

Removal of Selected Hazardous Air Pollutant Precursors by Dry Magnetic Separation

E. D. Brandner, R. R. Oder and R. E. Jamison
EXPORTech Company, Inc.
Building 242, Schreiber Industrial District, P.O. Box 588
New Kensington, PA 15068-0588
724-337-4415 / FAX 724-337-4470 / magsep@sgi.net
www.magneticseparation.com

ABSTRACT

Most trace elements in coal are associated with minerals that are removed by the MagMill™ (patent pending). In previous measurements, we found significant reductions of major trace elements (mercury, arsenic, selenium, and many others) by dry magnetic separation alone. In recent but separate measurements using a 3000 Lb/Hr beta prototype MagMill™, concentrations of trace elements including mercury, arsenic, selenium, beryllium, cadmium, chromium, cobalt, copper, lead, manganese, molybdenum, nickel, thallium, vanadium, and zinc were reduced in the clean coal product and concentrated in the mineral rich fraction removed from the coal.¹ In this paper, we report measurements and reductions of sulfur, mineral matter, and trace elements for three U.S. coals — a western Adaville-series coal, an eastern Upper Kittanning coal, and an eastern Pittsburgh seam coal.

INTRODUCTION

New EPA regulations are being considered for certain trace elements known as hazardous air pollutant precursors (HAPs). Some HAPs are found in coal and are released into the environment in the coal combustion process. Of the HAPs, mercury, arsenic, and selenium are of particular concern. Other HAPs can be controlled by efficient particulate control technology, but mercury, arsenic, and selenium can escape particulate controls and exit the power plant. Effective control of mercury, arsenic, and selenium will require new technologies.²

The MagMill™ is a new technology that removes mercury, arsenic, selenium, and iron pyrites from coal *before* combustion. The MagMill™ is a multi-stage magnetic separator

¹ 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, February 28-March 1, 2000, Salt Lake City, UT.

² Brown et al., "Mercury Measurement and Its Control: What We Know, Have Learned, and Need to Further Investigate," J. of the Air & Waste Management Association. p. 4, (June, 1999); U.S. Department of Energy Program Research and Development Announcement DE-RA26-98FT97098, "Solid Fuels and Feedstocks Grand Challenge."

retrofitted to a pulverizer at a power plant. A portion of the coal inside of the pulverizer (mill concentrated sample illustrated in Figure 3) is removed and fed to the magnetic separator. The magnetic separator removes paramagnetic particles (i.e., iron pyrites and many ash components) from the coal and returns the cleaned coal to the mill. The volume of material treated is several orders of magnitude greater than that removed through pyrite traps.

Trace elements are also removed because of their association with iron pyrites or ash forming minerals.³ Figures 1 and 2 illustrate the associations of mercury and arsenic with pyrite. The data curve shows a statistical relationship between mercury and pyrite measurements for coal samples taken from GPU/Sithe's Shawville Generating Station and discussed below. The image is an SEM micrograph of a pyrite particle coated with arsenic⁴ (arsenic covers the majority of the particle).

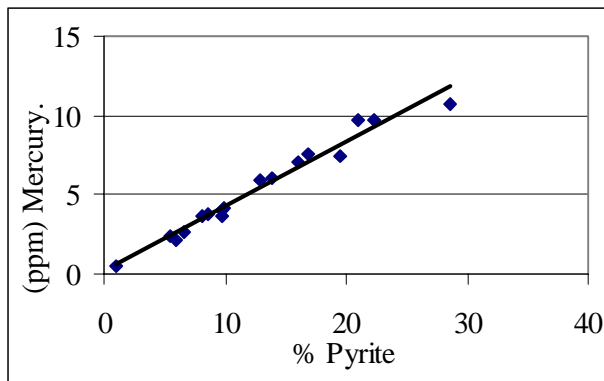


Figure 1. Associations of Mercury and Pyrite

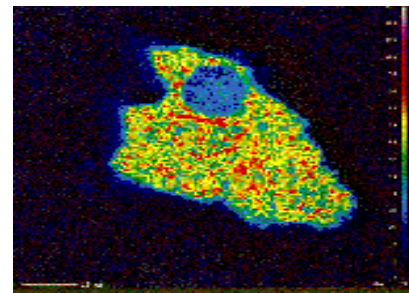


Figure 2. SEM Micrograph of a Pyrite Particle Coated with Arsenic⁴

In order to test the feasibility of the MagMill™, EXPORTech has sampled many different pulverizers and gathered many different coal mine samples to be separated in laboratory-scale magnetic separators. The current program, supported by the EPRI Upgraded Coal Interest Group (UCIG) and the U.S. Department of Energy, is investigating three different coals. Using dry magnetic separation, we have tested the removal of trace metals from the raw coals and mill concentrated samples prepared from these coals. The following diagrams identify the source of the material that was separated. The diagram on the left illustrates magnetic separation of the raw coal. The diagram on the right illustrates magnetic separation of a mill concentrated sample. For a MagMill™ installation, the “Clean Coal” from the magnetic separator in the diagram to the right would be returned to the mill (this will be illustrated by a return arrow to the mill).

³ Finkelman, Robert B., “The Use of Modes of Occurrence Information to Predict the Removal of the HAPs Prior to Combustion,” J. Coal Qual. 12, n. 4, p. 132(3), (Oct-Dec, 1993).

⁴ David J. Akers, et al., “HAPs-Rx™: Precombustion Removal of Hazardous Air Pollutant Precursors,” Proc., 1997 Coal Liquefaction & Solid Fuels Contractors Review Conference, September, 1997.

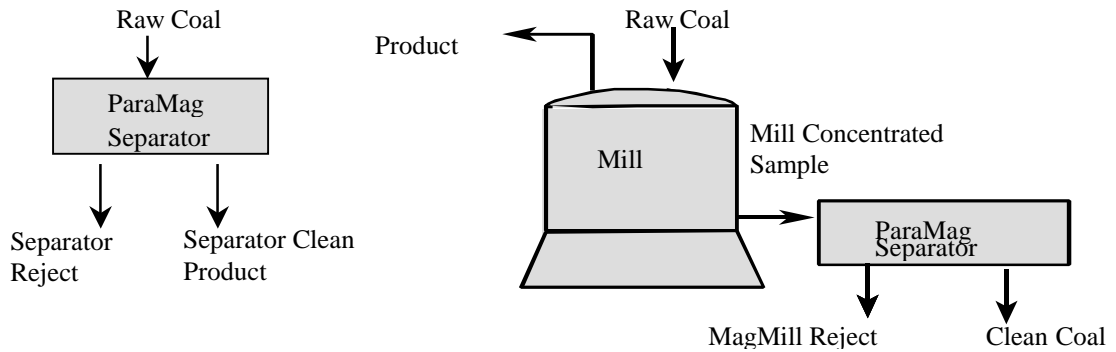


Figure 3. Sources of Material Processed

TEST COALS

The three raw test coals are an Upper Kittanning coal from north central Pennsylvania, an Adaville-series coal from Wyoming, and a Pittsburgh seam coal from southwestern Pennsylvania. Mill concentrated samples from the following two mills have also been gathered for analysis. At the time of sampling, Mill 4C at GPU/Sithe's Shawville Generating Station in north central Pennsylvania was grinding a blend of coals including the raw Upper Kittanning coal. Mill 5E at a second power generating station was grinding a deep cleaned Pittsburgh seam coal from the same source used for the work reported here.

Raw Coals

The characterizations of the raw test coals are summarized in Figure 4.

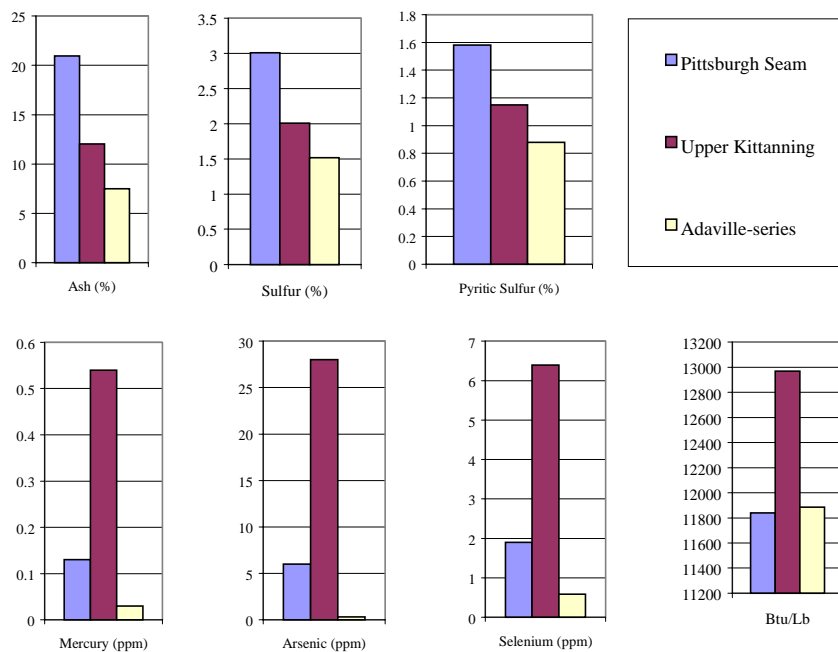


Figure 4. Characteristics of Raw Test Coals

The ash, sulfur, and pyritic sulfur concentrations for the raw Pittsburgh seam coal are the highest of the three coals. This coal is long-wall mined and represents the coal fed to the preparation plant which cleans the coal. The highest concentrations of mercury, arsenic, and selenium are observed in the raw Upper Kittanning coal.

The mercury, arsenic, and selenium concentrations in these raw coals have been reduced by magnetic separation. Figure 5 plots the reductions in $\text{LbSO}_2/\text{MBtu}$ as a function of the Btu's recovered in the clean coal fraction of the separation. At a Btu recovery between 90 and 95 %, the trace elements, pyrites, and ash were also measured and plotted.

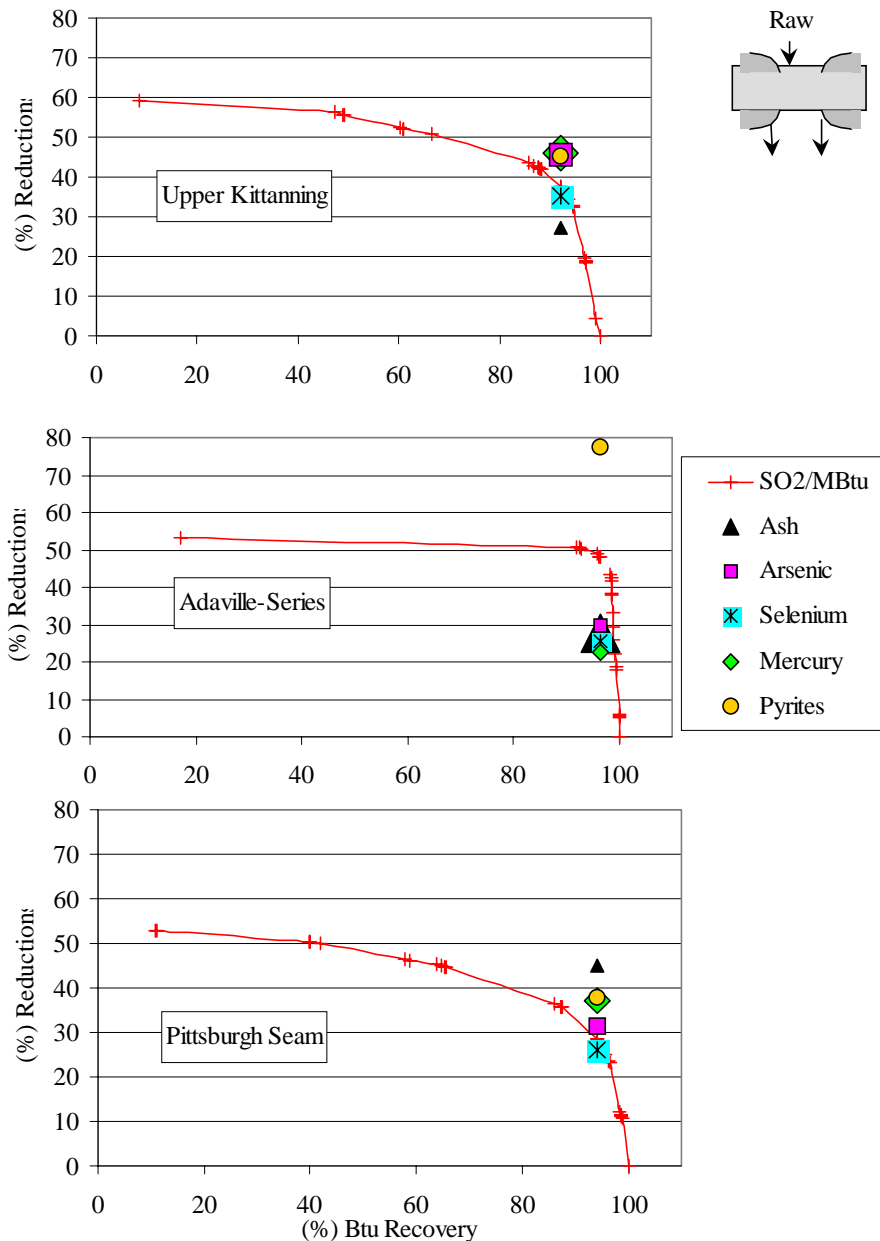


Figure 5. Measured Reductions in $\text{LbSO}_2/\text{MBtu}$

The $\text{LbSO}_2/\text{MBtu}$ curve is calculated from measured reductions in ash and sulfur as a function of Btu recovery. Sulfur reductions result from pyrite reductions. 90 – 95 % Btu recovery was targeted for the trace element measurements shown, but if lower recoveries of Btu's are tolerable, greater reductions in ash, pyrites, and trace elements can be achieved.

The observation that the mercury reductions and pyrite reductions are nearly equal in the Upper Kittanning coal and also in the Pittsburgh seam coal supports the statistical relationship of mercury with pyrites. This is also true for the arsenic reduction in the Upper Kittanning coal.

Mill Concentrated Samples

Figure 6 illustrates the location of some of the sampling ports on Mill 4C, an ABB CE Raymond 633 bowl mill at the GPU/Sithe Shawville Station.

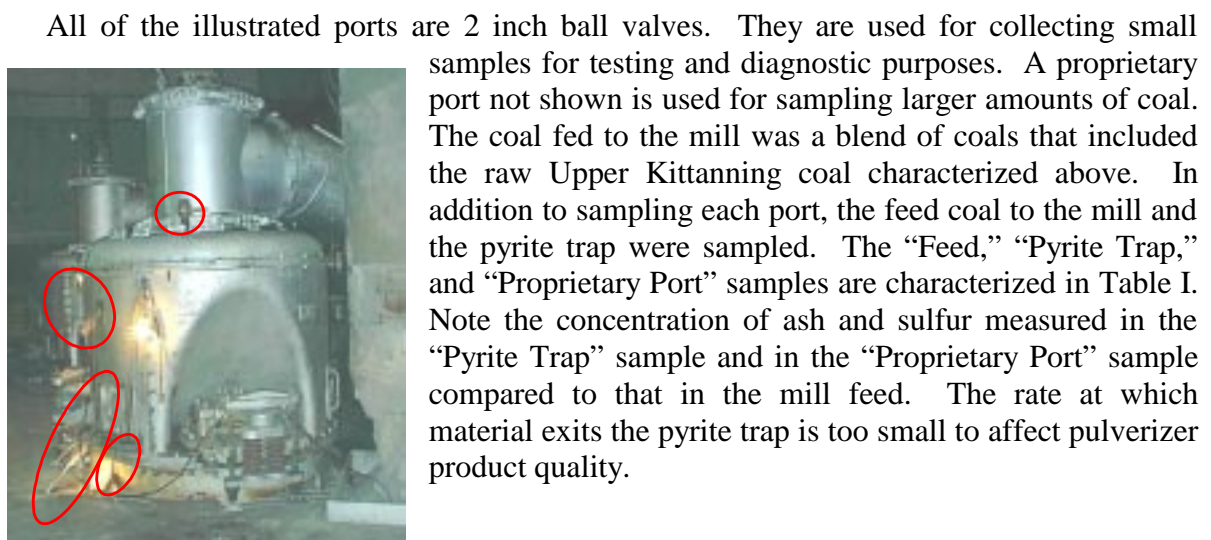


Figure 6. Sampling Port Locations

All of the illustrated ports are 2 inch ball valves. They are used for collecting small samples for testing and diagnostic purposes. A proprietary port not shown is used for sampling larger amounts of coal. The coal fed to the mill was a blend of coals that included the raw Upper Kittanning coal characterized above. In addition to sampling each port, the feed coal to the mill and the pyrite trap were sampled. The “Feed,” “Pyrite Trap,” and “Proprietary Port” samples are characterized in Table I. Note the concentration of ash and sulfur measured in the “Pyrite Trap” sample and in the “Proprietary Port” sample compared to that in the mill feed. The rate at which material exits the pyrite trap is too small to affect pulverizer product quality.

Table I. Characterization of Shawville Samples

Port	Ash (%)	Sulfur (%)	Btu/Lb	Rate (Lb/Hr)
Mill Feed	14.39	1.98	13005	26600
Proprietary Port	32.64	10.97	10045	414
Pyrite Trap	66.20	24.06	3141	54

As an example of magnetic separator performance, the reductions in $\text{LbSO}_2/\text{MBtu}$ are plotted versus percent Btu recoveries in Figure 7 for the mill concentrated sample withdrawn through the “Proprietary Port.” At 83% Btu recovery, measured reductions in pyrite, ash, mercury, arsenic, and selenium are also plotted. The curve is a running average of reductions in $\text{LbSO}_2/\text{MBtu}$ versus Btu recovery.

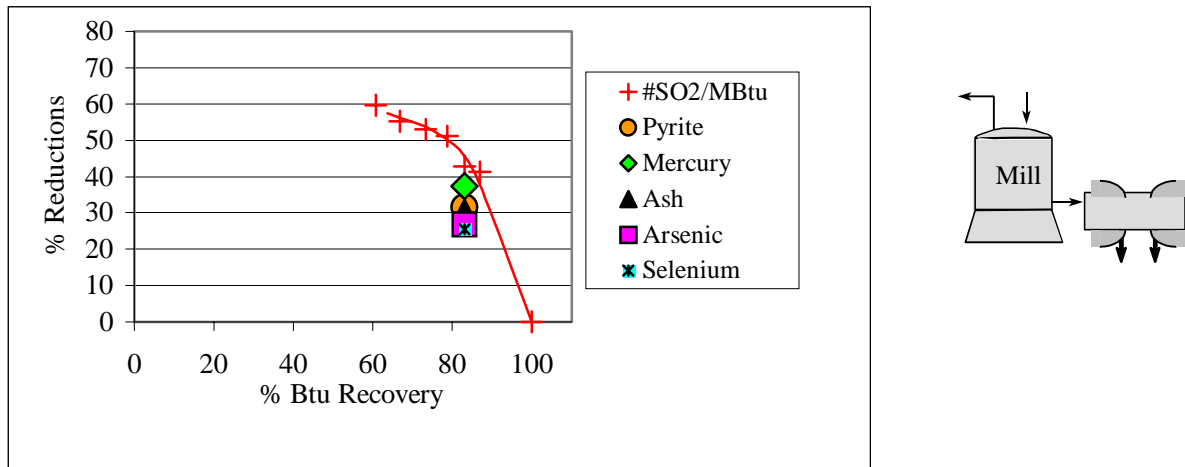


Figure 7. Magnetic Separation of Shawville Mill 4C Concentrated Sample

These measurements have been entered into ETCi's MagMill™ modeler to project potential reductions in the product for Mill 4C at Shawville. The modeler includes a mill grinding loop and a magnet beneficiation loop. The grinding loop is set-up by entering the measured characteristics of the feed coal and adjusting its grinding characteristics. These grinding characteristics are based on Rosin-Rammler parameters which are adjusted until the modeled material inside the mill matches the measured mill concentrated samples removed from the mill. The magnet beneficiation loop is set-up by simply entering the measured reductions and Btu recoveries illustrated in Figure 7. A major limitation of the mill modeler is the necessity of sampling the mill for each new feed coal used. Modeled reductions in MagMill™ product to the burner pipes based on the measured feed coal to Mill 4C are shown in Figure 8.

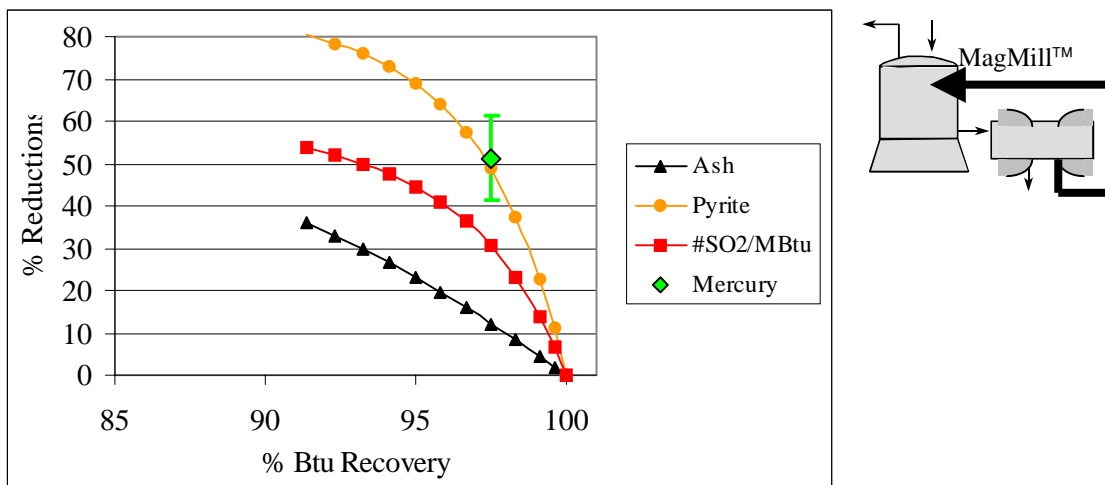


Figure 8. Modeled MagMill™ Product, Mill 4C, Shawville

Each data point represents a different amount of material being cleaned by the magnet beneficiation loop. The modeled product has 50% reductions in pyrite and mercury concentrations at 97% Btu recovery compared to the feed. Because of the greater concentration and liberation of pyritic sulfur and ash, these reductions are better than the reductions observed for the raw coals. The mercury reduction is calculated from a fit of measured mercury concentrations to measured pyrite concentrations for Shawville samples (see Figure 1). As calculated, the error bars grow as pyrite reductions increase.

ETCi has also sampled a Babcock & Wilcox MPS 89K mill. The plant burns a deep cleaned Pittsburgh seam coal from the same source as the raw Pittsburgh seam coal whose characteristics are shown in Figure 4. The analysis of material extracted from this mill is incomplete; however, data taken from the port identified in Figure 9 have been partially analyzed, and are given below.

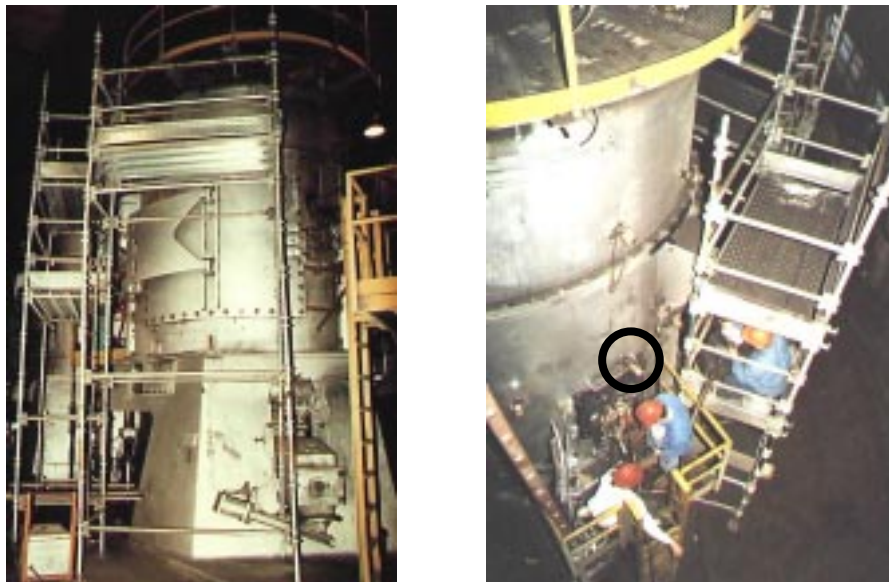


Figure 9. B&W MPS 89K Mill. Note port location identified in the photograph on the right.

Figure 10 illustrates the measured reductions in ash and sulfur and the reduction in $\text{LbSO}_2/\text{MBtu}$ for this port at 94 % Btu recovery. The coal was deep cleaned at the mine site, yet 35% of the remaining sulfur and 25% of the remaining ash in this mill concentrated sample are being removed by the magnetic separator. The mill is liberating ash and sulfur that was not separated by the deep cleaning process, and the magnetic separator is removing them from the mill product.

Mill Feed: 2.32% Sulfur 7.78%
 Magnet Feed: 13.09% Sulfur 21.15%

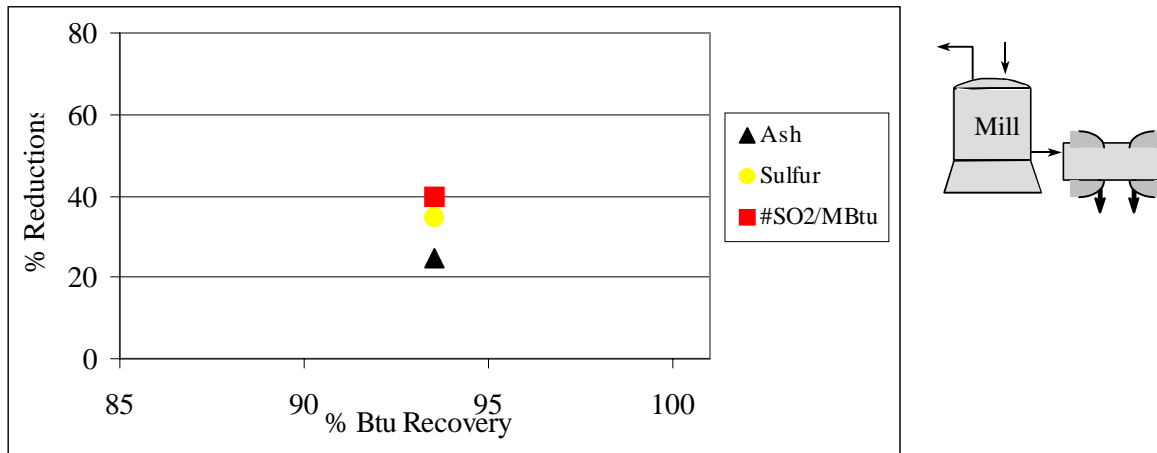


Figure 10. Magnetic Separation of Mill Concentrated Sample from Mill Grinding Deep Cleaned Pittsburgh Seam Coal

CONCLUSIONS

The MagMill™ incorporates a mill and a dry magnetic separator as a beneficiation tool. The mill liberates and concentrates pyrite and ash. Samples of concentrated pyrite and ash are removed from the mill for separation. The magnetic separator rejects pyrite and ash from the samples and returns the cleaned coal to the mill. Trace elements including mercury, arsenic, and selenium are associated with the rejected material. Because of this association, the MagMill™ has the ability to remove these trace elements from coal before burning them. Mercury reductions in excess of 40% have been observed at greater than 90% Btu recoveries.

ACKNOWLEDGEMENTS

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