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# *Dry Coal Cleaning with a MagMill™*

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## ABSTRACT

This paper presents preliminary test results obtained with a 0.38 kg/s (3000 lb-hr) beta prototype MagMill™. In processing Upper Freeport coal the beta prototype. recovered 82% of the weight of the feed and 91% of the heat content while reducing the potential emissions of sulfur, $kgSO_2/GJ$ ($lbSO_2/MBtu$), by 61%. Pyritic sulfur in the MagMill™ product was reduced by 78% compared to that in the feed. For all runs, the mill product was controlled between 70 to 80% finer than 74 μ particle size. Recoveries of mercury, arsenic, and selenium ranged from 35 to 45% of that in the feed. Power draw was reduced by 26% and mill throughput was increased by 9% compared to the pulverizer operating with no magnetic separator attached.


## 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 A concentrated stream of inorganic minerals is withdrawn from the pulverizer and processed by the magnetic separator. 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.

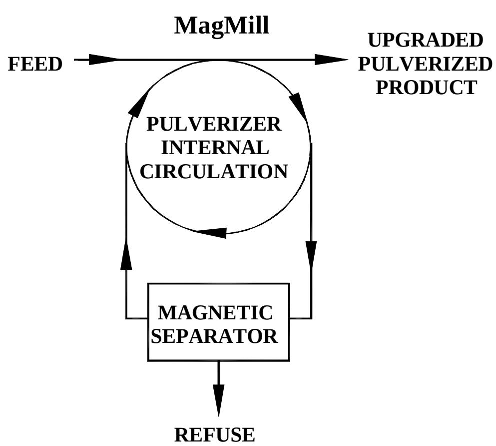


Figure 1. MagMill™ Concept

This 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 (Oder, 1999). Coal dependent, the net gain for the power plant can be significant. It is estimated that Eastern US pulverized coal fired power plants can save between $2 and $4 per 0.907 metric ton (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.

## MagMill™ CONCEPT

Coal is pulverized to reduce the particle size which improves combustion characteristics. A variety of mills are employed in power plants; a Babcock & Wilcox MPS 89 mill shown in Figure 2 is used here as an example. This is an air swept mill which produces coal which is 70% to 80% finer than 200 mesh or 74 μ. Coal is fed onto the surface of a rotating table in the grinding zone where it is crushed as the table rotates underneath large and heavy tires. 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. Ash and sulfur concentrate in this stream.

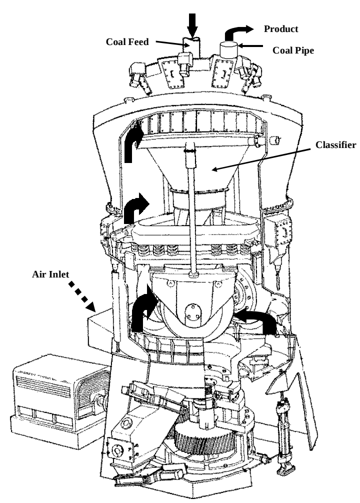


Figure 2. B&W MPS 89 Roller Mill

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, and 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.

A MagMill™ employs any one or a combination of dry separation methods including screening and electric and magnetic separation. It separates mineral gangue at a topsize smaller than that used in cleaning at the mine.

## FEASIBILITY TESTING

Feasibility testing has been carried out on operating pulverizers at the coal fired power plants in Pennsylvania, West Virginia, and Illinois shown in Table I. Samples of the internal circulation were obtained using test ports installed on the pulverizer. Magnetic separation tests were performed on the mill samples using a laboratory scale ParaTrap™ (Oder, 1991) magnetic separator 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 kg/s (tph) |
|---|---|---|---|
| Allegheny Power | PA | D-8 Ball | 9.3 (37) |
| Allegheny Power | WV | 823 Bowl<br>MPS 89 Roller | 11.3 (45)<br>12.9 (51) |
| Ameren/CIPS | IL | 633 Bowl | 4.0 (16) |

Table II summarizes projections of MagMill™ performance based on feasibility testing on an MPS 89 roller mill and an 823 bowl mill at the Allegheny Power Fort Martin Generating Station in Maidsville, WV and on a 633 bowl mill at the Ameren/CIPS Meredosia Generating Station in Meredosia, IL. The coals at Fort Martin were blends of deep cleaned coal from Southern Appalachia and coals from Southwestern Pennsylvania. Both coals at Meredosia came from the New Monterey No. 1 mine. One is a raw coal, the other a blend of raw and deep washed coal. Ash reductions between 12 and 22% and sulfur reductions between 28 and 45% were projected with heat recoveries ranging from 91 to 97%.

**Table II. Projected MagMill™ Performance**

| | Mill Feed | | Projected MagMill™ Performance | | |
|---|---|---|---|---|---|
| | **Concentration, wt. %** | | **Heat Rec. %** | **Concentration, wt. %** | |
| **Mill** | **Ash** | **Sulfur** | | **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*** |

* Fort Martin Generating Station
** Ameren/CIPS Meredosia Station
***Organic Sulfur Level

## PROTOTYPE TESTING

### Alpha Prototype MagMill™

ETCi has built and operates a 0.024 kg/s (200 lb-hr) alpha prototype MagMill™ which is used to demonstrate the concept and to develop input for ETCi's grinding model. This mill combines a continuously operating air-swept hammermill, modified for extraction of hard minerals, and a 0.024 kg/s (200 lb-hr) ParaTrap™ magnetic separator. It produces a product in the nominal minus 100 mesh or 0.149 mm size fraction. The flow sheet for the alpha prototype is shown in Figure 3.

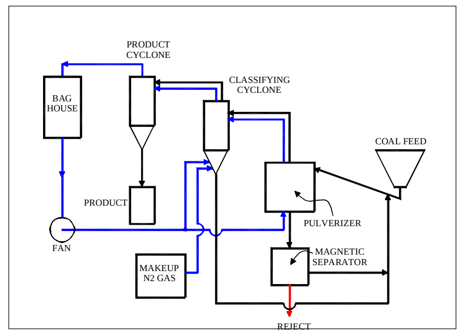


Figure 3. Flow Diagram for Alpha Prototype MagMill™

### 0.36 kg/s (3000 lb-hr) Beta Prototype MagMill™

Recently a 0.24 kg/s (one tph) ParaTrap™ magnetic separator was retrofitted to a 0.36 kg/s (3000 lb-hr) Hercules air swept ring/roller pulverizer at the pilot facilities of the Bradley Pulverizer company in Allentown, PA. A photograph of the prototype is shown in Figure 4. The ParaTrap™ separator is skid mounted so it can be moved to different sites for testing. The attachment of the magnet to the pulverizer is shown in Figure 4.

Figure 4. Beta Prototype MagMill™

The results of testing the prototype are of a preliminary nature. Time was not available to optimize the combined unit.

Characteristics of the raw Pennsylvania coals tested are shown in Table III.

**Table III. Characteristics of Test Coals**

| | 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 |
| Moisture, % | | |
| MJ/kg (Btu/lb) | 28.3 (12167) | 28.0 (12055) |
| HGI | 68 | 78 |

Pulverizer Operation and Control. The mill operation is controlled by mill and fan power draw and by internal pressure drop. The mill power draw is maintained constant during a run by automatically adjusting the coal feed rate. The fan power draw is chosen to provide the appropriate product fineness, 70 to 80% passing 200 mesh or 74 $\mu$, measured on line by a laser particle size analyzer, while maintaining a 519 Pa (2 in. w.c.) pressure drop across the classifier cyclone. A damper was used to maintain –259 Pa (-1 in. w.c.) in the mill base.

MagMill™ Circuit. Coal withdrawn from the mill was first screened to reject oversize material, coarser than 3.36 mm (6 mesh), which was too coarse to pass the second stage of magnetic separation. Oversize coal of very high ash and sulfur was rejected, but included in the material balance, while oversize coal of better quality was returned to the mill for additional size reduction. The undersize coal is fed to a two stage separator. The flow sheet is shown in Figure 5.

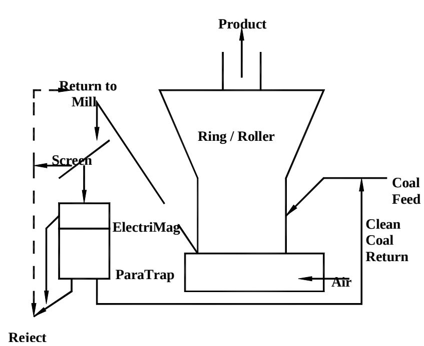


Figure 5. Beta Prototype Flow Sheet

The separator processes mill reject at a rate up to nominally 0.24 kg/s (2000 pounds per hour). It consists of a first stage ElectriMag™ Separator (patent pending) which can employ both triboelectric and magnetic fields. It prevents strong magnetic material from entering the flow path of the second stage ParaTrap™ magnetic separator and separates carbon fines for return to the pulverizer which otherwise might interfere with the operation of the second stage. The combined apparatus produces a clean coal for return to the pulverizer and a refuse fraction for discarding.

Samples of screen oversize, magnet reject, and mill product were taken every 600 s (10 minutes). Mill operating parameters including product particle size, mill power draw, mill fan draw, static pressure in mill base, and classifier pressure drop were recorded 12 times 60 s. For several runs, grab samples of the clean coal return and the mill reject streams feeding the first stage were also taken every 600 s (10 minutes).

Results. 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 0.238 kg/s (1980 lb/hr). The mill and fan consumed energy at the rate of 89.7 J/g (22.6 kw-hr per ton). MagMill™ operating conditions were varied for the remaining six runs. The gross chemical analysis 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 while reducing the potential emissions of sulfur, kg$SO_2$/GJ (lb$SO_2$/MBtu), by 61%. Pyritic sulfur in the MagMill™ product has been reduced by 78% compared to that in the feed.

**Table IV. Analysis of MagMill™ Products**

| Dry Basis | Feed | Mill Product | Reject | Cumulative Product & Reject | % Recovery |
|---|---|---|---|---|---|
| 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 | |
| Heat MJ/kg (Btu/lb) | 28.3 (12167) | 31.5 (13528) | 13.7 (5908) | 28.2 (12135) | 91.10 |
| kg$SO_2$/GJ (lb$SO_2$/MBtu | 1.72 (3.99) | 0.9 (2.11) | 12.1 (28.1) | 1.81 (4.42) | 39.07 |
| Volatiles | 28.06 | 30.95 | | | |
| HGI | 68 | | | | |

Measurements of trace metals for this run are summarized in Table V where the list of elements has been sorted by recovery in the MagMill™ product. One half of the 16 trace metals, including mercury, arsenic, and selenium, measured for the feed coal had recoveries of less than 50% in the MagMill™ product. Recalling that the recovery of iron pyrite was 22%, it is apparent that arsenic and pyrite are closely related for this coal.

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

| | Mill | | | Cumulative Product & Reject | % Difference with Feed | % Recovery |
|---|---|---|---|---|---|---|
| | Feed | Product | Reject | | | |
| **Thallium** | 1.40 | 0.47 | 5.70 | 1.43 | 1.8% | 27 |
| **Arsenic** | 55.00 | 18.00 | 190.00 | 49.43 | -10.1% | 30 |
| **Lead** | 12.00 | 4.60 | 40.00 | 11.07 | -7.8% | 34 |
| **Mercury** | 0.37 | 0.18 | 1.40 | 0.40 | 8.9% | 37 |
| **Nickel** | 13.00 | 9.30 | 51.00 | 16.92 | 30.2% | 45 |
| **Selenium** | 2.40 | 1.30 | 6.90 | 2.32 | -3.2% | 46 |
| **Manganese** | 33.00 | 17.00 | 85.00 | 29.43 | -10.8% | 47 |
| **Copper** | 15.00 | 9.60 | 45.00 | 16.07 | 7.1% | 49 |
| **Cobalt** | 4.10 | 2.70 | 11.00 | 4.22 | 2.9% | 52 |
| **Molybdenum** | 2.30 | 1.80 | 5.40 | 2.46 | 6.9% | 60 |
| **Chromium** | 19.00 | 18.00 | 34.00 | 20.92 | 10.1% | 70 |
| **Zinc** | 19.00 | 19.00 | 35.00 | 21.92 | 15.4% | 71 |
| **Vanadium** | 22.00 | 23.00 | 28.00 | 23.91 | 8.7% | 79 |
| **Berylium** | 1.20 | 1.20 | 1.20 | 1.20 | 0.0% | 82 |
| **Cadmium** | 0.22 | 0.21 | 0.15 | 0.20 | -9.5% | 86 |
| **Antimony** | 0.22 | 0.23 | 0.16 | 0.22 | -1.3% | 87 |

After steady state had been achieved, the power draw for the MagMill™, 72.9 (16.7 kw-hr/T), was 26% less that for the unmodified mill. Similarly, the throughput was increased to 0.26 Gkg/s (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.

ETCi is developing a computational model of grinding based on the work of Austin and Luckie (Austin, 1982). In the ETCi model, as developed at this point in time, 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 in the mill. Figure 6 shows the comparison of predictions and measurements of reductions in ash, sulfur, pyritic sulfur, and $kgSO_2/GJ$ ($lbSO_2/MBtu$) for four of the beta prototype runs (represented by different symbols) employing the Upper Freeport coal. The runs employed a wide range of mill sampling and magnetic separator operation alternatives. Agreement is encouraging.

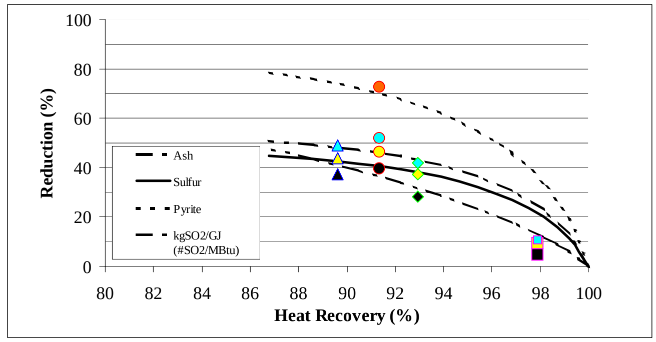

Figure 6. Comparison of Predictions and Measurements

## SUMMARY


Operation of the beta prototype has shown that the MagMill™ is capable of efficient cleaning of coal including separation of trace metals. Comparison of tests with prediction has provided a validation of the simulation of grinding. Reporting of the results for the Lower Kittanning coal and presentation of results of processing of deep clean coals is planned in the future. The technology offers the potential for low cost preparation of fuels for existing and advanced coal fired power plants.


## ACKNOWLEDGEMENTS


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