## Title Page

**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.

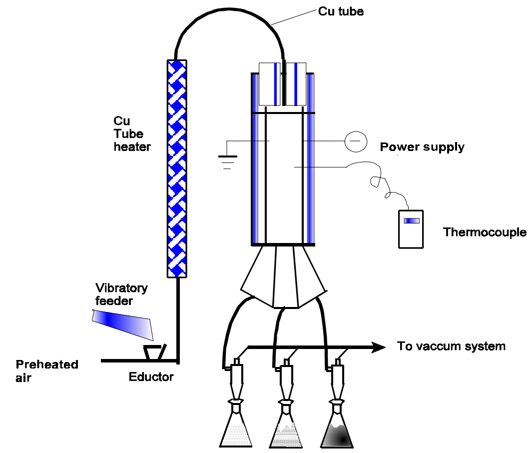


Figure 1. Schematic of the high temperature triboelectrostatic separator.

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) and Ca contents.

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 $CaSO_4$.]

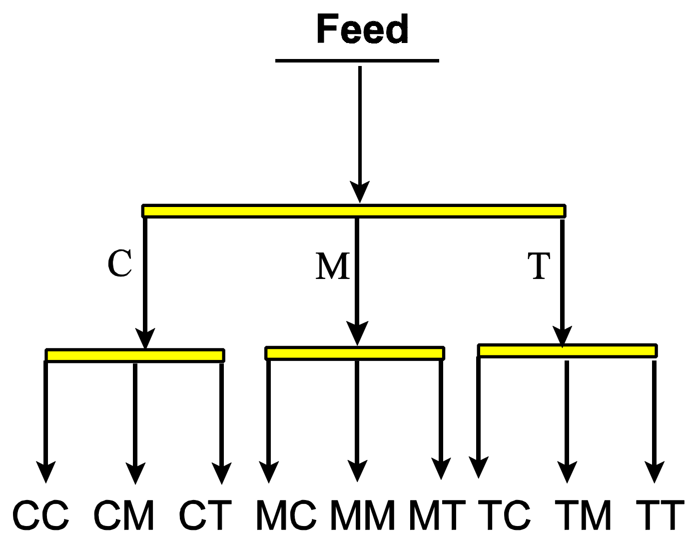

Figure 2. The flow sheet of the high temperature experiments using triboelectrostatic separation.

**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 reports, the effect that increasing the temperature of triboelectric processing had on carbon-ash separation efficiency was studied This increase was dramatic and suggested that triboelectric separation offers even better performance if temperatures up to 210º C were used.  The electric field strength was shown to be an important parameter to optimize for efficient carbon-ash separation.  Finally, little interactions between particles of different ashes were observed during the processing.  During this period, the performance for selectively recovering calcium carbonate and oxide from two combustion ashes at elevated temperatures was studied.  This assessment was based on a  recovery curve analysis.

The effect of temperature on ash+$CaSO_4$ rejection as a function of ash+$CaSO_4$ content of the feed to the triboelectic separator is presented in Figure 3.  In an FBC, it would be advantageous to reject selectively $CaSO_4$ and ash from the recycle stream while retaining $CaCO_3$ and CaO.  Cyclones do not allow selective capture, recycle or rejection.

The data in Figure 3 show that higher temperatures beneficially impact the selective rejection of $CaSO_4$+ ash.  For example, the rejection of $CaSO_4$+ash would be 23%, 34%, 47% and 76% if the $CaSO_4$+ ash content fed to the separator was 64%.  Figure 4 presents data on the rejection of ash versus the ash content when triboelectric separation experiments were performed at temperature from 17 °C to 185 °C.  These data are somewhat different than the ash recovery data presented in earlier reports where higher temperature coincided with better performance. Nevertheless, it is apparent that relatively high ash rejection can be achieved using triboelectric separation even though the sample is a complex mixture of ash + $CaSO_4$ + CaO + C.

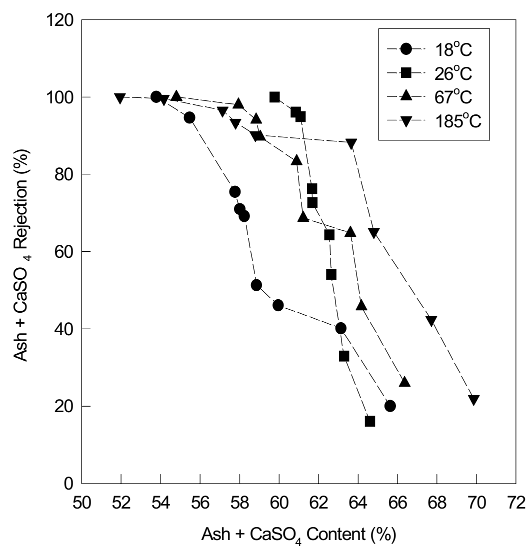


Figure 3.  Effect of temperature on rejection of fly ash + $CaSO_4$.

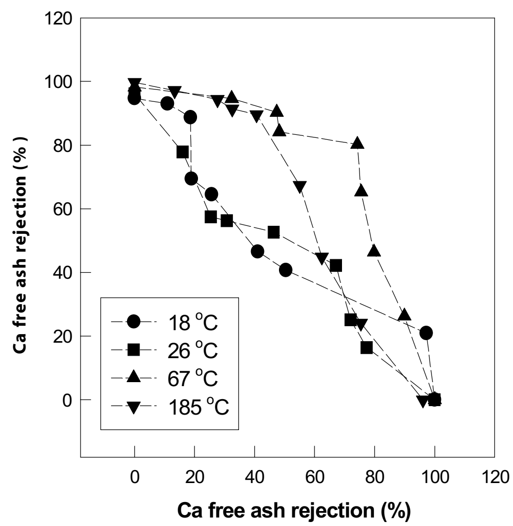


Figure 4.  Effect of temperature on the fly ash rejection (Calcium free).

Triboelectric separation data on the recovery of $CaCO_3$ + CaO versus $CaCO_3$ + CaO content are presented in Figure 5 for different temperatures of operation. As in the ash rejection data given in Figure 4, the highest recovery curve is not at the highest temperature. This behavior is not understood relative to ash recovery data presented in previous reports. It was expected that greater temperatures would improve the separation performance.

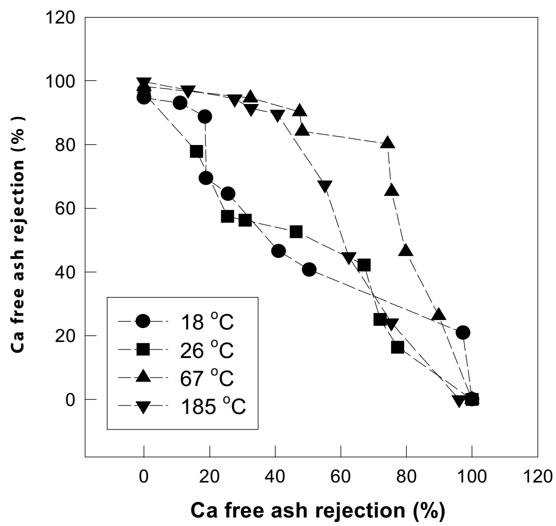


Figure 5. Effect of temperature on the rejection of fly ash (calcium free) from circulating fluid bed material.

**Conclusions**

The effects of operating parameters for a triboelectrostatic separator were studied to optimize preferential recycling/rejection efficiency in FBC systems. Several conclusions were reached during this investigation:

1. Triboelectrostatic separation may be beneficial in FBC systems to preferentially reject fly ash and recover unburned carbon. A 90% rejection rate of fly ash was achieved using a two stage process for Ash1 and Ash2.
2. For the rejection of $CaSO_4$, the higher the temperature, the better the rejection. However, for the recovery of $CaCO_3$, the highest recovery was obtained at a temperature of 67°C when testing a temperature range of 18ºC to 185ºC.
3. The electric field intensity is a key factor in preferential recycling/rejection in

CFBC/FBC systems. The higher the electric field intensity, the higher the separation efficiency for our triboelectrostatic separator.

4. The interaction among the particles of different ashes is insignificant relative to improving the separability of the ashes.

5. A two stage process is adequate to efficiently reject fly ash and $CaSO_4$ and to recover unburned carbon and $CaCO_3$+CaO. Very little increase accompanied further processing stages.

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**List of Publication and Presentations**

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