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MagMill™ Prototype Testing

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ABSTRACT

We report results of testing two raw coals, Lower Kittanning and Upper Freeport from north central Pennsylvania; the testing was done in a beta prototype 1½ ton per hour (tph) MagMill™ (patent pending) at the pilot plant facilities of Bradley Pulverizer Company in Allentown, PA. The prototype consists of a ParaMag™ magnetic separator retrofitted to a 3000 Lb/Hr Hercules air swept ring/roller pilot mill. For the runs reported here, the mill-product fineness varied between 70% and 80% finer than 200 mesh. The mill-product coal exhibited significant reductions in ash, sulfur, and $LbSO_2$/MBtu at Btu recoveries up to 94%. Recoveries of mercury, arsenic, and selenium for the two coals ranged from 33 to 71% of that in the feed on an equal Btu basis. The mill power draw was reduced up to 26% while the mill throughput was simultaneously increased by up to 12%.

INTRODUCTION

The MagMill™, which is a pulverizer and dry separator operating together, is a method for removing inorganic impurities from coal at the power plant. A high volume stream which contains concentrated inorganic minerals is withdrawn from the pulverizer and processed by the magnetic separator, "mill concentrated sample" shown in Figure 1. Clean coal is recovered and returned to the pulverizer for grinding to specification; concentrated minerals are rejected. In this fashion, inorganic minerals including sulfur and trace elements are reduced in the pulverizer output.

The advantages and benefits are summarized in Figure 1. The process improves plant performance by preferentially removing hard and abrasive minerals from the pulverizer before they are overground. The energy draw is reduced and the pulverizer throughput is simultaneously increased. Abrasive wear is reduced in the pulverizer and in all downstream equipment that is touched by the coal. The magnetic separator preferentially rejects iron sulfides. Lowering levels of iron sulfides to the burner reduces water wall wastage. Sulfur emissions are lowered and downstream catalyst poisoning in catalytic reactors is reduced. Entities associated with the iron sulfides, such as trace elements, are also separated.[1] Coal

[1] E.D. Brandner, R. R. Oder, and R. E. Jamison, "Removal Of Selected Hazardous Air Pollutant Precursors By Dry Magnetic Separation," To be published in the proceedings of the 25th International Technical Conference on Coal Utilization & Fuel Systems, Clearwater, FL, March 6-9, 2000.

dependent, the net gain for the power plant can be significant. It is estimated that Eastern U.S. pulverized coal fired power plants can save between $2 and $4 per ton of coal burned and pay out the retrofit in less than two years. For a 2000 MW plant burning bituminous coal the savings can be $15 million per year.

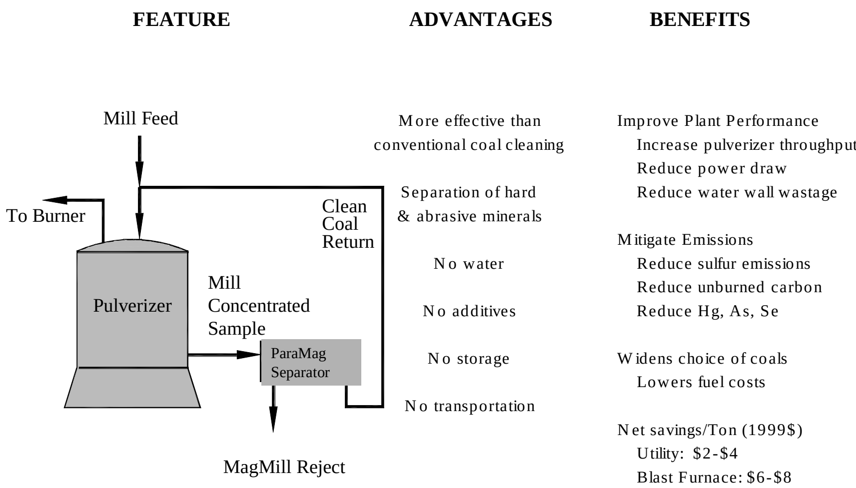

Figure 1. Feature, Advantages and Benefits of the MagMill™

MagMill™ CONCEPT

Coal is pulverized to reduce the particle size which improves combustion characteristics. A variety of mills are employed in power plants; an ABB CE Raymond bowl mill shown schematically in Figure 2 is used here as an example. This is an air swept mill producing coal which is 70% to 80% finer than 200 mesh. Coal is fed onto the surface of a rotating table in the grinding zone where it is crushed as the table rotates forcing coal between the table wall and the rollers. Hot air blown into the grinding zone around the inside circumference of the pulverizer lifts the fine particles produced in the grinding and conveys them to the top of the mill which houses a static classifier. There, oversize particles are returned to the grinding zone and the fines are blown through pipes to the burners. There is a continuous stream of particles circulating inside the pulverizer which carries oversize particles back to the grinding zone. Hard minerals carrying sulfur and trace metals concentrate in this stream.

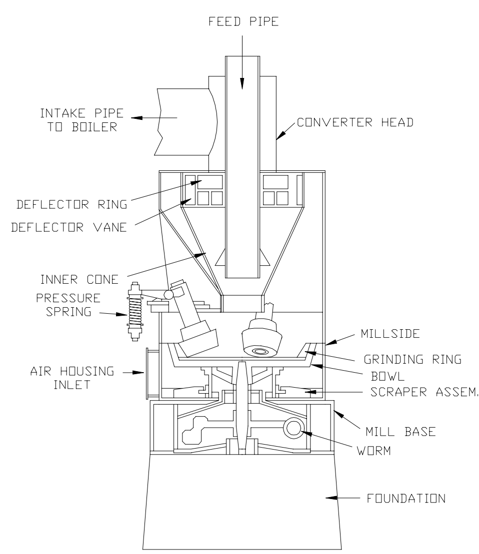

Figure 2. ABB CE Raymond Bowl Mill

The hard components of coal require the greatest number of passes through the grinding zone to reach size specification. These materials are concentrated inside the pulverizer on the basis of hardness and density**.** Minerals, especially iron sulfides and quartz, are generally the hardest components of coal. A portion of these minerals is withdrawn from the internal circulation of a MagMill™ and is sent to a dry beneficiation stage for rejection of the minerals and recovery of the carbon for return to the mill.

FEASIBILITY TESTING

Feasibility testing has been carried out on operating pulverizers at the coal fired power plants in Pennsylvania, West Virginia, Illinois and Ohio shown in Table I. Samples of the internal circulation in each mill were obtained using test ports installed on the pulverizer. Magnetic separation tests were performed on the mill samples using a laboratory scale ParaTrap™ magnetic separator[2] at EXPORTech Company, Inc. (ETCi) in New Kensington, PA. Performance of a commercial MagMill™ was projected using a computer simulation of the MagMill™ grinding operation.

Table I. Pulverizers Tested

Utility	**State**	**Mill**	**Throughput (tph)**
Allegheny Power	PA	D-8 Ball*	37
Allegheny Power	WV	823 Bowl MPS 89 Roller	45 51
Ameren/CIPS	IL	633 Bowl	16
FirstEnergy	OH	MPS 89 Roller	51
GPU	PA	633 Bowl	12

*Classifier sampled

Table II summarizes the computer projections of MagMill™ performance for each of the mills. The coals burned at the Allegheny Power Fort Martin Station were blends of deep cleaned coal from Southern Appalachia and coals from Southwestern Pennsylvania. Both coals burned at the Ameren/CIPS Meredosia Station came from the New Monterey No. 1 mine; one was a raw coal, the other a blend of raw and deep washed coal. Deep washed Pittsburgh seam coal was sampled at the FirstEnergy plant. These results will be reported at a later date. The GPU Shawville plant was burning a blend of Pennsylvania washed and raw coals. Ash reductions between 12 and 22% and sulfur reductions between 25 and 68% were projected with heat recoveries ranging from 91 to 97%.

[2] R. R. Oder, "Method of Magnetic Separation and Apparatus Therefore," U.S. Patents 5,017,283 (May 21, 1991); 5,127,586 (July 7, 1992); 5,176,260 (January 5, 1993).

Table II. Projected MagMill™ Performance

	Mill Feed		Projected MagMill™ Performance		
	Concentration, Wt.%			Concentration, Wt.%	
Mill	**Ash**	**Sulfur**	**Heat Recovery, %**	**Ash**	**Sulfur**
MPS 89*	12.0	2.0	97.5	9.4	1.3**
823*	8.5	1.8	97.5	7.4	1.3**
633†	23.25	1.11	91.4	18.5	0.61**
633†	8.45	1.93	97.4	7.4	0.61**
633‡	15.12	2.19	97.5	13.3	1.64

* Allegheny Power Fort Martin Generating Station
† Ameren/CIPS Meredosia Station
‡ GPU Shawville Station
** Organic Sulfur Level

PROTOTYPE TESTING

ETCi built and operates a 200 Lb-hr alpha prototype MagMill™ for demonstrating the concept and to develop input for ETCi's grinding model.[3] This mill combines a continuously operating air-swept hammermill, modified for extraction of hard minerals, and a 200 Lb-hr ParaMag™ magnetic separator and produces a product of nominally minus 100 mesh.

Figure 3. Beta Prototype MagMill™

A skid-mounted one ton per hour (tph) ParaMag™ magnetic separator was retrofitted to a 3000 lb-hr Hercules air swept ring/roller pulverizer at the pilot facilities of the Bradley Pulverizer company in Allentown, PA. The beta prototype MagMill™ shown in Figure 3 was operated in the summer of 1999.

Upper Freeport and Lower Kittanning raw coals from Pennsylvania were used for testing. Their characteristics are given in Table III.

[3] R. R. Oder, R. E. Jamison and E. D. Brandner, "Dry Coal Cleaning with a MagMill™," to be published in the proceedings of the 2000 SME Annual Meeting & Exhibit, Salt Lake City, UT, February 28-March 1, 2000.

Table III. Characteristics of Beta Prototype Test Coals (Dry Basis)

	Upper Freeport, Clarion County	**Lower Kittanning, Clearfield County**
Ash, %	19.59	21.01
Total Sulfur, %	2.43	5.26
Pyritic Sulfur, %	1.54	4.18
Organic Sulfur, %	0.89	1.01
Sulfate, %	0.00	0.07
Volatile Matter, %	28.06	21.51
Btu/Lb	12167	12055
HGI	68	78

MagMill™ Circuit

The beta prototype separator processes the mill concentrated sample (see Figure 1) at a rate up to nominally 2000 pounds per hour. It consists of a first stage ElectriMag™ separator (patent pending), which can employ both triboelectric and magnetic fields, and a second stage ParaTrap™ magnetic separator. The ElectriMag™ separator prevents strongly magnetic material from entering the flow path of the ParaTrap™ magnetic separator. The combined apparatus produces a clean coal for return to the pulverizer and a refuse fraction for discarding.

Mill operating parameters including mill power draw, mill fan draw, static pressure in the mill base, and classifier pressure drop were recorded 12 times/minute. These parameters are used to control mill operation. Samples of magnet reject and mill product were taken every 10 minutes. Product particle size was measured 12 times/minute by an on-line laser particle size analyzer.

BETA PROTOTYPE RESULTS

Upper Freeport Coal

Seven runs were made for the Upper Freeport Coal. The first run was used to set operating conditions for the unmodified pulverizer. Once steady state was reached, the unmodified pulverizer ground the Upper Freeport coal into the target size range at the rate of 1980 Lb/hr. The mill and fan consumed energy at the rate of 22.6 kw-hr per ton. MagMill™ operating conditions were varied for the remaining six runs. Measurements for Run #6 are given here. After steady state had been achieved, the MagMill™ power draw for Run #6, 16.7w-hr/T, was 26% less that for the unmodified mill. Similarly, the throughput was increased to 2170 Lb/hr, a 9% increase compared to that of the unmodified mill. This results from removal of the hard minerals before they are overground.

The gross chemical analyses of the MagMill™ products for Upper Freeport Run #6 are shown in Table IV. This run recovered 82% of the weight of the feed and 91% of the heat content. A sample of the MagMill™ product which contains one unit of heat contains only 23% of the iron pyrite contained in a sample of untreated coal which contains the same amount of heat. This means 77% less iron sulfide in the flame for low NO_x burners. The percent recovery of ash, sulfur, pyritic sulfur, heat content, and $LbSO_2$/MBtu in the MagMill™ product compared to the feed is shown in the last column.

Measurements of trace metals for this run are summarized in Table V where the list of elements is sorted by recovery in the MagMill™ product. In this table, the last column, "Percent to Burner," shows the amount of each trace metal in the MagMill™ product which would be sent to the burner expressed as a percentage of that in the coal fed to the pulverizer where both the MagMill™ product and feed supply the same amount of heat (Btu's). Six of the 16 trace metals, including mercury, arsenic, and selenium, measured in the MagMill™ product had less than 50% of that in the feed coal on an equal Btu basis. Recalling that the recovery of iron pyrite was 22%, it is apparent that arsenic and pyrite are closely related for this coal.

Table IV. Gross Chemical Analysis
MagMill™ Products
Upper Freeport Coal, Run #6

Dry Basis	Concentration (Wt.%)				Percent Recovery
	Mill			Cumulative Product & Reject	
	Feed	Product	Reject		
Wt.%	100.00	81.72	18.28	100.00	81.72
% Ash	19.59	11.90	55.04	19.78	49.16
% Sulfur	2.43	1.43	8.29	2.68	43.55
% Pyritic	1.54	0.39	6.09	1.43	22.26
% Sulfate	0.00	0.00	0.02		
% Organic	0.89	1.04	2.18	1.25	
Btu/Lb	12167	13528	5908	12135	
Heat Recovery					91.10
$LbSO_2$/MBtu	3.99	2.11	28.10	4.42	39.07
Volatiles	28.06	30.95			
HGI	68				

Table V. Trace Metals in MagMill™
Products (ppm in coal)
Upper Freeport Coal, Run #6

Trace Metal	Concentration (ppm Coal)				Percent Difference with Feed	Percent to Burner*
	Mill			Cumulative Product & Reject		
	Feed	Product	Reject			
Thallium	1.40	0.47	5.70	1.43	1.8%	30
Arsenic	55.00	18.00	190.00	49.43	-10.1%	33
Lead	12.00	4.60	40.00	11.07	-7.8%	37
Mercury	0.37	0.18	1.40	0.40	8.9%	40
Nickel	13.00	9.30	51.00	16.92	30.2%	49
Selenium	2.40	1.30	6.90	2.32	-3.2%	50
Manganese	33.00	17.00	85.00	29.43	-10.8%	52
Copper	15.00	9.60	45.00	16.07	7.1%	54
Cobalt	4.10	2.70	11.00	4.22	2.9%	58
Molybdenum	2.30	1.80	5.40	2.46	6.9%	66
Chromium	19.00	18.00	34.00	20.92	10.1%	77
Zinc	19.00	19.00	35.00	21.92	15.4%	78
Vanadium	22.00	23.00	28.00	23.91	8.7%	87
Berylium	1.20	1.20	1.20	1.20	0.0%	90
Cadmium	0.22	0.21	0.15	0.20	-9.5%	94
Antimony	0.22	0.23	0.16	0.22	-1.3%	94

*Based on equal Btu's to burner.

Lower Kittanning Coal

Five runs were made for the Lower Kittanning Coal. The first run was used to set operating conditions for the unmodified pulverizer. Once steady state was reached, the unmodified pulverizer ground this coal into the target size range at the rate of 2623 Lb/hr. The mill and fan consumed energy at the rate of 16.6 kw-hr per ton. MagMill™ operating conditions were varied for the remaining four runs. After steady state had been achieved, the power draw for Run #4, 14.6 kw-hr/T, was 11.6% less that for the unmodified mill. Similarly, the throughput was increased to 2948 Lb/hr, a 12.4% increase compared to that of the unmodified mill.

The gross chemical analysis of the MagMill™ products for Lower Kittanning Run #4 are shown in Table VI. This run recovered 87% of the weight of the feed and 94% of the heat content. When put on an equal Btu basis, the emissions of sulfur, $LbSO_2$, were reduced by 58% and pyritic sulfur in the MagMill™ product was reduced by 35% compared to that delivered by the feed coal.

Measurements of trace metals for this run are summarized in Table VII where the list of elements is sorted by recovery in the MagMill™ product. Two of the 16 trace metals, mercury and thallium, had recoveries in the MagMill™ product which were approximately less than 50% of that in the feed. Recalling that the recovery of iron pyrite was 61%, it is apparent that mercury, arsenic, and pyrite are closely related for this coal.

Table VI. Gross Chemical Analysis of MagMill™ Products Lower Kittanning Coal

	Concentration (Wt.%)				
Dry Basis	Feed	Mill Product	Reject	Cumulative Product & Reject	Percent Recovery
Wt.%	100.00	86.72	13.28	100.00	86.72
% Ash	21.01	15.48	54.27	20.63	65.07
% Sulfur	5.26	4.01	15.57	5.55	62.71
% Pyritic	4.18	2.70	11.34	3.85	60.86
% Sulfate	0.07	0.01	0.04	0.01	
% Organic	1.01	1.30	4.19	1.69	
Btu/Lb	12055	12904	5599	11934	
Heat Recovery					93.77
$LbSO_2$/MBtu	8.73	6.22	55.62	9.30	58.00
Volatiles	21.51	23.23			
HGI	78				

Table VII. Trace Metals in MagMill™ Products (ppm in coal) Lower Kittanning Coal Run #4

	Concentration (ppm Coal)					
Trace Metal	Feed	Mill Product	Reject	Cumulative Product & Reject	Percent Difference with Feed	Percent to Burner*
Thallium	0.81	0.41	3.8	0.86	-217.8%	45
Mercury	0.38	0.22	1.6	0.40	-30.6%	51
Arsenic	5.7	4.6	26	7.44	-11.2%	58
Nickel	7.2	7.2	38	11.29	-101.8%	60
Lead	10	7.1	30	10.14	-27.5%	65
Manganese	15	12	50	17.05	-10.5%	66
Selenium	5.8	4.7	16	6.20	-12.2%	71
Zinc	14	15	50	19.65	-1.4%	71
Molybdenum	2.4	2	5.2	2.43	-13.6%	77
Cadmium	0.07	0.12	0.28	0.14	-6.1%	80
Cobalt	2.6	2.5	5.3	2.87	-1.0%	81
Chromium	15	17	33	19.13	-56.8%	83
Copper	12	12	23	13.46	-6.9%	83
Vanadium	15	17	27	18.33	-6.2%	87
Berylium	0.75	0.81	0.99	0.83	-22.2%	91
Antimony	0.06	0.2	0.13	0.19	-40.3%	98

*Based on equal Btu's to burner.

A measure of the uncertainty in these results is the difference between the measured value for feed samples and that calculated on a composite of the mill product and reject. The average percentage difference between concentration measurements based on feed is compared for the two coals in Table VIII.

Table VIII. Average Percentage Difference Between Concentration Measurements

	Upper Freeport		**Lower Kittanning**	
Measurements	**Average of Percent Difference**	**Standard Deviation**	**Average of Percent Difference**	**Standard Deviation**
Ash, Forms of Sulfur, and $LbSO_2$/MBtu	-3.7	8.5	-0.5	5.9
Trace Metals	3.1	10.8	-35.4	55.1

Trace metal measurements for the Upper Freeport coal exhibited uncertainties in line with those of the measurements of ash, etc., while uncertainties in the trace metal measurements for the Lower Kittanning coal are an order of magnitude greater. The reason for this is not understood at this time.

COMPUTATIONAL MODEL

ETCi is developing a computational model of grinding along the lines given by Austin and Luckie.[4] In the current version of the ETCi model, measurements of the size distribution and quality of coal emerging from the grinding zone are input to the program. Using results of laboratory measurements of magnetic separator performance on mill reject samples, the program calculates the effects of the magnetic separator loop on the quantity and quality of coal produced by the mill. Figure 4 shows the comparison of predictions and measurements of reductions in ash, sulfur, pyritic sulfur, and $LbSO_2$/MBtu for four of the beta prototype runs (represented by different symbols) employing the Upper Freeport coal. A similar comparison is shown in Figure 5 for the Lower Kittanning coal. Only runs for which the product fineness was between 67 and 75% finer than 200 mesh were considered. The runs employed a wide range of mill sampling and magnetic separator operation alternatives. Agreement is encouraging.

[4] L. G. Austin and P. T. Luckie, 1982, "An Analysis of Ball-and-Race Milling Scale-up to Industrial Mills," Power Technology, Vol. 33, pp. 127-134.

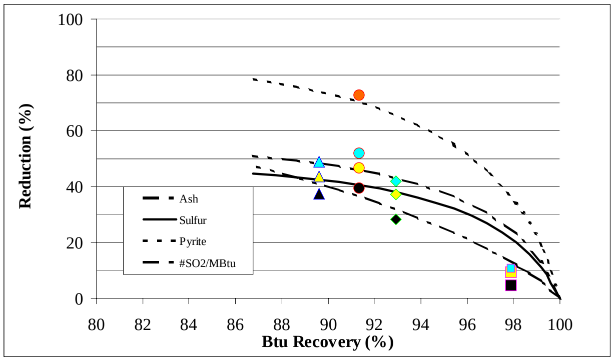

Figure 4. Comparison of Predictions and Measurements, Upper Freeport Coal

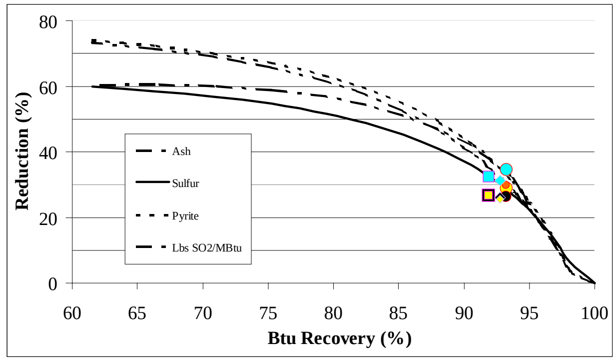

Figure 5. Comparison of Predictions and Measurements, Lower Kittanning Coal.

SUMMARY

Operation of the beta prototype has shown that the MagMill™ is capable of efficient dry cleaning of coal including separation of trace metals. Similar results obtained in sampling of power plant pulverizers are reported by Brandner (Footnote 1). Comparison of tests with prediction has provided a validation of the simulation of grinding. The technology offers the potential for low cost pre-combustion separation of mercury and arsenic for existing and advanced coal fired power plants.

ACKNOWLEDGEMENTS

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