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Report Title: **Preferential Recycling/Rejection in CFBC/FBC Systems Using Triboelectrostatic Separation**

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Abstract

Circulating Fluidized Bed Combustion (CFBC) and Fluidized Bed Combustion (FBC) with recirculation are widely used technologies in the US for power generation. They have the advantage of fuel flexibility, and low NO_X and SO_X emissions. Typically, as partially combusted fuel is circulated in the system, only a split stream of this circulating stream is rejected, with remainder recycled to the combustor. As a consequence, there is unburned carbon and partially used, valuable, calcium hydroxide in the reject stream. If these useful materials in the reject stream can be recovered and sent back to the combustor, the efficiency of the system will be increased significantly and the equivalent emissions will be lower.

This project studies an innovative concept to incorporate triboelectric separation into CFBC/FBC systems in order to preferentially split its recycle/reject streams based on material compositions of the particles. The objective is to answer whether useful constituents, like carbon, calcium carbonate and calcium hydroxide or oxide, can be selectively separated from combustion ash at elevated temperatures. Laboratory experimental studies are performed at temperatures from 25ºC to 210ºC, the data from which are presented in the form of recovery curves. These curves present quality-versus-quantity information useful for predicting the efficacy of triboelectric separation as applied to CFBC/FBC byproduct recycling and/or rejection.

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Executive Summary

Circulating Fluidized Bed Combustion (CFBC) and Fluidized Bed Combustion (FBC) with recirculation are widely used technologies in the US for power generation. They have the advantage of fuel flexibility, and low NO_X and SO_X emissions. Typically, as partially combusted fuel is circulated in the system, only a split stream of this circulating stream is rejected, with remainder recycled to the combustor. As a consequence, there is unburned carbon and partially used, valuable, calcium hydroxide in the reject stream. If these useful materials in the reject stream can be recovered and sent back to the combustor, the efficiency of the system will be increased significantly and the equivalent emissions will be lower.

This project studies an innovative concept to incorporate triboelectric separation into CFBC/FBC systems in order to split preferentially its recycle/reject streams based on material compositions of the particles. The objective is to answer whether useful constituents, like carbon, calcium carbonate and calcium hydroxide or oxide, can be selectively separated from combustion ash at elevated temperatures.

Laboratory-scale experiments were performed using a specially designed and insulated triboelectric separator. Combustion byproducts were pneumatically transported into the electric field of the separator using heated air, the temperature of which was adjusted between 25ºC to 210ºC. Products were collected in three cyclones placed after the electric field zone. They were analyzed for carbon or loss-on-ignition (LOI), ash, and calcium-containing species. From these analytical data, recovery curves were calculated that defined the efficacy of the triboelectric separation processing. These data show that increasing the temperature, over the range possible with the experimentation, increased the separation performance for most byproducts that were tested. Although more research is necessary, triboelectric separation can be used to preferentially recycle or reject combustion byproducts.

Introduction

FBC technologies are widely used in the US for power generation. One main advantage of FBC is its fuel flexibility. As a consequence, a wide range of fuels, including coal, lignite, peat, wood chips, municipal waste and other industrial byproducts, can be combusted efficiently. Low combustion temperatures and limestone addition enable low NO_x and SO_x emission.

The recirculation or recycling of solids is common practice during FBC operation. Recycling can be accomplished by using cyclones, the products from which are either rejected to a by-product stream or recirculated to the combustion zone. This common practice causes unburned char to be discharged with the reject ash, and ash particles to be recycled to the combustor. Process efficiency is thus reduced because of a direct BTU loss of the unburned carbon in the ash and unnecessary recirculating of ash particles. A similar situation also occurs in recycling available calcium ($Ca(OH)_2$, $CaCO_3$, and CaO) and used calcium ($CaSO_4$), i.e. no selective recycling or rejection occurs. A triboelectrostatic separator, in place of or before a cyclone, may enable recycle of the useful material such as unburned carbon and available calcium, while rejecting fly ash and spent sorbent.

An idealized FBC would recycle all useful material, i.e. char and available calcium, and reject only non-useful material, i.e. ash and $CaSO_4$. Triboelectrostatic separation technology may be useful for accomplishing selective recycle and rejection. It may also meet other process requirements, including in-line installation; low cost; and minimum equipment addition.

Triboelectric separation relies on establishing bipolar charge on the surface of different particles (Ban et al., 1994a, 1994b, 1994c, Kelly, 1989). Bipolar charge is a consequence of the differences in materials' surface properties and particle-particle and/or particle-wall contacts (Nguyen, 1988). By passing a bipolar charged powder through an external electric field, positively charged particles can be separated from negatively charged particles.

This study examines the feasibility of a new and innovative concept of using a triboelectrostatic separator in FBC systems to increase their overall efficiency. The project focuses on the key issue of whether FBC recirculating streams can be separated on a basis of material composition by triboelectrostatic separation at elevated temperatures.

Experimental

A high-temperature separator was built to simulate beneficiation of the recycle stream from a FBC system. It contained a metal frame, electrodes and inlet/outlet ports. The high voltage (~ 30kV) electrodes were insulated using mica. A schematic of the separation system is presented in Figure 1.

The triboelectrtostatic separation system included an air flow meter, heating and electric field controls, and a sample collection system. From the vibratory feeder, the sample flowed through a insulated copper tube, which was heat traced. The separation chamber and cyclone were also heat traced. After flowing though the copper charging tube, the charged powders were injected into the separation chamber. It contained two parallel copper electrodes and used voltages between 5kV and 25 kV. Typically, unburned carbon reported to the negative plate and ash reported to the positive plate. Uncharged particles did not report to any plates but were recycled.

To simplify the design and the control of temperature, only the charging tube and injection air were heated. A thermocouple was placed into the separator and was used to monitor temperature during separation processing.

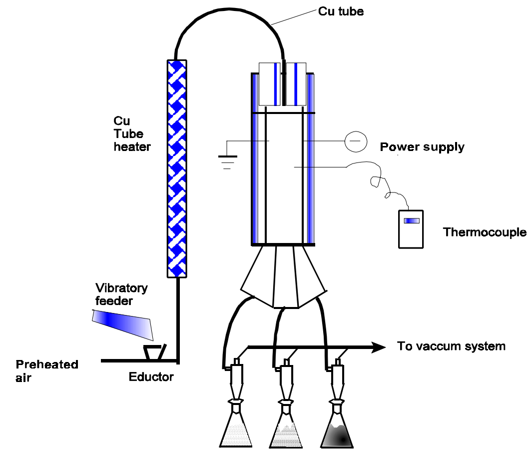

Figure 1. Schematic of the high temperature triboelectrostatic separator.

Five samples were used during our experiments. Two were obtained from ABB Power and Combustion Engineering, Inc. One consisted of fine particles and the other was slag-like and calcium rich. The other samples were obtained from utilities in the US. Most experiments used a tree-type, open flow sheet process (shown in Figure 2). The experimental procedure included separating the feed into three products: C, M and T. These three products were processed further in the same separator to produce nine products: CC, CM, ... , TT. A recovery curve was generated by weighing the samples and analyzing their LOI (loss on ignition) content.

The sample concentration of SO_3, total CaO, total carbon, mineral carbon and ash were measured. From these analytical data, the $CaCO_3$, $CaSO_4$, available CaO, Ca free ash and Ca free mineral were calculated using following equations:

$\%CO_2$ = Mineral carbon ×44.011/12.011;

$\%CaCO_3 = \%CO_2 \times 100.08/44.011$

$\%CaO^* = \%CaCO_3 - \%CO_2$;

$\%CaSO_4 = \%SO_3 \times 136.13/80.06$

$\%CaO^{**} = \%CaSO_4 - \%SO_3$;

Total Calcium = Total CaO×40.069/56.069

Salt %CaO = $\%CaO^* + \%CaO^{**}$;

Available %CaO = Total %CaO-Salt %CaO

Ca free ash = %ash-$\%CaO^*$-$\%CaSO_4$-Available %CaO

Organic carbon = Total carbon-Mineral carbon

Ca free mineral = 100-Organic carbon-$\%CaCO_3$-%CaS- Available %CaO.

**[CaO^* is the content of CaO on a basis of $CaCO_3$ and CaO^{**} is the content of CaO on the basis of $CaSO_4$.]

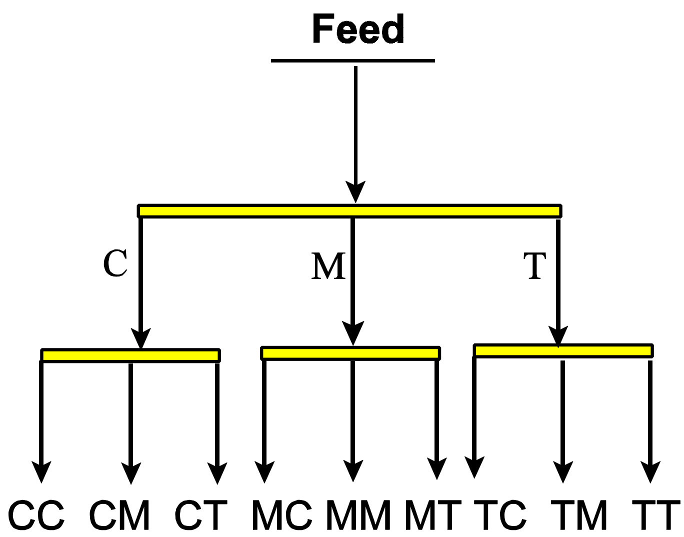

Figure 2. The flow sheet of the high temperature experiments using triboelectrostatic separation.

Results and Discussion

An objective of the experiments was to determine whether unburned carbon and CaO could be selectively recycled from products typical to FBC's. Because recycle products are at high temperature, the laboratory experiments were also done at high temperatures. Operational parameters of the triboelectric separator, such as the injection flow rates and electric field strengths, were varied to measure their effects on separation. The results are presented using recovery curves or scaled recovery curves. The recovery curves give direct beneficiation information whereas the scaled recovery curves give comparative beneficiation information by canceling out the effects of feed grade (Jiang et al,1998).

The effect of temperature on particle tribocharging was studied by Gupta (1990). He measured pyrite and oil shale charge as a function of temperature and found that the charge-to-mass ratio increased with temperature over a range of 20ºC to 43 ºC. Nguyen (1988) reported that increased humidity decreased the average charge of glass beads. Ban (1994) showed a different view of the effect of temperature on charging. For silica particles, he found that the charge-to-mass ratio decreased with increasing temperature; at 100 ºC, the silica charge was approximately 40% of the charge at 20 ºC. For the coal particles, an increased temperature negligibly affected particle charge. Because the application of a triboelectric separator in a recirculation loop of a FBC would require high temperature, it was important to measure the effect of temperature on the separation of components contained in FBC-like ash, including $CaSO_4$, $CaO+CaCO_3$ and carbon.

In the previous technical report, it was shown that increasing the temperature of triboelectric processing increased carbon-ash separation efficiency. This increase wass dramatic and suggested that triboelectric separation offers even better performance if temperatures up to 210º C were used. In addition, the electric field strength was shown to be an important parameter to optimize carbon-ash separation.

During this reporting period, the maximum performance attainable for carbon-ash separation and the influence of particle-particle interactions were studied. These two factors are important because the separator uses pneumatic transport of the physical mixtures, during which time significant particle-particle interactions occur.

To assess the maximum extent to which carbon and ash can be separated, experiments were performed to determine the optimum gas velocity to use for transporting the combustion ash to the electric field zone of the separator. The assessment was based on a recovery curve analysis. The optimum velocity was then used during acquisition of the following data.

Experiments were performed to define the effect of staging on product recovery, where staging is defined as the number of times the products were processed in the separator (see Figure 2). Data for five stage processing are presented in Figure 3. It can be observed that the ash recovery curve for two stage processing (presented in previous report) was close to the ash recovery for five stage processing. Therefore, in an application for selective recycle, there is a limit to the amount of product which can be extracted by modifying the in-line triboelectric equipment configuration.

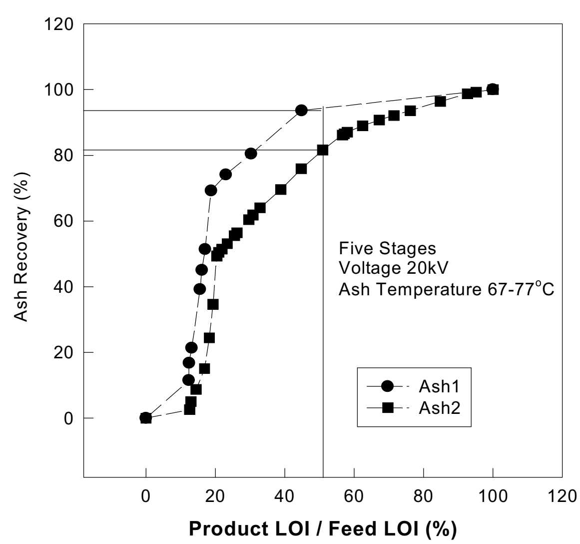

Figure 3. Recovery of fly ash using five stage processing.

The extent to which selective product extraction can be accomplished is dependent on: the technology used for extraction; the operating parameters of the separator; and the properties of the feed stream. An understanding of the latter is yet to be achieved for triboelectric processing. In addition, the influence of particle interactions on triboelectric performance is not known. These interactions cause tribocharging but their influence on the overall separation performance has not been studied

Hence, two combustion ashes, Ash2 and Ash3, having different separation performance - as shown in Figure 4 - were mixed in the proportions 75% / 25%, 50% /50%, and 25%/75%. These mixtures were then subjected to triboelectric separation to measure whether the better performing sample-Ash2-would promote separation in Ash3. These data, presented in Figure 5, show a near linear increase with increasing concentration of Ash2. Therefore, mixing a poor performer with a good performer does not increase the response of the poor performer. In other words, particle interactions do not dominate separability performance in our triboelectric separation technology.

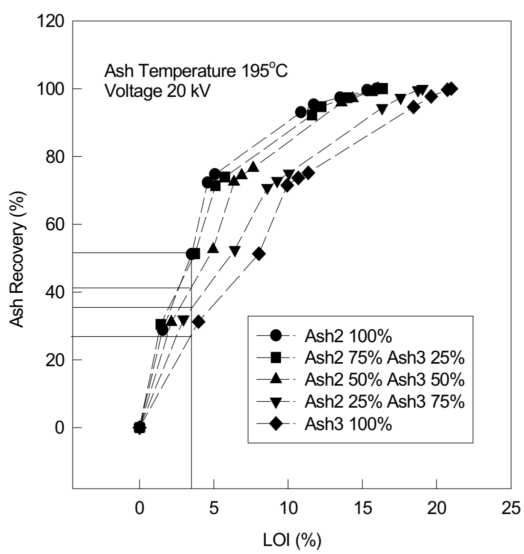

Figure 4.. Effect of mixing samples on separation performance.

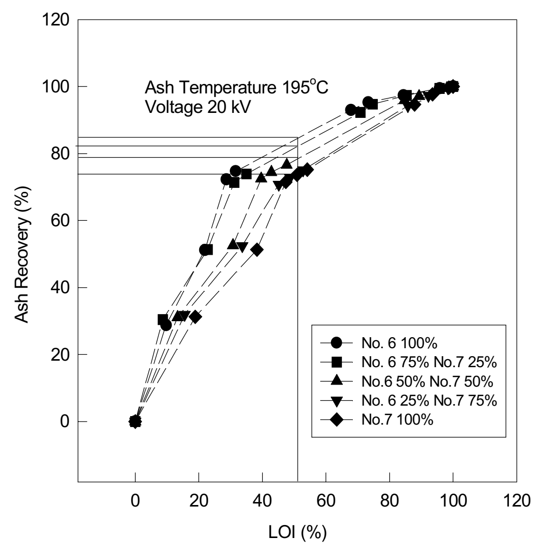

Figure 5. Scaled recovery curves for physical mixtures of Ash2 and Ash3.

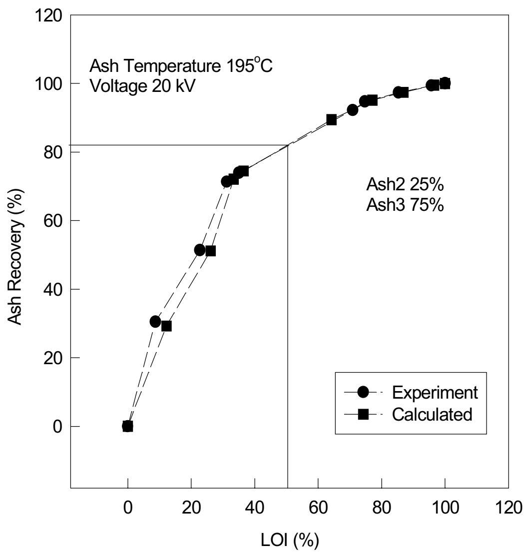

Figure 6. Scaled recovery curves for 25:75 ratio of Ash2 and Ash3, experimental and calculated data.

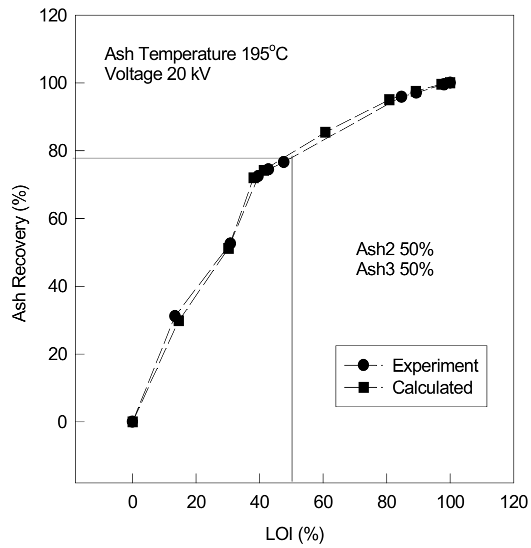

Figure 7. Scaled recovery curves for 50:50 ratio of Ash2 to Ash3 , experimental and calculated data.

This conclusion also is obtained from data plotted on a relative LOI basis (Figure 5). Therefore, it is possible to calculate the separation performance of a mixture of ashes if the recovery curves for the two pure ashes are known because the performance for the mixture will likely be a linear combination of the individual performances. Such calculations were performed and are presented in Figure 6-8. They confirm that particle interactions between the components of the different ashes do not dramatically influence separability of the components of the mixtures.

Conclusions

For a mixture of two different combustion ashes, there are insignificant inter-particle interactions that cause either decreased or increased separation performance. Rather, the separation performance of the physical mixture was a linear superposition of the performance of each ash. These data suggest that it would be possible to predict processing performance of ash mixtures if the performance of each ash was known. In addition, a two stage processing scheme separates carbon and ash to near the maximum that is attainable; additional processing stages did not increase the carbon-ash separation performance.

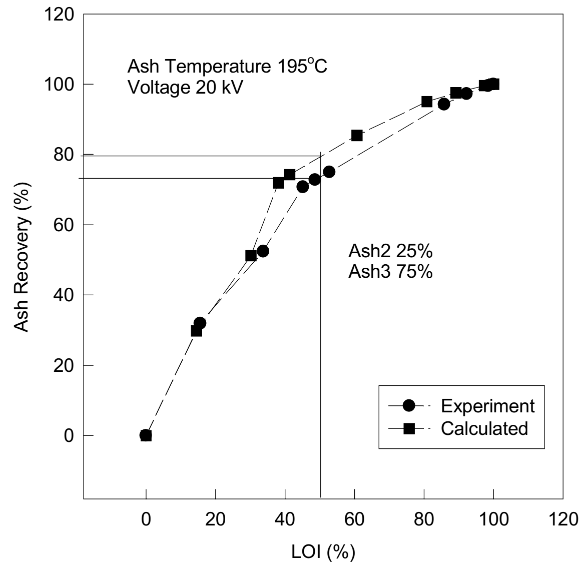

Figure 8. Scaled recovery curves for 75:25 ratio of Ash2 and Ash3, experimental and calculated data.

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