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The Magnetic Fraction of Coal Fly Ash: Its Separation, Properties, and Utilization

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A laboratory-size electromagnetic device has been built to separate the high-iron magnetic fraction from coal fly ash. Fly ash, the fine particulate matter produced when pulverized coal is burned, contains an average of 18 wt. percent iron expressed as Fe_2O_3 found in a distinctive fraction of finely divided, dense, largely spheroidal particles of high magnetic susceptibility. Seventy to eighty percent of the iron in bituminous coal fly ash is found in this fraction which represents about 20 weight percent or 10 volume percent of the fly ash. In this work the iron-rich fraction has been characterized as to particle size, composition, and density. It appears to have a market potential as a material for preparation of high-density media used in coal washing and other mineral dressing processes. Dense-media material, which costs about $100 per metric ton, is being utilized in increasingly large quantities as the demand for washed coal expands. The magnetic fraction also appears to have potential as a source of iron. If further processing can reduce the silica level found in the fraction as it is separated from the ash, pellets with a composition similar to taconite can be prepared for use as blast furnace feed. Separation and use of this fraction of the coal ash could be profitable for utility companies and could be the beginning of the utilization of the large amount of ash which now constitutes a waste disposal problem.

INDEX DESCRIPTORS: Fly ash, magnetite, coal beneficiation.

Coal fly ash, a waste product of combustion, is being produced in increasing quantities as the use of coal to meet our nation's energy needs continually increases. The reduced availability of fuel oil and natural gas, and the slowed development of nuclear power, have raised coal consumption to unexpected levels. As the demand for coal increases, lower grade, higher ash content coals are being burned. At the same time, better ash removal facilities are more effectively removing ash particles from the combustion gases. Both of these factors tend to further increase coal ash production. The data for coal consumption and ash production during this period of reduced oil and natural gas availability are presented in Figure 1 (1).

Coal ash is collected in two forms, bottom ash which falls from the flame, and fly ash which is entrained in the combustion gases and constitutes about 60 percent of the total. In 1976, over 36 million metric tons of coal fly ash were produced. There are construction and agricultural applications for fly ash, but about 90 percent of the material is buried or ponded as waste. Now utility companies are finding ash disposal more difficult because leachable toxic elements from the ash can contaminate ground water (2-4).

Chemical analysis shows that coal fly ash contains valuable metal constituents, the major ones being aluminum and iron. Figure 2 presents analytical information for fly ash recovered from bituminous coals mined in the United States (5,6). A typical fly ash will contain about 18 wt. percent iron oxide and about 20 wt. percent aluminum oxide.

Table 1. *Composition of Fly Ash and Fractions Obtained by Magnetic Separation*[a]

Constituent	Chemical Composition, Wt. Percent Whole Fly Ash	Magnetics[b]	Nonmagnetics[b]
SiO_2	43.1	9.7	48.4
Al_2O_3	18.0	5.1	19.7
Fe_2O_3	18.8	85.0	6.7
CaO	4.5	0.7	5.3
MgO	0.7	0.8	0.2
TiO_2	0.8	0.8	0.3

[a] Fly ash was collected by mechanical precipitators from a dry bottom type boiler using coal from western Kentucky and southern Illinois. This particular sample was received from the Lakeside Power Plant, Milwaukee, Wisconsin.

[b] Whole fly ash separated as 15 wt. percent magnetics and 85 wt. percent nonmagnetics.

SEPARATION OF FLY ASH FRACTIONS

Our research has shown that the major part of the iron oxide in fly ash can be separated by taking advantage of its magnetic susceptibility. Using a low gradient electromagnetic separator, about 70 to 80 percent of the iron can be extracted from the bulk of the ash, and the aluminum oxide and silicon oxide contents in the magnetic fraction will each be about 10 wt. percent or less. To accomplish this separation, the laboratory-scale moving field electromagnetic device shown in Figure 3(a) was designed and built. Dry fly ash material is fed by a vibrator into

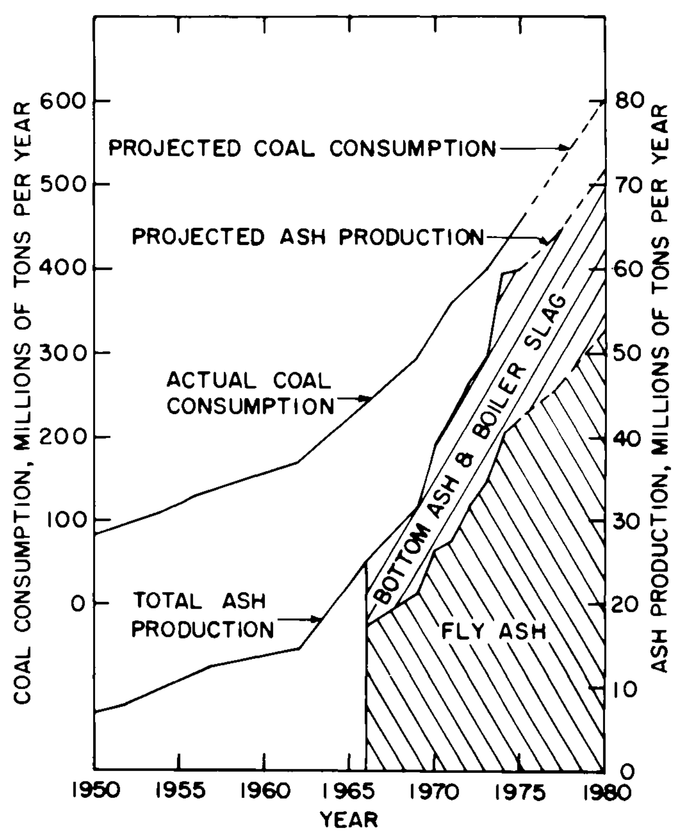


Figure 1. Coal consumption and ash production by U.S. electric utilities (1).

the magnetic field, and magnetically susceptible particles are drawn to and pulled along the magnetic surface. The nonmagnetic particles remain on the vibrator tray and fall off the end of the tray. Figure 3(b) shows the separator in operation. The magnetic particles agglomerate and then, due to collisions with one another, fall from the magnetic field into a receiver. Both fly ash fractions are passed through the magnetic separation step three times in order to assure a complete separation. Typical analyses of the resultant separated ash fractions are shown on Table 1.

PROPERTIES OF THE MAGNETIC FRACTION OF FLY ASH

The magnetic ash fraction is dense and consists of very small particles. Sieve analyses showed that 71 wt. percent of the material passed through a 325 mesh screen (44 μm particle size or less). To complete the size analysis, the material less than 325 mesh was examined using a Coulter Counter. (Coulter Counter Model TAII, Coulter Electronics, Inc., Hialeah, FL.)This instrument determined particle diameters to one μm by measuring electrical resistivity changes as particles pass through an orifice. Particle size information for the entire magnetic fly ash fraction is shown on Figure 4.

Another indication of the extremely small particles which comprise the magnetic fraction of fly ash is found in the scanning electron microscope photograph shown in Figure 5. The scanning electron microscope provides high magnification observations with a depth of field about three hundred times greater than an optical microscope. From the photograph it is evident that most of the particles are spherical in shape, some with textured surfaces and others quite smooth.

Supplementary information concerning the magnetic fraction was obtained by sectioning individual particles and then chemically analyzing representative ones. Dry ash particles were mounted in a hard plastic material and the surface was then carefully ground to expose

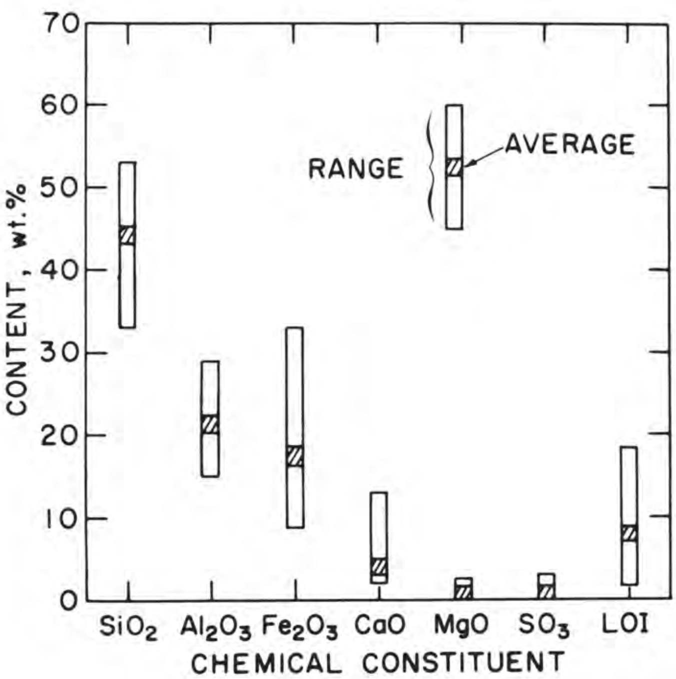
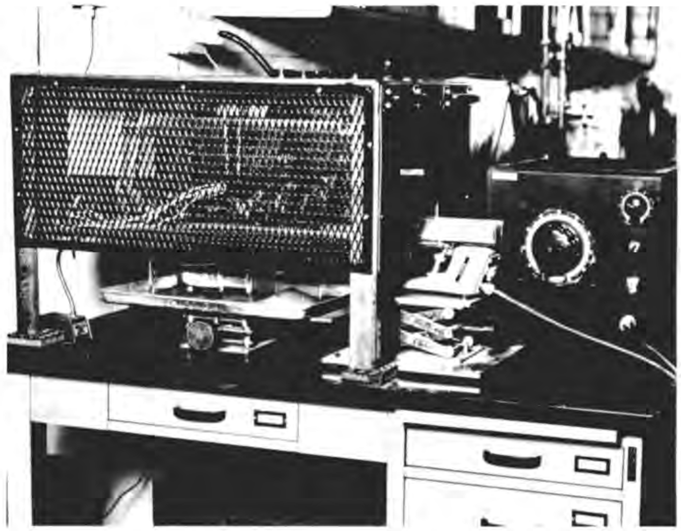


Figure 2. Range and average content of different chemical constituents in United State fly ashes (5, 6).



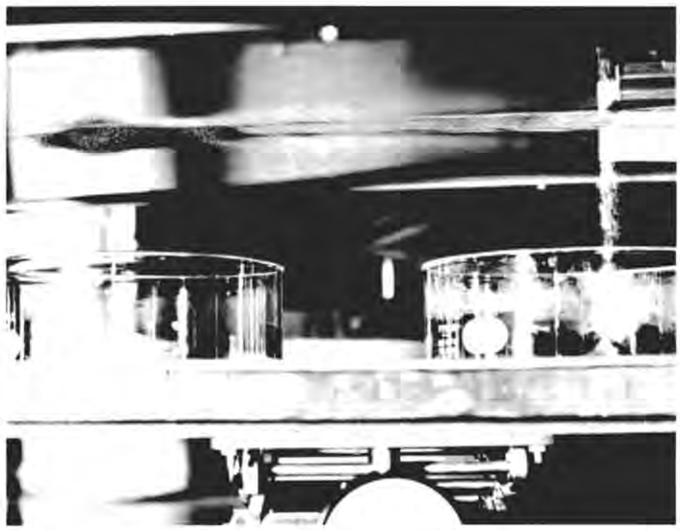


Figure 3. (a) Electromagnetic separation device used to separate ferromagnetic particles from coal fly ash. (b) View of magnet surface showing the magnetic particles on the surface and the non-magnetic ones falling into a collector.

particle interiors. Figure 6 shows photomicrographs of sectioned magnetic fly ash particles. It can be seen that individual particles are quite different, exhibiting separate phases, grain boundaries, twinned crystals, or voids. This would be expected of molten particles which solidify very rapidly and at different rates as they leave the flame.

Chemical analyses of individual sectioned particles were obtained using an electron microprobe. The more reflective particles were found to consist mostly of iron oxide while the darker particles also contained measurable amounts of the oxides of aluminum, silicon, titanium, calcium, and magnesium. Figure 7 shows photographs of two sectioned particles and traces of the x-ray spectra for each as measured with the electron microprobe. The back reflected x-ray spectra have peaks with indicate elemental concentrations in the particles. Elements heavier than fluorine can be detected by the microprobe, and quantitative elemental concentrations of the particles can be calculated from the spectra.

UTILIZATION OF THE MAGNETIC FRACTION OF FLY ASH

About 20 wt. percent, corresponding to about 10 volume percent, of the fly ash can be inexpensively and easily separated magnetically. This high iron, high density fraction can be marketed for use in preparation of high-density media. High density suspensions have many applications in the beneficiation of minerals (7-9) including the washing of coal (10-13). Heavy-media flotation of coal, which removes pyritic sulfur, will be increasingly employed as the need to mine and burn lower quality coal arises. In 1972 almost 265 million metric tons of coal were cleaned and by 1985 this amount may increase to 365 million metric tons (10). Heavy-media consumption is about 0.6 kg/ton of enriched coal (13), so utilization of the magnetic fraction of fly ash in coal processing could provide a substantial market. The heavy-media material used today is either natural magnetite or manufactured ferrosilicon particles. They sell for $100 per metric ton or more.

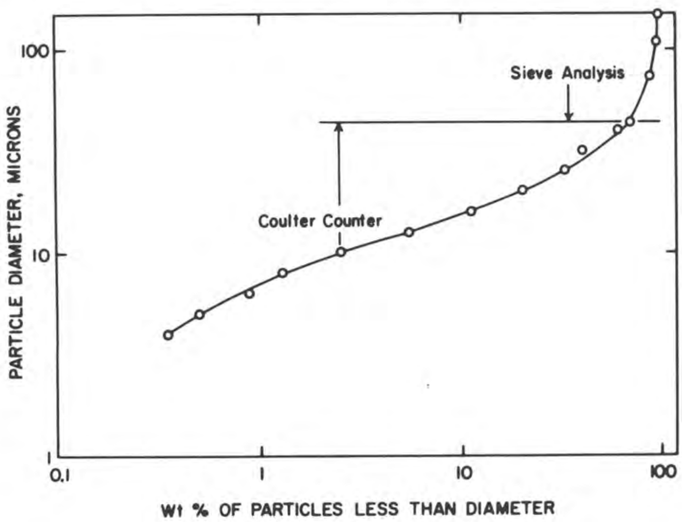


Figure 4. Size analysis of the magnetic fraction of fly ash.

Figure 5. Scanning electron photomicrograph of particles from the magnetic fraction of fly ash, (750 X).

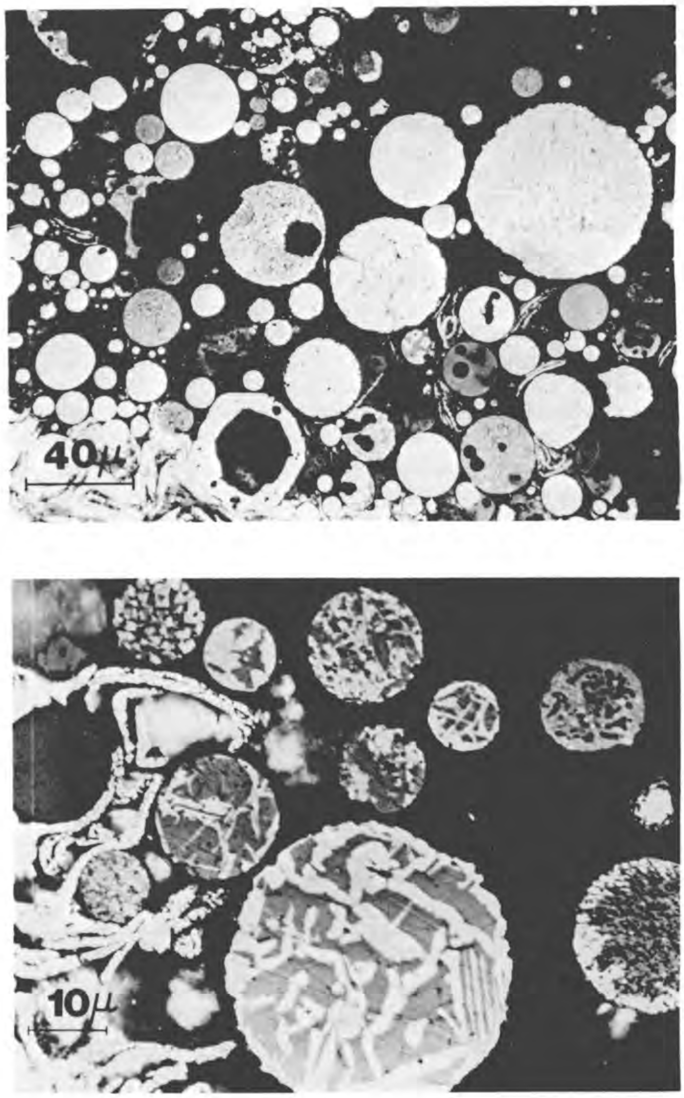
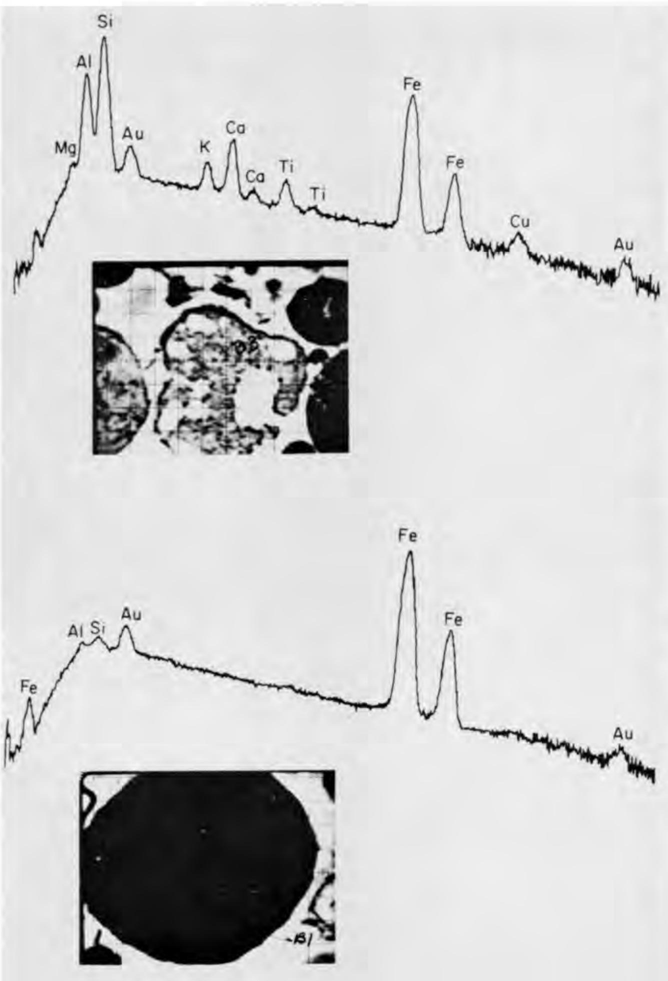


Figure 6. Photomicrographs of the cross-sections of particles from the magnetic fraction of fly ash.

There also may be applications for magnetic fly ash as a seed material in high-intensity, high-gradient magnetic processes for desulfurizing coals (14). This usage may become significant in the future since it has been predicted that over 90 million metric tons of U.S. coal per year may be cleaned in this manner (15).

Another possible use would be as iron ore. The potential iron recovery from the coal fly ash produced by a power plant generating 1,000 MW electrical power would be over 54,000 metric tons per year. To use the magnetic fraction as an iron ore, the contaminate levels of silicon oxide and aluminum oxide would have to be reduced. Various acid and alkali extractions explored to date only have been able to reduce the levels shown in Table 1 by about 50 percent. An acceptable material for blast furnace feed should have a combined silicon and aluminum oxides content of less than 5 wt. percent. When a treatment procedure is developed which will reduce the silicon and aluminum oxides to this level, the next step would be to pelletize and sinter the ash to provide a dust-free, transportable product ready for use in the blast furnace. Utilization of the high-iron fraction as ore would provide about 10 percent of our annual iron requirement, and would reduce iron imports by about one-third. This would improve our balance of payments by a significant amount each year.



SUMMARY

Coal is being used to generate about one-half of our national electrical power requirements (16); in some states it provides over 90 percent. It is our abundant energy resource. The coal mining industry is expanding rapidly and plans are underway for many new, large, coal burning electrical power generation facilities. The usage of coal to meet our national needs may double in the next ten years. This would mean that by 1985 to 1990, the annual coal consumption would be about one billion metric tons, and this would produce about 100 million metric tons of coal fly ash. From this amount of fly ash, 10 million metric tons of iron and 10 million metric tons of aluminum could be recovered.

Most of the iron in the fly ash is contained in magnetically susceptible particles; a magnetic separation will recover 70 to 80 percent of the iron. This concentrate fraction, being dense and of very small particle size, can be used in the preparation of heavy-media suspensions used in coal washing and mineral beneficiation processes, and as a seed material in high-gradient magnetic coal desulfurization processing. With further treatment to remove detrimental impurities, the magnetic ash material holds promise as an ore for iron production.

ACKNOWLEDGEMENT

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