the mill up the side opposite the feed. The top size of the mill product is controlled by the screen opening. A second product exit port was added in the MagMill^{TM} configuration to discharge relatively fine-size particles, which are the MagMill^{TM} product; the original port discharges relatively coarse particles, which are withdrawn from the mill's internal circulation and sent to the magnetic separator.

Three major modifications were made to the original product exit port at the bottom of the mill to accommodate withdrawal of the coarse reject material. First, the opening area could be significantly reduced by closing off up to 60% of the screen opening extending above the bottom of the pulverizer to be able to adjust withdrawal rates. Secondly, the size of the screen opening was decreased to accommodate the intermediate particle size for magnetic separation. Thirdly, air is blown into the bottom of the pulverizer through the coarse reject withdrawal port to prevent fines from exiting through the withdrawal port and to pneumatically convey the fine particles out the product port at the top of the mill.

The product port at the top of the mill was designed to prevent loss of coarse particles. This was achieved by reversing the direction of the hammer rotation to counterclockwise as indicated in the drawing and by the addition of a baffle to prevent the particles in circulation from bouncing directly into the product port.

The number of the hammers was increased and the hammer rotation speed was reduced to make the impacts between the hammers and the particles and/or between the particles gentler and more frequent to enhance selective grinding.

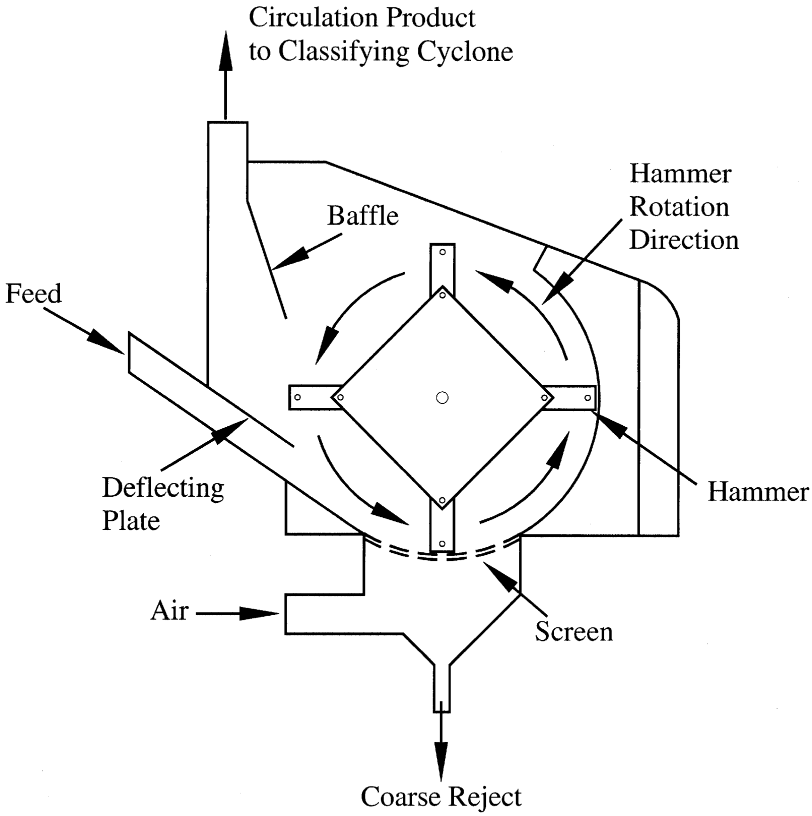


FIGURE 1. Modified hammer mill.

A deflecting plate, extending deep into the mill very close to the hammer tips, was added, which isolated the feed port from the grinding chamber.

Alpha Prototype MagMill™

The flow sheet of the Alpha prototype MagMill™ is shown in Figure 2. This system conveys feed coal, clean coal product from the magnetic separator, and classifying cyclone underflow to the mill.

The modified hammer mill has a capability of grinding a 57 HGI coal at 90 kg/hr at about 58% finer than 150 microns. The MagMill™ product size analysis for a 57 HGI Clarion Seam coal is shown in Table 1.

Partially ground coarse reject material is withdrawn through the bottom of the mill and transferred to the ParaMag™ separator. The rate of coal withdrawal at this exit port is affected by the screen opening size, the rate at which intermediate size particles are created by grinding,

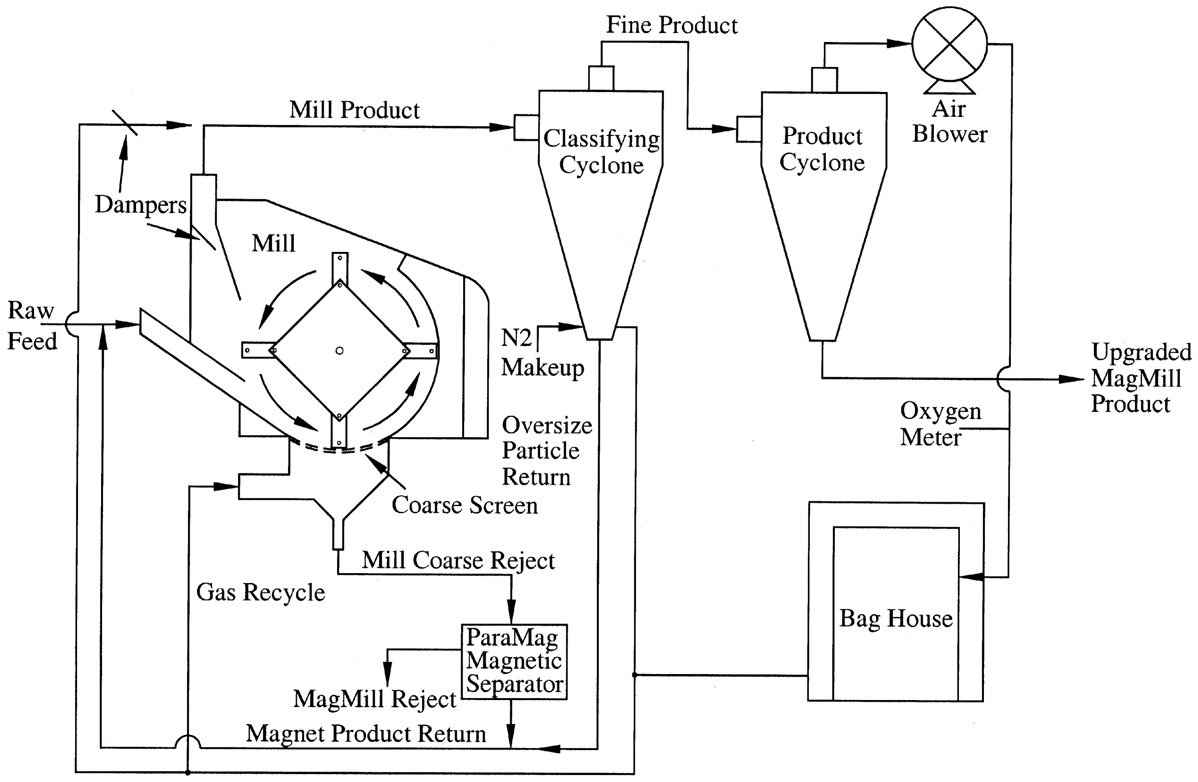


FIGURE 2. Alpha prototype MagMill^{TM} flow sheet.

TABLE 1 MagMill^{TM} product particle size analysis, Clarion seam coal, HGI = 57

Screen fraction (microns)	wt%
+595	3.29
297 × 595	7.14
149 × 297	29.01
74 × 149	27.03
−74	33.54
Total	100.00

the amount of screen area, the rate of gas flow into the base of the mill, recycling of classifying cyclone underflow, and the particle size distribution in the coal bed in the bottom of the mill just above the screen surface.

The magnetic separation system consists of a ParaMag^{TM} Magnetic Separator (Patent Pending) and a magnetic separation product return screw conveyor. The ParaMag^{TM} separator has two stages, a rotary drum permanent magnetic separator (MagScalper^{TM}) and an electromagnet ParaTrap^{TM} Magnetic Separator [10–12].

The clean coal product from the ParaMag^{TM} separator is transported via screw conveyor to the mill feed conveyer. The refuse from the magnetic separator is rejected as a final refuse. The clean coal return is weighed automatically and continuously; the reject, discharged continuously from both stages of the magnetic separator, is caught and weighed as a batch.

The pneumatic conveying system consists of a blower and ductwork. The air blower is capable of providing air flow at 0.02 kmol/s with a pressure head up to 0.38 m of water. The system serves two functions. The first is to convey the fine-size mill product particles from the grinding chamber to the MagMill^{TM} product collector; the second is to prevent the fines in the hammer mill from going into the coarse reject.

The product collection system consists of a classifying cyclone, a separating cyclone, and a bag filter. The cyclones and bag filter separate fine-size particles from the air stream. The underflow from the classifying cyclone can be collected as a separate product or can be returned to the mill feed conveyor belt via a weighing screw conveyor. The output of the product cyclone is collected in a drum sitting on a platform scale.

In order to reduce the risk of explosion of the fine dust during the operation of the MagMill^{TM}, an explosion prevention system employing nitrogen inerting was put in place to reduce the oxygen concentration level below 12 volume percent in the recycling air stream. Oxygen content is continuously monitored using an oxygen sensor.

MagMill^{TM} Operation

The raw coal feed rate is manually adjusted to prevent overflow at the feed to the magnetic separator. The refuse screen area cannot be changed without shutting down the mill, and the effect of air flow by mill damper adjustment is limited. Recycling classifier underflow also affects the mill refuse withdrawal rate.

Between 100 and 150 min running time is required for the MagMill^{TM} to reach steady-state operation.

MagMill^{TM} Tests and Analysis

Test coals

Approximately 3,629 kg of raw Lower Kittanning Full B seam coal from Clearfield County, PA, and 907 kg of raw Upper Freeport seam coal from Armstrong County, PA, were used in the test program. A second Upper Freeport seam coal, identified in this paper as sample UF1, was procured from a different source.

The coal samples were air dried, crushed to 9.5 mm top size, split by long pile and alternate shoveling, and barreled for later MagMill^{TM} testing. Representative samples of each coal and head samples for each test run for each coal were characterized for ash, sulfur, heat content kJ/kg, kg Sulfur/MJ, and HGI. The averaged data are summarized in Table 2. The ash of the UF1 head sample was 14% higher than the average of the five Upper Freeport samples (including the UF1 sample), the sulfur was 9% lower, the kJ/kg was 2% lower, and the kg Sulfur/MJ was 5% lower. A statistical relationship between the kJ/kg and the ash and sulfur content of each of the coals was determined by fractionating representative samples of the 0.95 mm top size coal, reduced to 2.38 mm, into components with differing magnetic susceptibilities by processing through the ParaTrap^{TM} magnetic separator. Each pass through the separator yields nine different magnetic susceptibility fractions. The ash, sulfur, and MJ/kg are determined for these fractions and used as input to the correlation. This has resulted in the following relations:

Samples LK1-LK4: $\text{Heat/kg (MJ/kg)} = 36.698[1 - 0.0102 * \text{Ash}(\%) - 0.0036 * \text{Sulfur}(\%)]$. $R^2 = 0.9992$.

Samples UF2-UF4: $\text{Heat/kg (MJ/kg)} = 36.077[1 - 0.0118 * \text{Ash}(\%) + 0.0080 * \text{Sulfur}(\%)]$. $R^2 = 0.9997$.

These correlations are used to calculate the MJ/kg of all the test samples once the ash and sulfur have been measured.

TABLE 2 Average characteristics of 5 Lower Kittanning and 5 Upper Freeport coal samples

Coal	Ash (wt%)	Sulfur (wt%)	MJ/kg	μgS/MJ	HGI
Lower Kittanning	21.3	5.9	27.93	2.1	76
Standard Deviation	0.9	0.4	0.37	0.17	
Upper Freeport	23.1	2.6	26.99	0.95	57
Standard Deviation	1.2	0.2	0.50	0.09	

A Clarion seam coal with a Hardgrove Grindability Index similar to the Upper Freeport seam coal was used to measure size distribution of the alpha prototype products.

MagMill^{TM} Testing

The mill was operated both with and without recycling the classifying cyclone underflow back to the pulverizer, with differing air flow rates through the mill grinding chamber, and with mill refuse screen openings ranging from 41% to 100%. The test matrix and qualitative results are given in Table 3.

The data in the column marked "Coarse Refuse Screen Opening" are expressed as a percentage of the full screen opening. The data in the column "Air Flow Damper Opening" qualitatively indicate the air flow rate through the pulverizer. The largest opening, 12.7 cm, will have the highest air flow rate.

Steady-State Conditions

Figure 3 illustrates the time required to reach steady state for magnet refuse, cyclone product, and baghouse samples.

Operating conditions that lead to magnetic separator feed rates which are large proportions of the raw coal feed rate achieve the highest levels of ash and sulfur reduction at the expense of energy recovery. The trend in ash and sulfur reduction with energy recovery can be seen in Table 3. It is more apparent for the Upper Freeport seam coal than for the Lower Kittanning seam coal due at least in part to the lower HGI value for the Upper Freeport seam coal. These cases are generally characterized by high levels of coal recycled through the magnetic separator and take a long time to reach steady state.

Magnetic Separator

The "Concentration Ratios" given in Table 4 are the ratios of the ash and the sulfur concentrations in the feed to the magnetic separator to the concentrations in the feed to the MagMill^{TM}. The stream withdrawn

TABLE 3 Alpha prototype MagMill^{TM} exploratory results

			MagMill operating conditions					MagMill results			
					Pulverizer				Reduction		
Coal	Sample no.	HGI	Raw coal feed (kg/hr)	Feed rate magsep/raw coal (%)	Coarse refuse screen opening (%)	Air flow damper opening (cm)	Classifying cyclone underflow recycle	Heat rec. (%)	Ash (wt%)	Sulfur (wt%)	μgS/MJ (%)
Lower Kittanning	LK1	76	31.4	142	100	2.5	No	90	27.7	29	35
Lower Kittanning	LK2	76	38.2	87	82	2.5	No	92	27	29	34
Lower Kittanning	LK3	76	38.1	117	59	2.5	No	95	27	28	34
Lower Kittanning	LK4	76	47.2	12	41	2.5	No	>99	14	19	23
Upper Freeport	UF1	57	29.0	98	100	5.0	Yes	93	41	31	40
Upper Freeport	UF2	57	44.7	43	100	2.5	Yes	93	24	27	32
Upper Freeport	UF3	57	48.8	25	100	2.5	No	95	22	23	29
Upper Freeport	UF4	57	48.7	20	100	12.5	Yes	97	15	20	24

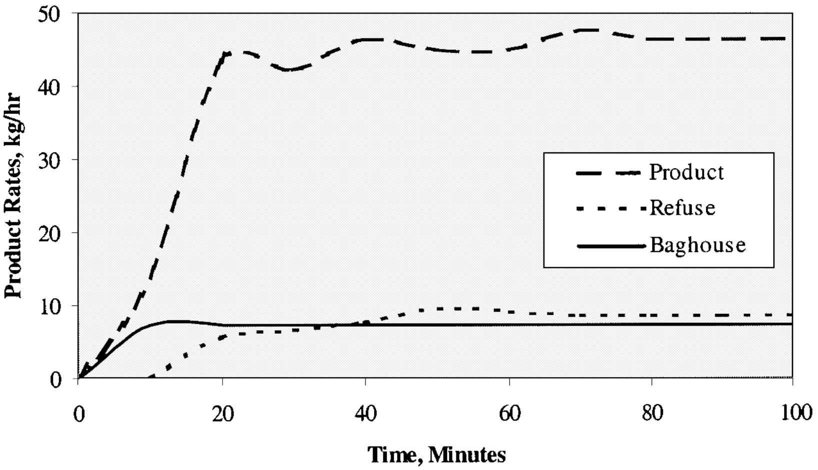


FIGURE 3. MagMill^{TM} product rates, Upper Freeport seam coal.

from the pulverizer is called the mill concentrated stream (mcs). It is the feed to the magnetic separator. This stream gives an indication of the buildup in concentration of hard minerals inside the pulverizer. As the magnetic separator feed rate increases in relation to the feed rate to the MagMill^{TM}, the values of the ratios decrease and the ash and sulfur reductions in the MagMill^{TM} product increase. Simultaneously, the energy recovery for the MagMill^{TM} decreases.

The performance of the magnetic separator in treating pulverizer coarse reject is given in Table 5, which shows materials balance around the magnetic separator loop for the Upper Freeport runs. The values for ash and sulfur reductions and energy recovery pertain to the magnetic separation product returned to the mill in relation to the feed to the magnetic separator which was taken from the mill. The ash reductions are relatively unaffected by the feed rate to the separator while the sulfur reductions are strongly affected.

The data for sample UF4 also shows the materials balance around the entire MagMill^{TM} circuit. Note that the magnetic separator rejected mineral matter with 71% ash and 8.5% sulfur from a MagMill^{TM} feed of 23% ash and 2.6% sulfur. Even so, the "cleaned" return from the magnetic separator had 30% ash and 11% sulfur, indicating a negative sulfur reduction by the magnetic separator loop for this test run. The MagMill^{TM} showed a 24% reduction in kg Sulfur/^{M3J} at 97% energy recovery. There is a limit to which the magnetic separator circuit can reject high ash and sulfur refuse which is imposed by the size of the opening in the mineral reject flow path. This run has reached that limit.

TABLE 4 Alpha prototype MagMill performance measurements, Upper Freeport coal

				MagMill^{TM} product		
		Concentration ratios*			Reductions	
Sample no.	Magnetic separator feed rate % raw coal feed rate	Ash (%)	Sulfur (%)	Heat recovery (%)	Ash (wt%)	Sulfur (wt%)
UF4	20	2.1	3.5	98	18	20
UF3	25	1.6	2.6	96	23	23
UF2	43	1.5	2.1	94.5	25	25
UF1	98	1.1	1.7	93	41	31

*Magnetic separator feed/mill feed.

Air Flow and Classifying Cyclone Recycle

As shown in Table 3 for the Upper Freeport samples, increasing air flow through the pulverizer decreases the ratio of the magnetic separator feed rate to the raw coal feed rate because less coal can exit the mill reject port at the bottom of the mill. The air flow rate can be controlled to a certain extent by the flow damper located at the product port on the top of the pulverizer.

Recycling the classifying cyclone underflow affects the mill and magnetic separator performance. The rate of withdrawal of mill reject (feed to the magnetic separator) is increased when the classifying cyclone underflow is returned to the mill. This affects magnetic separator performance. This is illustrated in Figure 4 for the Upper Freeport Coal. The effects on magnetic separator feed rate are illustrated in the upper portion of Figure 4, where the ratio of the magnetic separator feed rate to that of the raw coal and of the mill (raw coal plus recycle) are shown. The slight negative value of the curve for the ratios at <10 min is an artifact of the graphics program.

In mill operation, the raw coal feed rate is adjusted to prevent overflow of the magnetic separator feed. As the mill approaches steady state, a time greater than 40–80 min in the upper portion of Figure 4, the ratio of the magnetic separator feed rate to that of the mill feed is not substantially affected by recycle of cyclone underflow. The ratio of magnetic separator feed rate to that of the raw coal is affected, however, since the raw coal feed rate is reduced to compensate for increased recycle of magnetic separator clean coal and classifying cyclone underflow. As the mill approaches steady state, the ratio of magnetic separator feed rate to

TABLE 5 Magnetic circuit performance, Upper Freeport runs

							Reductions		
Sample	wt%	Ash (wt%)	Sulfur (wt%)	MJ/ kg	μgS/ MJ	Heat Rec.(%)	Ash (wt%)	Sulfur (wt%)	μgS/MJ (wt%)
UF1 Magnet Loop									
Clean	74.20	14.93	4.31	30.95	1.39	90.71	47.31	6.45	23.48
Refuse	25.80	66.90	5.47	7.84	6.97				
Composite	100.00	28.34	4.61	25.31	1.82				
UF2 Magnet Loop									
Clean	49.11	20.69	5.08	28.72	1.77	67.68	47.87	13.13	36.97
Refuse	50.89	58.01	6.59	13.23	4.98				
Composite	100.00	39.68	5.85	20.83	2.81				
UF3 Magnet Loop									
Clean	55.65	23.12	7.94	28.50	2.79	79.38	46.41	0.91	30.53
Refuse	44.35	68.26	8.11	9.29	8.72				
Composite	100.00	43.14	8.01	19.98	4.01				
UF4 Magnet Loop									
Clean	30.89	30.13	10.65	26.29	4.05	58.36	48.18	−16.20	38.50
Refuse	69.11	70.66	8.50	8.38	10.14				
Composite	100.00	58.14	9.17	13.91	6.59				
UF4 MagMill Circuit									
Product	92.46	18.35	1.98	28.82	0.68	96.75	15.39	20.40	23.93
Refuse	7.54	70.66	8.50	8.38	10.14				
Composite	100.00	22.29	2.47	27.28	1.13				

the raw coal feed rate increases, indicating more recycle through the magnetic separator.

The effects of recycling the classifying cyclone underflow on magnetic separator performance are illustrated in the lower portion of Figure 4. The levels of ash and sulfur are greater and the weight recovery is less in the magnetic separator refuse stream when the classifying cyclone underflow is not recycled to the pulverizer. Coal recycled from the classifying cyclone dilutes the pulverizer coarse reject stream fed to the magnetic separator. The effects of air flow and of classifying cyclone underflow recycle are opposite; high air flow produces similar effects to the absence of cyclone underflow return. Figure 5 shows that the weight

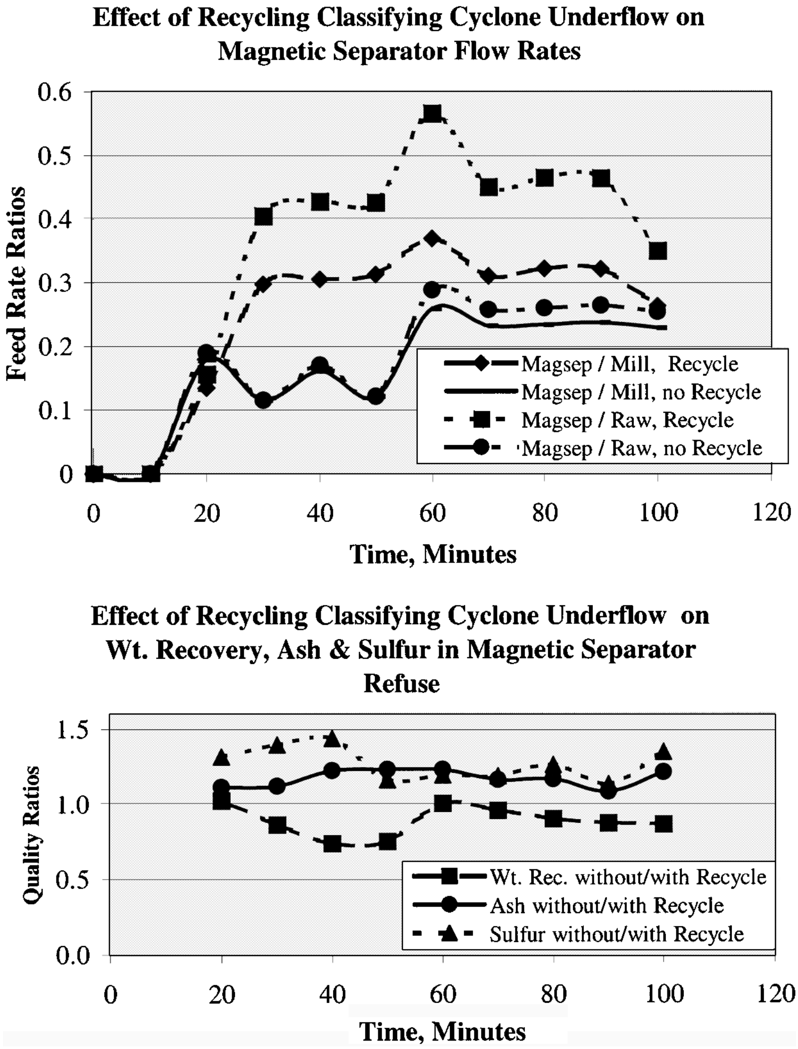


FIGURE 4. Effects of cyclone underflow recycle on feed rated and magnetic separator refuse quality, Upper Freeport seam coal.

recovery in the magnetic separator refuse is reduced with increased air flow, while the ash and sulfur levels are increased. The effects on ash and sulfur levels in the magnetic separator refuse are more pronounced in this case than when the cyclone underflow is not recycled.

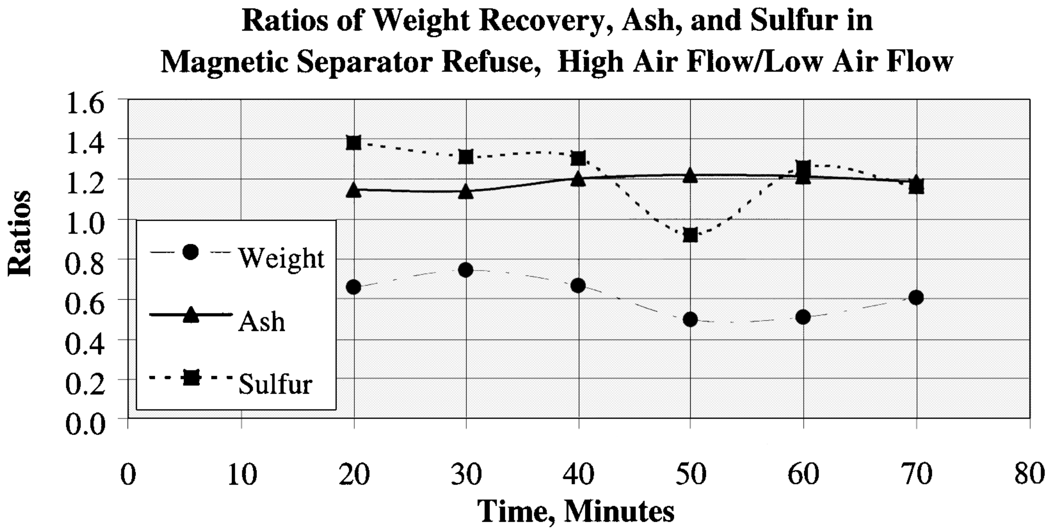
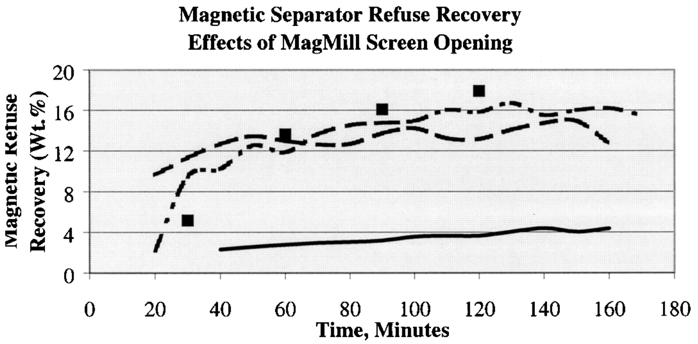
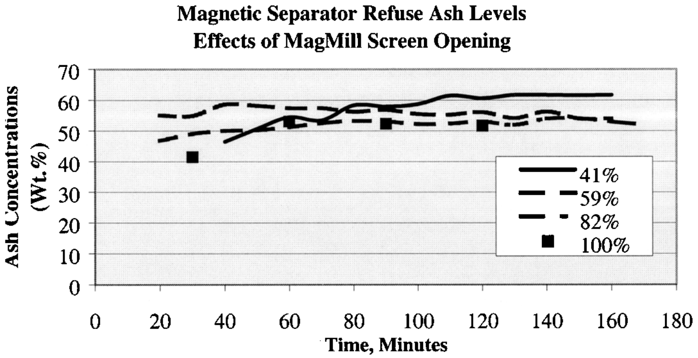


FIGURE 5. Effects of air flow on magnetic separator refuse quality, Upper Freeport seam coal.





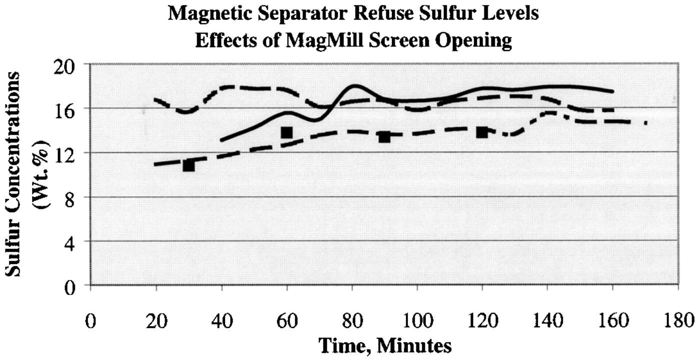


FIGURE 6. Effects of screen opening, Lower Kittanning seam coal.

Screen Opening

Lower Kittanning seam coal was used to investigate the effects of changing the area of the mill coarse refuse screen. Figure 1 shows the configuration with the screen 100% open. A baffle, which covered the screen surface from the mill feed side towards the back of the mill in the direction of rotation of the hammers, was introduced to lower the amount of screen area that is open to passage of coarse refuse. The effects of the screen opening on the weight recovery of the magnetic separator refuse stream relative to the raw coal feed to the mill and ash and sulfur levels of the magnetic separator refuse are shown in the top of Figure 6. The openings ranged from 41% to 100%.

The weight recovery of the magnetic separator refuse was lowest for the 41% open area. At steadystate, approximately 160 min into the run, the refuse fraction recovered 4% of the raw coal feed. The recoveries for the cases of 59%, 82%, and 100% open area were significantly higher, and while there are systematic differences, the recoveries were all the same to within ±2% upon reaching steady state. The average of these three cases is approximately 14%, which is significantly higher than that for the 41% screen opening. It appears that opening the screen on the side of the mill away from the mill feed transmits more weight to the magnetic separator and that the greatest increase in the recovery occurs in the 41–59% opening range.

The two lower portions of the figure indicate that the material extracted from the mill through the back portions of the screen, however, is higher in ash and sulfur than the material extracted toward the side in which the feed is introduced. The ash and sulfur levels in the magnetic separator refuse, 62% and 17.5%, respectively, are the highest for the 41% open screen area and least for the 100% open area where ash and sulfur levels are 52% and 14.5%, respectively. The average of ash and sulfur values in the magnetic separator refuse at 160 min into the run were 55 ± 5% and 15.5 ± 2%, respectively. The screen opening can provide a method to adjust the amount and quality of coal fed to the magnetic separator.

SUMMARY

Work with the alpha prototype MagMill^{TM} has helped to delineate the important process parameters controlling the operation of the novel beneficiating mill. The pulverizer acts as a first stage of beneficiation, operating on the basis of differences in the grindability and the density of the materials being ground. The hydrocarbon component of bituminous coal is relatively soft, while quartz and sulfide mineral contaminants are relatively hard. Material extracted from the internal circulation of the mill illustrates the buildup in concentration of hard materials in the mill. This material serves as feed to a dry magnetic separator for rejection of mineral gangue and recovery and recycle of carbon for grinding to product specification. Measurements on two raw coals from North Central Pennsylvania have shown the potential of the MagMill$^{\text{TM}}$ for dry cleaning of coal.

The pulverizer in the 90 kg/hr alpha prototype MagMill$^{\text{TM}}$ is a hammer mill and as such is a qualitative model for the Riley Stoker Attrita mill used in commercial operation. The alpha prototype has been useful in identifying and studying the effects of operating parameters such as air flow, mill withdrawal rate, cyclone underflow recycle, etc.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the contributions of Russell E. Jamison and Gregory D. Crusan in building the alpha prototype and of Mr. Jamison, Mr. Crusan, and Dr. Yuru Feng in carrying out the test work reported in this paper. This work was supported in part by the U.S. Department of Energy SBIR program through DE-FG05-94ER81764 and by the Upgraded Coal Interest Group of the Electric Power Research Institute, Agreement WO3852-01. Lower Kittanning coal was supplied by Bradford Coal Company of Clearfield, PA.

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