ABSTRACT

Coal burning power plants in Illinois produce a substantial amount of coal combustion byproducts (CCBs) each year. Extracting value-added products from fly ash, a major constituent of CCBs, has been an important research area for the last few decades. On average, fly ash produced from burning Illinois coal contains 15% or more of magnetic materials, the majority of which are fine magnetite particles called fly ash derived magnetite (FAM). This project explores the possibility of substituting FAM for natural magnetite (NM) in preparing and maintaining dense media circuits in coal preparation plants. The incentive for this project is that NM is in short supply in the U.S. and hence has a high market value above $200/ton adding considerably to coal preparation costs.

This study developed a suitable processing scheme to economically extract high-grade magnetite from Illinois coal fly ash. The proprietary flow sheet enriched magnetite content up to 96% in the FAM product from 17% in the fly ash feed. FAM was found to produce a relatively less stable (but not unstable) medium in comparison to that of NM apparently due to the spherical shape and slightly coarser particle size distribution of the former. The coal cleaning performance, i.e., combustible recovery and ash rejection relationships, obtained from a 6-inch diameter dense media cyclone using dense medium prepared from both FAM and NM, were quite similar. However, the density offset with the use of FAM-based dense medium was relatively high. The high density offset did not translate to high product ash content apparently due to the easy cleaning characteristic of the coal used in this study. However, a better understanding of this phenomenon is needed and the suitability of FAM-based medium for a variety of coal types needs to be investigated.

A preliminary economic analysis conducted for a hypothetical mini-plant having a fly ash handling capacity of 100 tons per hour (tph) indicates the cost of FAM extraction to be nearly $5/ton. This cost does not include the cost of thermal drying that will be required to reduce the moisture content of FAM filter cake to near zero level.
EXECUTIVE SUMMARY

This project is of particular importance to Illinois coal because of its high pyritic sulfur content, which is converted to magnetite during the combustion process. Magnetite is a valuable product with a current market value above $200/ton. It is used in coal preparation to form dense media slurries. Fly ash produced from burning Illinois coal, especially using pulverized coal combustion (PCC) type boilers, may have significant (30% in some cases) amounts of magnetite. The aim of this project was to determine if this fly ash derived magnetite (FAM) could be extracted at relatively low costs and proven to form an effective dense medium in coal preparation plants. Successful extraction of magnetite at high grade from fly ash may provide an additional revenue stream to utility companies and thus, greater incentive (financial as well as environmental) to burn Illinois coal.

This study had two major objectives. The first one was to develop a simple and low cost process flow sheet for extracting FAM from Illinois fly ash. The second objective was to study the effectiveness of this FAM as a dense medium for density-based physical separation processes commonly used to clean coarse coal in Illinois and elsewhere. In the single study of similar kind conducted on Illinois coal fly ash (also funded by the ICCI), Honaker et al. (1997) were successful in recommending a process flow sheet to enrich magnetite present in fly ash to a very high grade but at low recovery. The flow sheet utilized four stages of concentration; two using dry magnetic separation and two using wet magnetic separation. Such a process can be very cost intensive. An investigation into the utility of FAM was beyond the scope of this previous study.

A proprietary process flow sheet has been developed in the present study to extract magnetite at high grade and relatively high recovery from Illinois coal fly ash. Magnetite content of 17% in feed fly ash was enriched up to 96% in the FAM product using the newly developed flowsheet.

FAM was found to be lighter and slightly coarser than natural magnetite (NM) commonly used for dense medium applications. FAM particles were found to have solid specific gravity in the range of 3.53 to 3.61 in comparison to the range of 4.78 to 4.92 for NM. Although the d₈₀ of both FAM and NM particles were nearly 55 micron, approximately 28% and 6% of FAM were finer than 45 micron and 22 micron, respectively, whereas corresponding figures for NM particles were 42% and 21%. The spherical shape of FAM particles and their slightly coarser size distribution affected the stability of dense medium to some extent. However, FAM-based dense medium of 1.4 and 1.3 densities were sufficiently stable to conduct dense medium cyclone tests and evaluate FAM’s suitability for dense medium applications.

Combustible recovery and ash rejection relationships obtained from a 6-inch diameter dense medium cyclone using dense medium prepared with FAM and NM were quite similar. The probable error (Eₚ) for dense medium cyclone tests conducted using FAM-based medium was ~0.06, which compares favorably with the probable error obtained from NM-based dense medium for cleaning 2.4 mm x 0.6 mm coal. However, the
density offset of ~0.35 obtained using FAM-based dense medium was high. For FAM medium densities of 1.4 and 1.3, the respective specific gravity of separations obtained from the dense medium cyclone were 1.74 and 1.73. This high density offset did not result in high ash content in the product apparently due to easy cleaning characteristics of the coal used in this study. However, a better understanding of this phenomenon is needed and the suitability of FAM-based medium for a variety of coal types needs to be investigated.

A preliminary economic analysis conducted for a hypothetical mini-plant producing nearly 14 tons per hour (tph) of FAM by treating 100 tph of fly ash indicated the cost of FAM extraction to be nearly $5/ton. However, this cost does not include the cost of thermal drying that will be required to reduce the moisture content of FAM filter cake to near zero level. In addition, this cost analysis also assumes that fly ash is freely available at the utility plant site where the FAM extraction plant would be located.

A civil engineering study conducted to investigate the effect of FAM extraction on the compressive strength property of residual non-magnetic fly ash failed to produce a conclusive finding. Concrete specimens prepared using 10% and 30% fly ash replacements (percentage of cement replaced in a concrete mix by fly ash) indicated that the compressive strength does not change due to FAM extraction. However, specimens using 20% fly ash replacement indicated that compressive strength does change due to FAM extraction. A more comprehensive civil engineering study needs to be conducted to investigate the effect of FAM extraction on useful properties of the remaining fly ash and to take suitable measures required to remediate any loss in strength and other properties of the residual fly ash.