Characteristics of Fly Ashes and Processing Conditions Affecting Carbon-Ash Separation under Pneumatic Transport, Triboelectric Processing

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ABSTRACT

In the EU and US there is tremendous potential for increasing the use of coal combustion fly ashes (CCA) as mineral admixtures in concrete and for decreasing concomitant construction costs. To achieve this potential, the ash industry requires flexibility in technological approaches because ashes from different sources have highly-variable characteristics. One approach is triboelectric separation. It relies on charging ash and carbon particles in a bipolar manner and then their separation under the action of an electric field. Charge magnitude and polarity are affected by moisture, both within the atmosphere and adsorbed on the particles. Studied experimentally, it has been found that the deleterious effect of moisture becomes more severe as particle size decreases; particles greater than 75 micrometers in diameter are nearly unaffected whereas particles smaller than 45 micrometers show up to a 400% decrease in their separability at low exposure levels. Slow and fast adsorption mechanisms are also evident.

INTRODUCTION

Due to its pozzolanic properties, coal combustion fly ash is a commercially valuable additive for the production of blended cements and concrete mixtures. It is an abundant mineral resource with a production rate in Italy near 1 million tons per year; in Europe near 40 million tons per year; and in the US near 110 million tons per year.[1,2] High disposal costs, increased interest in improving the environmental impacts of coal utilization are making fly ash utilization an increasingly attractive alternative to disposal.

However, in Europe the standards for concrete manufacturers require fly ash loss-on-ignition (LOI) to be less than 5%;[3] in the US, ASTM standards specify LOI's less than 6%, [4] whereas industry generally accepts only less than 3%. These values are difficult for utilities to attain because of the use of low-NOx burners, thus prohibiting fly ash usage in concrete. As a consequence, intensive investigations have been carried out worldwide to determine how to economically remove unburned carbon from fly ash produced at coal-fired utilities.

Triboelectrostatic separation has been studied as a cost-effective solution for ash beneficiation and is commercially practiced. In the gas transport, triboelectrostatic process, particles acquire positive and negative charge by contact electrification between each other or against pipes through which they are transported.

Unburned carbon particles can be assumed to possess a work function equal to that of graphite (4.0 eV) and ash a work function equal to that of silica or alumina (SiO_2: 5 eV; Al_2O_3 : 4.7 eV), respectively.[5-7] These assumptions lead to positive carbon and negative ash particles, as is generally observed during laboratory and industry processing. These bipolarity charged particles are then separated within an electric field cell.

Although it is possible to give a qualitative description of triboelectrostatic charging during fly ash beneficiation by assessing the work function of idealized particles, a particle's work function can be modified by chemical conditioning, even water adsorption. If the effects of surface conditioning were known and controllable, the performance of triboelectrostatic beneficiation technology for the removal of unwanted carbon from fly ash may be enhanced.[8,9]

Water adsorption is known to enable surface ion mobility and, as a consequence, to create reversed charge on carbon and fly ash particles during tribocharging.[8,10] However, it is not clear whether surface conditioning plays a dominant role during carbon-ash beneficiation because many other variables also may influence performance, eg particle concentration in the carrier gas, particle size, temperature, electric field strength, degree of turbulence. Hence, in this study the effect of surface moisture and thermal treatment were investigated to better understand their influence on gas transport, triboelectrostatic beneficiation.

EXPERIMENTAL

A parallel plate separator with a maximum feed rate capacity of 10 kg/h was used for this study. Unlike in previous studies,[7,11-14] the ashes were injected close to the positive plate because such a configuration was found to enhance carbon separation, especially at high feed rates.[15] The detail of the separator is described elsewhere.[15]

It was possible to vary the relative humidity of the gas contacting the ashes by mixing dry N_2 with moistened N_2 gas. Heating tape was wrapped around the ash charging tube leading to the electric field cell. The temperature of the ash-laden gas could then be controlled by thermocouple monitoring the temperature at the injection point at the top of the cell.

To quantify the selectivity of the process, ash product yields (W_A/W_F) and the decrease in LOI (LOI_{dec}=1-LOI_A/LOI_F) were calculated. W_A , W_F and LOI_A , LOI_F are the weight and the LOI contents of low LOI ash products and feed ash, respectively.

The fly ashes used in this study originated from two utilities, both fitted with low-NO_x burners. The fly ash labelled as CS came from an American coal-fired utility and had an average LOI of 7.0%. Three other ashes, labelled as FA1, FA2 and FA3, came from an Italian utility burning the same bituminous coal, and had average LOI's of 21.0% and 30.5%, respectively.

Scanning electron microscopy (SEM) was accomplished using a Zeiss DSM 942 electron microscope.

Standard screens of 45, 75 and 150 μm were used to sieve the Italian ashes into three fractions with size ranges: <45 μm, labelled as FAS (S = small particle size); 45-75 μm, labelled as FAM (M = medium particle size); and 75-150 μm, labelled as FAL (L = large particle size). Because the fractions with smaller particle sizes typically have lower LOI's, and because samples were to be studied in each size fraction with LOI contents covering a broad range, the S fractions from FA1, FA2 and FA3 were mixed in different proportions, as where the M and L fractions to create a series of ashes with specific size range and widely variant LOI contents. The different protocols for ash treatment used in this study are described in the following.

RESULTS AND DISCUSSION

Table 1 presents results obtained for the CS ash. The parent exhibited very low carbon separation, with the ash product having less than a 6% decrease in LOI. Ash sample CS was exposed to nitrogen having 100% relative humidity and dried (protocol TR1). Upon saturation with moisture and then drying (TR1), obvious charge reversal occurred because the LOI of the positive polarity product (LOI +) was higher than the parent and the negative polarity (LOI -) product. On the other hand, simply exposing it to ambient room conditions caused important physical-chemical properties to change, negatively affecting carbon-ash separability.

As compared to the data in Table 1, the drying of the CS ash and then immediately processing it created a three-fold change in the LOI even though the ash yield was approximately constant. This enhancement in carbon-ash separability was eliminated within the first two hours of exposure to ambient conditions, and no further change was observed for additional exposure. Charge reversal was not observed as a consequence of the treatment.

Since charge reversal plays a marginal role in increasing separation efficiency, there may be little room for improving triboelectrostatic system performance by chemical modifications which affect the mobility of surface ions. In fact, the separator geometry used in this study relies on the mobility of carbon particles; they were barely charged for the parent ash and did not significantly undergo charge reversal. On the other hand, additional experiments were performed in which the parent CS was stored in the glove box overnight under low relative humidity (<20%) at 60 °C and then processed immediately when removed from the glove box (Protocol TR2). Results presented in Table 1 (CS - TR2) confirm that the degree of carbon-ash separation was increased as compared to the parent ash, the effect of which is probably related to the removal of surface moisture.

Table 1: Triboelectrostatic separation results for fly ash CS under different experimental conditions

	CS As-received	CS-TR1	CS- TR2
Ash Yield (%)	89.6	23.8	75
LOI parent (%)	6.4	7.4	6.6
LOI + (%)	6.1	8.4	5.75
LOI - (%)	9.7	4.3	9.1
LOI_{dec}	5.8	42.3	12.6

TR1: samples treated according to procedure TR1; TR2: samples treated according to procedure TR2.

Improvements in the performance of triboelectrostatic beneficiation related to surface moisture removal is evidently related to physical-chemical changes in the charging step and/or the separation step. For the latter issue, it is surmised that adsorbed water affects charging and separation because higher surface moisture lowers the degree of particle liberation. As a consequence, the charging process would be enhanced because the surface area per unit mass of ash that is available for tribocharging increases when cluster size is reduced and carbon-ash separation would be enhanced because particle liberation is increased.

Small ash particles may coalesce because surface forces between particles are enhanced by water. If moisture removal weakened cohesive forces between the particles in fly ash the charging process would be enhanced because the surface area per unit mass of ash that is available for tribocharging increases when cluster size is reduced. Furthermore, carbon-ash separation would be enhanced because particle liberation is increased.

It is then reasonable to examine whether increasing treatment temperature would affect the LOI_{dec} when the ash and carbon particles were of the same size. This issue was studied by using several synthetic fractions (FAL, FAM, FAS), processed either at room temperature or 80 °C with an applied electric field of 2 kV/cm.

Results for samples FAL (size 75-150 μm) show that the decrease in LOI's and yields were barely affected by treatment temperature. Results for samples FAM (45-75 μm) are shown in Figure 1. With no heating, the LOI_{dec} and yields were not affected by the LOI content of the ash. A remarkable increase in separability was achieved after heating for samples having LOI contents below 15%. These effects may be influenced by the liberation within ash-carbon and ash-ash clusters.[8] Although ash-ash clusters are more likely to be disaggregated when the temperature is increased, forces other that those caused by moisture maintain ash particles interlocked in carbon at high LOI's, the influence of ash-carbon clusters may overwhelm any effects of the liberation of ash-ash clusters.

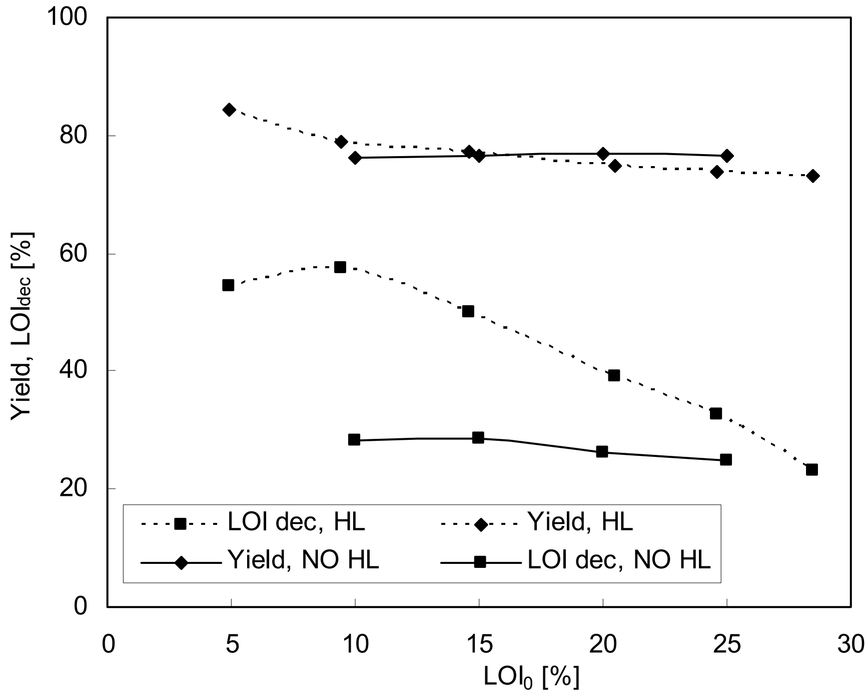

Fig. 1: Effect of heating line on separation performances (Yield and LOI_{dec}) for synthetic mixture FAM. HL: Separation with the heated line; NO HL: Separation without the heated line.

Figure 2 displays results for samples FAS (<45 μm). Without heating, the LOI_{dec} was below 10% and decreased to ~0% when the sample LOI was 15%. While for sample FAL the effect of space charge could be significant, i.e. a high concentration of charged carbon particles negating the effect of the electric field, in this case an elevated specific charge of small particles[13] could also cause separation efficiency to decrease at high LOI.

Upon heating of the sample, a four fold increase in the LOI_{dec} occurred and the ash product yield was also slightly increased. These two effects agree with the influence of disaggregating ash-ash clusters. Carbon-ash clusters would not be as dominant nor influential for this particle size fraction.

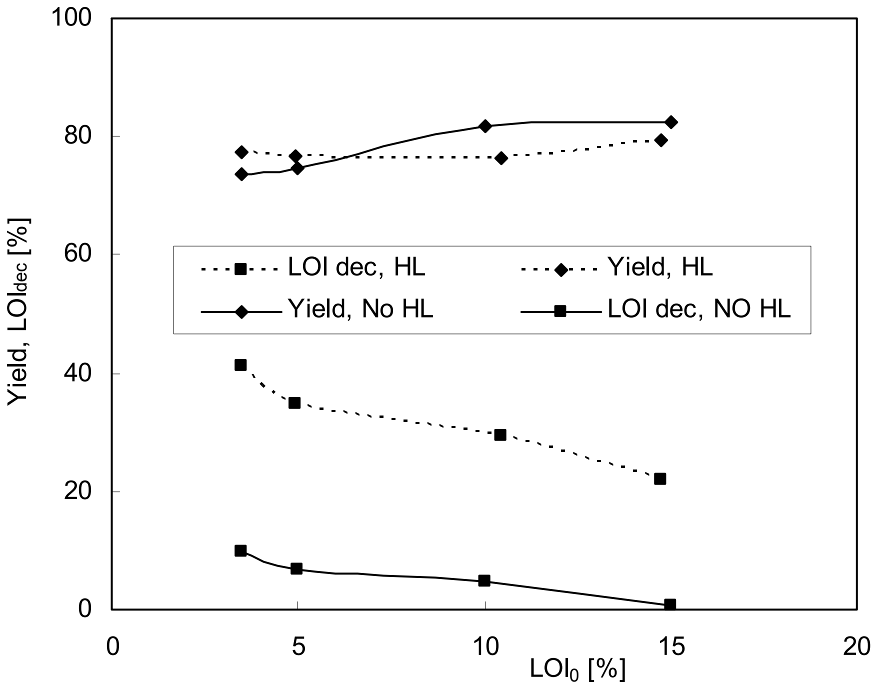

Fig. 2: Effect of heating line on separation performances (Yield and LOI_{dec}) for synthetic mixture FAS. HL: Separation with the heated line; NO HL: Separation without the heated line.

CONCLUSIONS

Gas transport, triboelectrostatic beneficiation was used to experimentally investigate how relative humidity and water adsorption affects carbon-ash separability of four coal combustion fly ashes. Significant beneficial effects of heating ashes before or during triboelectrostatic beneficiation were observed. These results were related to changes in particle surface characteristics and particle-particle adhesive forces caused by adsorbed moisture. The increase in carbon-ash separabilities upon heating was most evident for ashes having the smallest particle size. Coupling enhanced separabilities with changes in ash product yields, it was hypothesized that disaggregation of ash-ash and ash-carbon clusters was also influential in improving beneficiation performance. Overall, the triboelectrostatic beneficiation of fine sized powders before and after heating easily delineates their propensity to adsorb ambient moisture.

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