Technology Development for Carbon-Ash Beneficiation by Pneumatic Transport, Triboelectric Processing

John M. Stencel[1], Tian Xiang Li[1], Tapiwa Gurupira[1], Charles Jones[1], James K. Neathery,[1] Heng Ban[2] and Ralph Altman[3]

[1]Center for Applied Energy Research, University of Kentucky, Lexington, KY 40511

[2]Southern Research Institute, 2000 Ninth Avenue South, Birmingham, AL 35255

[3]EPRI, Franklin Building, Suite 513, 5726 Marlin Road, Chattanooga, TN 37411

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ABSTRACT

Fly ash with high unburned carbon, often measured as loss-on-ignition or LOI, is not acceptable for applications such as concrete production. High LOI's in fly ashes are becoming more of a problem with the installation of low NO_x burners. Therefore, an efficient and economic dry beneficiation technology that removes carbon from fly ash can generate significant economic and environmental benefits for the power industry.

As a alternative to floatation and carbon burnout, triboelectrostatic separation using new gas transport technology has the potential for low cost, dry beneficiation of high LOI fly ash. The applicability of this pneumatic technology to a wide variety of fly ashes has been examined. It has shown promise of offering significant advantages for fly ash beneficiation. An estimate of costs for major equipment and the planned operation of a full-scale triboelectrostatic separator is discussed.

BACKGROUND

The ASTM C-618 specification for using fly ash as an admixture in concrete requires that the loss-on-ignition (LOI) be less than 6%.[1] With the installation of low NO_x burners, the unburned carbon in many fly ashes from coal burning utilities has increased to unacceptable levels for such cement applications.[2] Since unburned carbon constitutes typically over 90% of the LOI for class F fly ashes, an efficient and economic beneficiation technology that removes carbon from fly ash may generate significant economic and environmental benefits for the power industry.

As an alternative to flotation or wet beneficiation and carbon burnout, triboelectrostatic beneficiation technology has emerged as a way to separate finely-sized particulate with the potential for high efficiency, low cost and no secondary waste.[3-8] High LOI fly ash may be beneficiated, under dry conditions, into a low LOI ash stream for cement applications, and a high LOI or carbon-rich stream for blending with coal to recover its BTU value or as feedstock for other value-added products. The triboelectric technology described in this paper uses gas transport processing, and no water or chemicals are needed. The processing cost is estimated to be lower than that from most other beneficiation technologies.

Scale-up of dry, triboelectrostatic technology using gas transport of the ash is currently underway at the Center for Applied Energy Research (CAER) of the University of Kentucky.[8-15] The technology has progressed to the development of a pilot-scale, continuous-feed, 500 kg/hour facility. In previous fly ash beneficiation studies, the separation performance was observed to be sample dependent. No predictive method is available that could assess quantitatively the separation performance of electrostatic technology for a particular fly ash sample. Experimental testing remains the only means to evaluate how fly ash will respond to beneficiation processing.

EXPERIMENTAL

Fly ashes were obtained from power stations burning various types of coals. All had been collected by utility personnel from either electrostatic precipitator (ESP) hoppers or storage silos. These utilities had a wide variation in location in the US and used a wide variation of coals. Some of these utilities provided more than one fly ash for testing because they operated more than one power plant.

The LOI values and carbon concentrations of the fly ashes were measured. The LOI analyses included the use of a muffle furnace at 950±50°C for one hour with 1 g of sample, measuring the mass of the sample before and after the burnout. The measurement of carbon was accomplished using a LECO CHN-600 instrument.

A bench-scale, continuous-feed triboelectrostatic separator system, shown in Figure 1, was used to beneficiate the fly ashes. The electrostatic separation chamber consisted of parallel electric field plates across which a DC voltage was applied, producing an electric field strength between 100-200 kV/m. The ash feed rate to the separator was between 2-20 kg/hr.

Fly ashes were fed to the tribocharging unit by using either a screw feeder or a vibratory feeder. Both feeders contained sealed environmental tanks in which the ashes could be stored. They were metered into a pneumatic transport tube and then entrained in carrier air. The particle laden flow out of the separation chamber was split into three streams: one from the positive electrode (low LOI ash), one from the negative electrode (high LOI ash) electrode, and one at the middle of the separator. Two high-efficiency cyclones mounted in series, followed by a baghouse, were used to capture the ash as it eluded from the separator. The balance between feed mass and product mass was always greater than 95%.

To develop a recovery curve for each ash when using the continuous-feed separator, a two-stage processing procedure was established. This procedure, depicted in Figure 2, included collecting the products - labelled as C, M and T - from each of the three outlets of the separation chamber and then reprocessing each of these products. From these three products, a total of nine final product fractions, labeled as CC-through-TT, were obtained from the recycle operation of the triboelectric beneficiation unit. In combination with the mass of each product, the LOI values of these nine products were used to plot a recovery curve that presents a cumulative data set for each particular ash.

Figures 3 and 4 show recovery curves for some of the thirty ashes that were tested. The LOI’s of these ashes were between 3% to 30%; data in Figures 3 and 4 are for LOI’s between 9%-14%. As the LOI increases, more carbon needs to be removed to produce an ash acceptable as a cement admixture. However, the absolute LOI content does not predict the extent to which low LOI ashes can be produced. For example, the recovery at 3% LOI for Ash 8 (which has a parent LOI content of near 9%) is 55% whereas the recovery at 3% LOI for Ash 10 (which also has a parent LOI content near 9%) is 75%.

Typically, a product labeled as M in Figure 2 has many physical characteristics similar to the feed or parent material. It is a product which may be recycled in a staged operation; hence, understanding its beneficiation performance is important for the design of an efficient processing system. In our experience, the efficiencies by which carbon can be removed from the sample sets labeled as M have been nearly identical to that of the parent ashes. If the performance was less, it has been surmised that the amount of interlocked carbon within the M product may have been greater than in the original feed.

In addition to the material factors, the potential dependence of recovery curves on different triboelectric separation system also need to be investigated. If a product like that labeled as M can be beneficiated, it suggests that the system under investigation can be further optimized. Therefore, different recovery curves obtained from the same separation unit can be compared to show relative responsiveness of each fly ash, and recovery curves for the same fly ash obtained from different triboelectric separation units can be compared to show the efficiency of each unit. Care should be taken when comparing recovery curves of different fly ashes from very different separator units because the result may reflect difference in material characteristics, separation system efficiency, and/or both.

The type of particle transport, use of pressurized air, and a continuous particle feed and collection system that were used in our tests resemble conceptual designs of an industrial separation system. Hence, the results reported herein are suggested to be more industrially useful than those obtained in the previous batch tests. However, the recovery rates in this study can only be used as a evaluation tool to estimate beneficiation performance at the current technology level. They do not define the limit of separation. Because the technology is still at a developmental stage, it is believed that it can be further improved to achieve better beneficiation performance. Hence, at the CAER, ash beneficiation testing is underway using a 250 kg/hr feedrate.

A cost estimation was performed for our gas transport, triboelectric system using bench-scale data and concepts. The design information required for the estimation included process flow/operation diagrams and product output capacities, and the costing is based on estimates of major equipment, materials and labor. However, due to the uncertainty in the equipment that would be used at 20 ton/hour scale, we chose to analyze a much smaller scale, a 2 ton/hour unit, and then use this estimate for a 20 ton/hour scale.

Because it is not reasonable to use the cost of labor for a 2 ton/hour unit to project the costs for a 20 ton/hour unit, the labor cost estimated here is for a 20 ton/hr unit instead. The processing cost for a ton of fly ash at a 20 ton/hr scale is not expected to exceed that for the 2 ton/hr unit. The costs are based on the original fly ash as-processed, and according to a 20 year linear depreciation of equipment without any salvage value. The direct labor cost for a 20 ton/hour unit is estimated to be about 1 \$/ton. It is based on the salary and benefits of one operator at a rate of 20 \$/hr. Other operation costs for a 2 ton/hour unit estimated here is the utility cost (electricity cost) for processing a ton of fly ash. Based on the energy needed for operating a triboelectric beneficiation system, the electricity cost for a 2 ton/hour unit is about 0.20 \$/ton based on the rate at 0.05 \$/KW·hour.

Therefore, the total cost estimated here is approximately 3 \$/ton, contingency included. This economic estimation is only a best estimate based on the current bench-scale units, and is meant to provide a basis for more accurate economic analysis.

CONCLUSIONS

In conclusions, our current ash beneficiation study shows that: fourteen of twenty five ashes had over 50% recovery at less than 3% LOI; beneficiation performances using the bench-scale, continuous-feed triboelectric separator mirrored the performances using a laboratory-scale, batch-feed separator; the estimated processing energy cost is less than four kW-hour/ton for a 20 ton/hour system.

These results further confirm that gas transport, triboelectric separation may be a cost effective way of reducing the LOI level for fly ashes. Further efforts should be placed on scale-up of the technology with continued attention to the economic assessment. We are operating a proof-of-concept, 250 kg/hr triboelectric system now. Use of this platform during the next months may be able to determine whether the technology could be brought into the commercial markets in the near future

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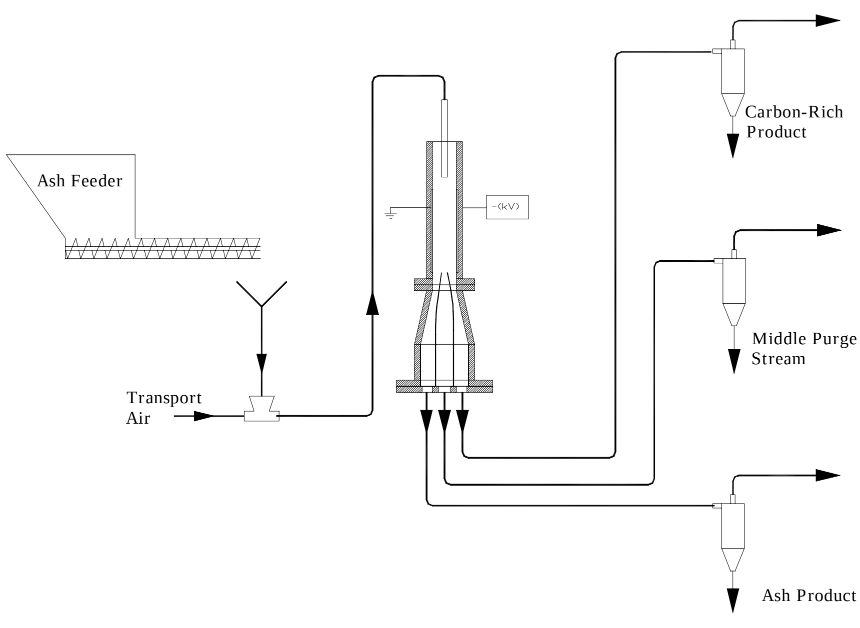

Figure 1. Schematic of continuous feed, bench-scale triboelectric separation system.

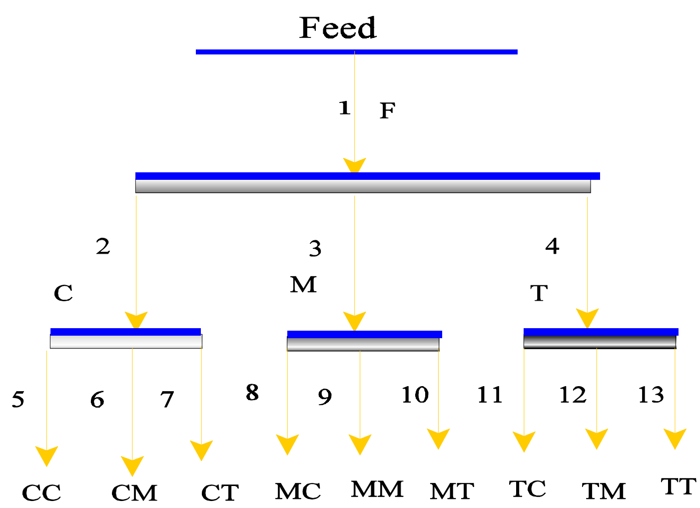

Figure 2. Processing scheme for the combustion fly ashes.

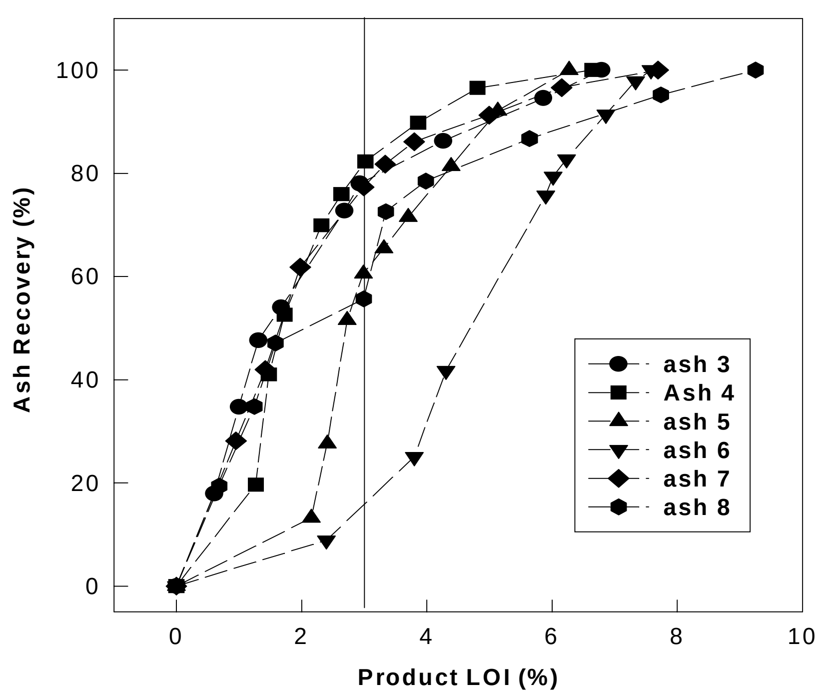

Figure 3. Recovery curves for coal combustion fly ashes.

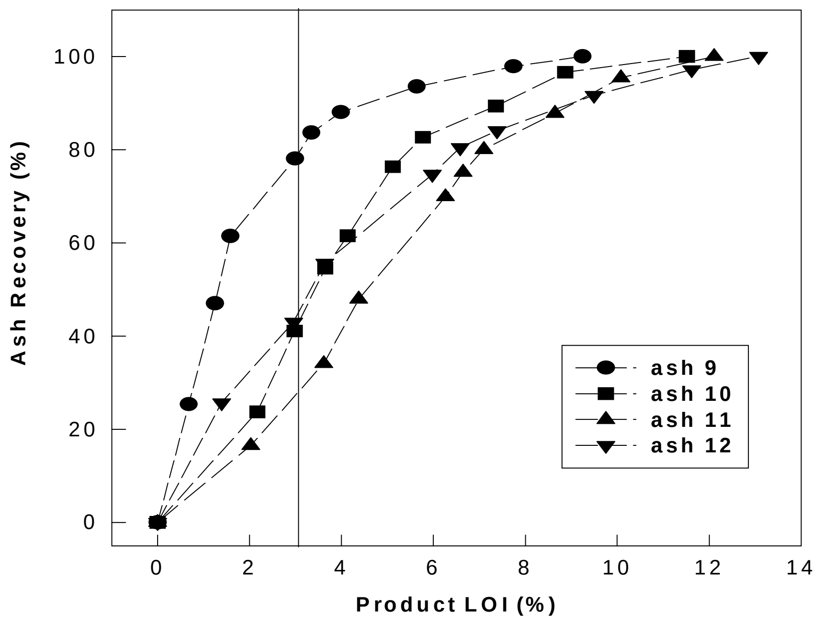

Figure 4. Ash recovery curves for coal combustion fly ashes.