Dry Triboelectrostatic Separation of Carbon from Fly Ash: Proof-of-Concept Testing

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REPORT SUMMARY

Triboelectrostatic separation of carbon from flyash represents a promising option for recovering low carbon fly ash from coal-fired power plants for reuse in applications such as concrete production. This report summarizes the performance of a bench triboelectrostatic separator for nineteen fly ash samples obtained from United States utilities burning a variety of coals and producing fly ash with a range of carbon concentrations.

Background

Fly ash with high unburned carbon often measured as loss-on-ignition or LOI values are undesirable for applications such as concrete production. High fly ash LOI's are becoming more of a problem with the installation of low NOx burners. Therefore, an efficient and economic separation technology that removes carbon from fly ash can generate significant economic and environmental benefits for the power industry.

As an alternative to flotation and carbon burnout, triboelectrostatic separation has the potential for high efficiency and low cost dry beneficiation of high LOI fly ash. However, the applicability of triboelectrostatic separation to a wide variety of fly ashes needs to be determined because of the large variation of coal types and combustion conditions.

Objective

To characterize the performance and the feasibility of applying triboelectrostatic technology for the separation of carbon and ash using representative US coal combustion fly ashes.

Approach

Batch laboratory triboelectrostatic separation tests were conducted to determine the performance of carbon-ash separation on nineteen fly ashes. About 10-20 grams of each fly ash were used for each test, and a total of nine separated fractions were collected and analyzed for mass distribution and carbon content. The data were processed to generate a recovery curve at different carbon concentrations for each fly ash. Some of

the ashes were sieved to remove the coarser ash fractions before triboelectrostatic separation.

Results

The current findings, based on batch laboratory-scale testing, show that triboelectrostatic separation is a viable approach for reducing fly ash LOI. With triboelectrostatic separation and no sieving to remove large particles, seven of the nineteen ashes evaluated had >50% recovery of low carbon (<3%) ash. When the remaining ash samples with <50% recovery of low carbon ash were first dry sieved before triboelectrostatic separation, eight more samples had >50% recovery. Pre-sieving of coarse ash fractions appear to improve the overall performance of triboelectrostatic beneficiation of high LOI fly ash. Further work is needed to show that the triboelectrostatic separation process can be operated continuously and economically at a larger scale.

EPRI Perspective

Fly ash sale and utilization for utilities can have a significant impact on the cost of power production. Fly ash with high loss-on-ignition (LOI) values are undesirable for applications such as concrete production. High fly ash LOI's are becoming more of a problem with the installation of of low NOx burners. The current study on removing carbon from ash through a dry, triboelectrostatic separation shows the potential of using this technology for LOI reduction. Larger-scale tests will be needed to confirm the performance of the triboelectrostatic separation process and provide data for engineering and economic analysis so that comparisons with other options can be made.

Interest Categories

Waste and water management

Keywords

Ash utilization

High carbon ash

High LOI ash

Ash Beneficiation

Electrostatic Separation

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The authors would like to thank and acknowledge all the utility contacts and especially those who provided fly ash samples for the study. Because it is impossible to list all their names without missing some of them, their names are not individually listed here. But the authors would like to express deep gratitude to their cooperation. We hope that the results reported here would help them in assessing and identifying separation technologies.

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1

INTRODUCTION

This report presents the results of a proof-of-concept study conducted by the Center for Applied Energy Research, University of Kentucky for the Electrical Power Research Institute under Research Project No. WO 3176-22. The purpose of this project is to provide the electrical utility industry with information on the performance of dry, triboelectrostatic technology for beneficiating carbon and ash in various fly ashes. The present study is intended to evaluate the applicability of the dry, triboelectrostatic separation technology to various fly ashes from United States power plants.

Project 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 NOx 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 in fly ash usually constitutes nearly 90% of the LOI value for class F fly ash[3], an efficient and economic separation 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 [4] and carbon burnout, [5] triboelectrostatic separation is a dry beneficiation technique which has emerged as a way to separate finely-sized particulate with the potential for high efficiency, low cost and no secondary waste.[6-10] Using triboelectrostatic separation, high LOI fly ash may be beneficiated, under dry conditions, into a low LOI ash stream for cement applications, and a carbon-rich stream for blending with coal to recover its BTU value or as feedstock for other value-added products.[9-10] Triboelectrostatic technology can use pneumatic processing, and no water or chemicals are needed. The processing cost is potentially lower than other beneficiation technologies.

Dry, triboelectrostatic technology using pneumatic handling is currently under development at the Center for Applied Energy Research (CAER) of the University of Kentucky.[11-16] In previous, fine particle beneficiation studies, including fly ash, the separation performance was observed to be sample dependent.[11] Currently, no predictive method is available that could assess quantitatively the applicability of triboelectrostatic technology to a particular sample. Experimental testing remains the only means to evaluate how a fly ash would respond to this separation processing.

Triboelectrostatic separation technology needs to be tested for its applicability to a wide variety of fly ashes because of the large variation of coal types and combustion conditions that are used commercially. The performance of the technology for each fly ash has to be quantified to provide a basis on which a technical and economic evaluation at a commercial scale can be performed. Based on a recent approach developed at the CAER for assessing the performance of carbon and ash separation using dry technology[11], the relationship between recovery (yield) and quality of the products can be determined using a laboratory-scale, analytical triboelectrostatic separator. This separator can provide a standardized recovery curve for each ash tested and, thereby, provide a foundation on which a realistic separability for a single-pass processing of dry triboelectrostatic technology can be assessed.[11]

Objective

The objective of the proposed work is to determine the low carbon ash recovery available with triboelectrostatic separation for various coal combustion fly ashes.

Report Organization

Section 2 describes fly ash sample collection and analyses. Section 3 describes the experimental setup of the triboelectrostatic separator. Section 4 presents the results and analyses of the separation testing. Section 5 presents a summary discussion of key conclusions of this work.

2

SAMPLE COLLECTION AND PREPARATION

Sample Collection

Twenty-nine fly ash samples were obtained from power stations burning various types of coals. Ash samples were acquired from either electrostatic precipitator (ESP) hoppers or storage silos. Approximately five gallons of each fly ash were shipped to CAER for the study. The utilities where the ash was produced represent a wide variation in location and use a wide variation in coal types. Some of these utilities provided more than one fly ash for testing because they operate more than one power plant.

The color of all the samples can be categorized into two general types: one with a gray-to-dark gray color, and the other with a tan-to-sandy color. The eastern US bituminous coals generally produced a grayish color fly ash. With varying coal origination and/or combustion conditions, the color varied from light-gray to dark-gray, sometimes even black when the carbon content was high. It is generally believed that the content of magnetite and carbon in fly ash are the two major contributing factors to its dark color. The western US sub-bituminous and lignite coals usually produced a sandy-colored fly ash.

Size and Carbon Analyses

The carbon contents in the fly ashes, as-received from the utilities (hereafter called "original" ashes), were very different for the two color categories of ashes. The gray-to-black ashes usually had 2 - 28% carbon, while the sandy-colored ashes usually have low, sometimes even less than 1%, carbon. Nineteen of the 29 samples contained more than 3% carbon and these ashes were chosen for triboelectrostatic beneficiation of the carbon and the ash. The carbon contents of the original 29 ash samples is shown in Figure 2-1.

Wet sieving was used to classify 12 of the 19 fly ash samples into six size fractions: [meshes -500, -400+500, -325+400, -200+325, -100+200, +100] or [<25, 25-38, 38-45, 45-75, 75-150, >150 µm]. The mass percent of the ashes in each size fraction was measured after the samples were dried in a over at 95 ^{O}F for over 24 hours. The carbon content of the original ash and the sized fractions were analyzed (Carbon Hydrogen Nitrogen

Determinator, CHN 600, LECO Corporation) to determine the carbon distribution in the ash. The mass and carbon content in the original fly ashes and in each of their size fractions were also used to obtain the total amount of carbon in each size fraction.

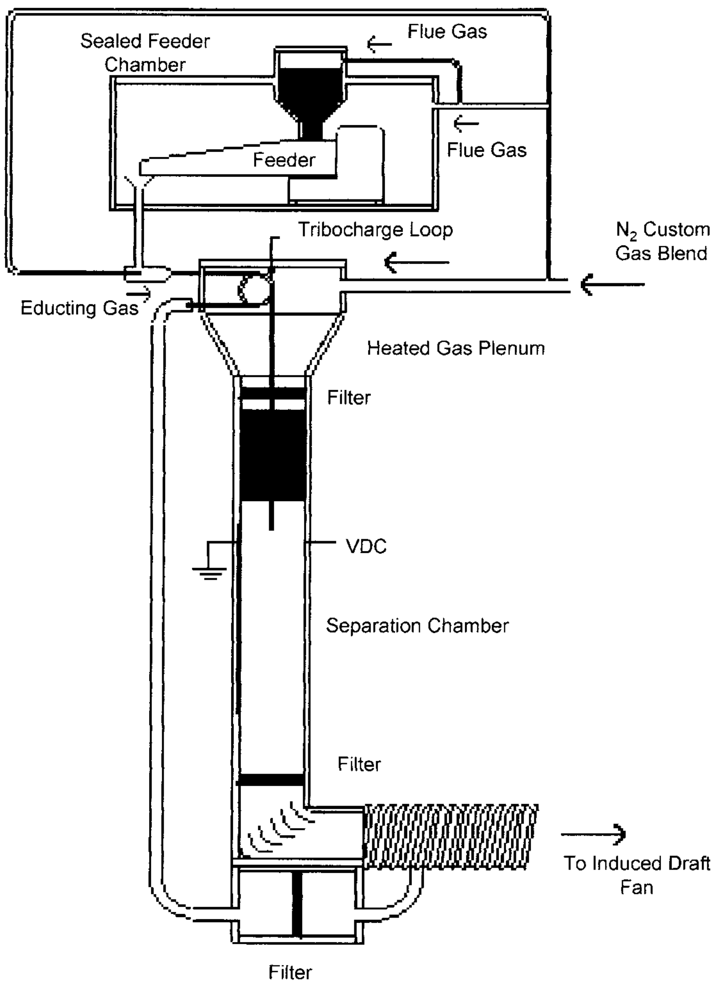

Figure 2-1
Percent carbon in as received fly ash samples.

The characteristics of the original fly ashes were quite different in terms of particle size and carbon distribution. The size distributions consisted in general of two peaks - one below 25 µm and the other around 45 - 150 µm, depending on the fly ash. For most samples, about 50-75% of the mass had below 25 µm particle diameter, and about 70-80% of the mass had below 45 µm (325 mesh) particle diameter. However, the fly ash from EKP Dale station has a very large peak around 75 µm, resulting in a less than 25% mass below 25 µm, and about 40% mass below 45 µm. Another fly ash from EKP Spurlock station has similar size distribution with 45% mass below 25 µm and 65% mass below 45 µm.

The carbon content in each size fraction of the ashes had the same monotonic trend: the carbon content increased with increasing fly ash particle size. Generally, the carbon content was the lowest in the < 25 µm fraction, ranging from 1% to 5%; and was the highest in the > 150 µm, ranging from 25% to 65%. The sample with the greatest carbon content (~65%) in the > 150 µm fraction was an ash from Cinergy. Potomac (Dickerson) had the lowest carbon content in the > 150 µm fraction, ~23%.

However, the distribution of the absolute amount of carbon in these fly ashes was very different. Some fly ashes had a bimodal carbon distribution with one peak around 75 - 150 µm, and the other peak in the <25 µm fraction. Some other fly ashes had more carbon in the two ends of the size fractions, < 25 µm and >150 µm. Another fly ash (EKP Dale) had very little, almost no carbon in the < 25 µm fraction. In general, the amount of carbon in the >45 µm fractions of most of the ashes accounted for 30-70% of the total carbon in these samples.

It is generally recognized that, for most fly ashes, coarse size fractions have more carbon. This characteristic is used in traditional carbon removal technology which simply uses a size classifier to remove coarse particles. Because the carbon content is significantly higher in coarse particles, the technology is sometimes able to remove a sufficient amount of carbon to satisfy the ASTM standard for LOI. The results of this study indicate that size classification for carbon removal may only work for some fly ashes. Many of the ashes had more carbon in the <45µm fraction than would be allowable by the ASTM standards and this carbon was not removable by a simple size classification.

Scanning electron microscope (SEM) images of some fly ashes were recorded to examine their morphological characteristics. A Toshiba OS16-H016 SEM with an energy dispersive spectrometer (EDS) at the CAER, equipped with a computerized image processing capability, was used for the analysis. The SEM images of the ash particles were recorded at two different magnifications. If the composition of a particle needed to be determined, the EDS was used to show whether a particle contained primarily carbon or ash.

The amount of carbon in the different size fractions may also indicate the combustion condition of the sample. From the SEM pictures, we observed particles typical to those expected after various stages of combustion. In general, the particles in the fly ashes were observed to be angular-shaped (uncombusted coal particles), melted or porous (partially combusted coal - char), very porous or skeletal in shape(char), small fragments of the skeleton (char), and spherical (ash). The size distribution of the carbon may represent a distribution in the stages of combustion to which the coal particles were exposed. For example, coarse char particles with little porosity may have originated from early combustion stages, whereas fragmented and porous pieces of char may have originated from the later combustion stages.

3

EXPERIMENTAL SETUP AND PROCEDURE

Triboelectrostatic Separator

A laboratory scale triboelectrostatic separation system, shown in Figure 3-1, was used in the fly ash beneficiation study. It is a pneumatic particle transporting system with particle tribocharging, electrostatic separation, and particle collection sections. Beneficiation of the carbon and ash is achieved in a gas-particle suspension.

Feeding of the fly ashes to the tribocharging unit was accomplished by using a vibratory feeder which was contained in a sealed environmental tank. Each ash was metered into a pneumatic transport tube where it was entrained in a nitrogen carrier gas. The gas-particle mixture was then passed through a copper tribocharger loop where the fly ash was charged by particle-wall and particle-particle contacts. The exit of the charger was connected to a separation chamber which contained a parallel copper plate configuration, across which was established a high intensity electric field. A filter was placed at the bottom of the separation chamber to retain any particles which were not deflected to or fell off the copper plates. The exit of the separation chamber was connected to an induced draft fan.

For each test, about 10 grams of fly ash was weighed and loaded into the vibratory feeder. The average carrier gas flow velocity in the copper tribocharger was about 15 m/s. The electric field strength was maintained at 100-200 kV/m.

A procedure was established for sample collections and analyses. For each test, there were a total of nine or ten sample fractions collected; eight were from four axial regions on each of the two electrodes, one from the center filter at the bottom of the separator, and one was removed from the plexiglass windows at the edges of the Cu electrodes. These fractions were weighed and, along with the feed, analyzed for their carbon content.

The data from these fractions were used to construct a recovery curve which depicts a continuous relationship between product recovery and product quality. The curve can be used to identify the realistic ash recovery, as the mass percentage of the input ash recovered at the product stream, at any product quality, i.e., carbon content.

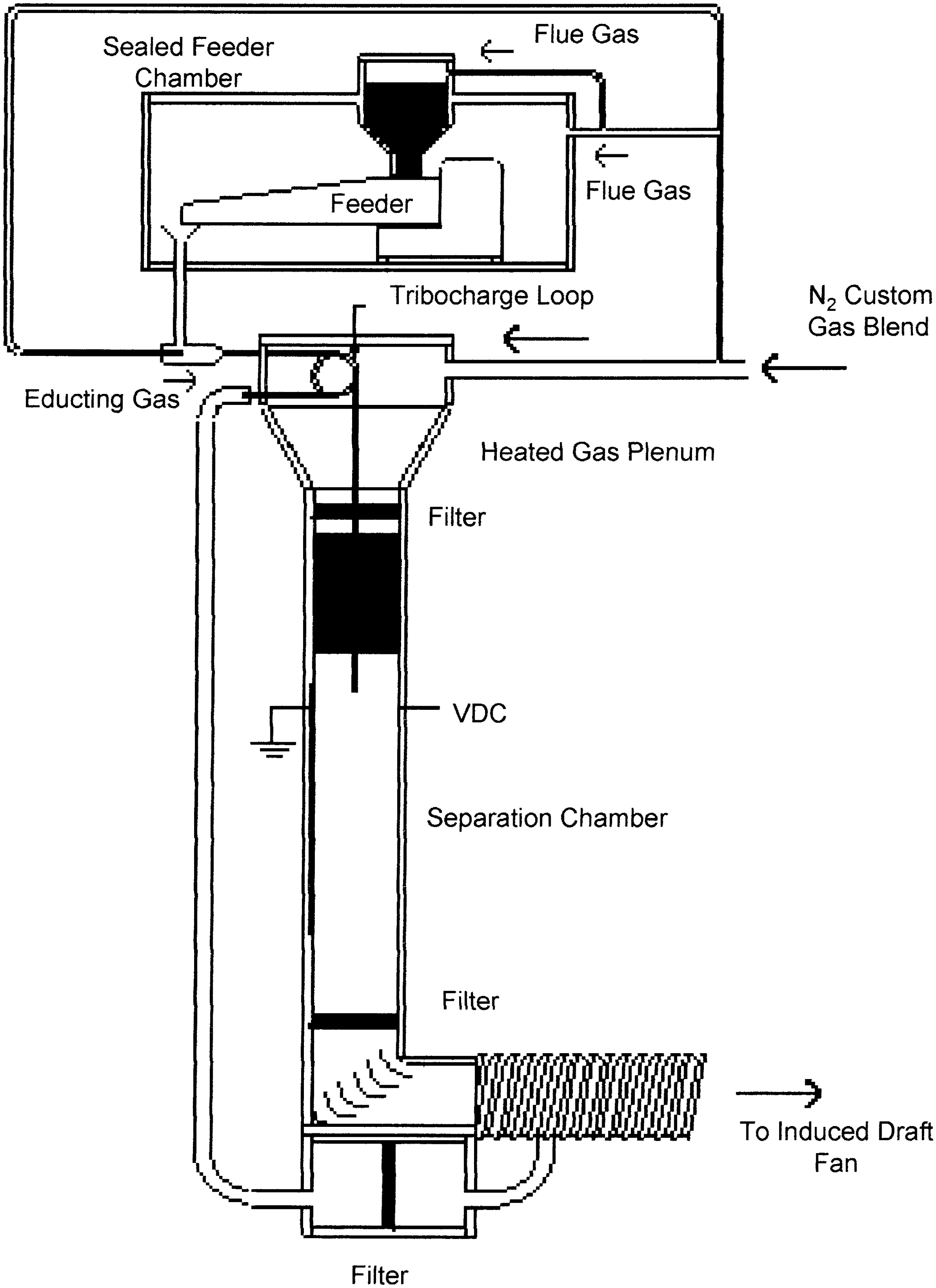

Figure 3-1
The schematic of the laboratory triboelectrostatic separation system.

When a fly ash had lower than 50% ash recovery at 3% carbon content, a dry sieving at 45 µm (325 mesh) was used to classify the fly ash into two fractions, which were then subjected to the triboelectrostatic beneficiation individually. Dry sieving was performed on 12 of the 19 ash samples

Scanning Electron Microscopy (SEM)

The SEM was also used to characterize each ash relative to their separability. After each beneficiation test, samples were collected from predetermined locations throughout the electrostatic separation chamber and their weight and carbon content determined. Representative sample fractions were examined using SEM and EDS. Usually, several SEM images at different magnifications of the carbon-rich products, ash-rich products and the original ash feed were examined to compare particle morphological characteristics.

4

RESULTS AND DISCUSSION

During the operation of the triboelectrostatic separation system, the carbon-enriched component was deposited on the negative electrode and the ash-enriched component was deposited on the positive electrode. These components were retrieved separately for a low carbon ash fraction and a high carbon ash fraction.

The depositions were in the form of long, narrow ribbons of material, starting from near the exit of the transporting tube and extending to the end of the copper plates. Analysis of up to four sequential axial sections of the deposited samples showed the carbon content on the negative electrode decreased with distance from the inlet and the carbon content on the positive electrode increased with distance from the inlet of the electrostatic separator. Since the carbon and ash content on the electrodes could be represented by continuous distributions, it was possible to make an arbitrary split of the separated products that satisfied desired purity requirements. However, as in any physical separation process, higher purity products are achieved at the expense of lower recovery (yield).

Sieving some ashes before triboelectrostatic separation often increased the total low carbon ash recovered. Recycling the ash-enriched fraction collected on the positive electrode near the exit of the system also tended to increase the total low carbon ash recovered. These results are discussed in this section.

Table 4-1 lists triboelectrostatic separation recoveries of low carbon ash($\leq$ 3%) for the 19 samples with an initial carbon content > 3%. Twelve ashes with less than 50% low carbon ($\leq$3%) ash recoveries were dry sieved to remove the coarse ash fraction and then triboelectrostatically beneficiated when necessary to reduce the ash carbon content to $\leq$ 3%. The size classifications and ash recovery of the dry-sieved fraction are shown in the table for these 12 ashes. Two samples with an initial recovery of 55% were also sieved. The samples were dry sieved at 200 mesh (<75 µm) or 325 mesh (<45 µm).

Table 4-1
Summary of low carbon (≤3% C) fly ash recoveries using triboelectrostatic beneficiation of as received and sieved ash fractions

			Sieved Ash Fraction				
ID	**Original Ash %C**	**% Tribo-electrostatic recovery of<3% C ash**	**Sieved size (um)**	**wt% of original ash**	**%C**	**% Tribo recovery of sieved ash fraction at ≤3% C**	**Net Tribo recovery (% of original ash) at ≤3% C**
1	11.09	42	<75	95.6	10.57	65	62.1
2	13.67	38	<75	96	7.4	62	60
3	7.27	40	<75	56.8	3.21	98	55.6
11	6.35	35	<75	90	3.49	84.9	76.4
16*	14.61	5	<75	61.5	2.29	100	61.5
21*	3.57	45	<75	81.6	2.8	100	81.6
23	13.14	20	<75	75.2	5.72	75.2	52.6
26	7.46	35	<75	89.7	5.71	50	45
27	17.98	23	<75	71.4	9.34	38	27.1
28	21.82	A	<75	78.9	18.15	A	A
29	28.29	A	<75	69.9	17.1	A	A
4*	5.36	55	<45	33.1	1.92	100	33.1
24	13.26	42	<45	96	10.8	55	53
25	9.16	55	<45	97	8.7	82	80
15	4.44	70					
18	6.99	60					
19	3.94	80					
20	5.11	70					
22	5.69	50					

Note: A: The samples responded poorly to the separation.
* Fine fractions contained < 3% carbon after sieving

Figure 4-1 presents a summary of the ash recovered with low carbon content (≤3%) for the 19 ashes evaluated. As shown, ≥50% ash recovery of low carbon ash was possible with one pass through the triboelectrostatic separator for 7 of the 19 ashes evaluated. The remaining 12 ashes were dry sieved to removed the coarse fraction. The carbon content in the fine fraction of two samples was <3% after sieving and no additional separation was necessary to achieve a net ash recovery of ≥ 50%. Triboelectrostatic separation was performed on the remaining 10 samples and a net low carbon ash recovery of ≥ 50% was achieved on 6 of the 10 samples. Two samples which had been delivered wet responded poorly to beneficiation and mechanical sieving, recovering less than 30% of low carbon ash.

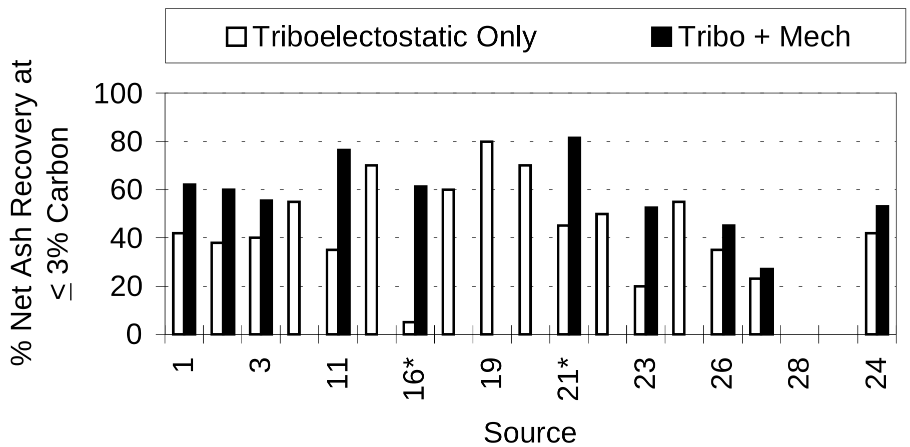

Figure 4-1
Percent fly ash recovered with ≤3% carbon content for 12 fly ashes with an initial carbon content of > 3%.

Size classification (sieving to remove the coarse fraction) of ash before triboelectrostatic beneficiation improved the performance of the separation processing in the laboratory unit. In addition to this beneficial effect, there may be other reasons to consider size classification as one of the steps in the processing. Because the carbon content in the coarse fraction is greater than the carbon content in the finer fraction, size classification can usually reduce carbon content of the recovered fine fraction. If an ash consists of a carbon-ash physical mixture independent of particle size, its beneficiation would be expected to be better the lower the carbon content. Another reason to consider size classification is that the ASTM standards set limits on the particle size of the ash when used as a physical admixture to cement; in addition, the smaller the size, usually the more reactive is the ash. Therefore, a size classification would improve the quality of the fly ash for cement application. Finally, the conditions in a size classifier are usually very turbulent and lead to extensive differential particle charging. Hence, a size classifier may serve partly as a particle charging unit.

Comparing the beneficiation data from sieved versus from original fly ash aids in the understanding of particle charging and separation process. When an ash is sieved into coarse (>75 µm) and fine (<75 µm) fractions, the ash recovery at ≤3% carbon is usually better than the ash recovery for the original fly ash. This improvement indicates interactions between the coarse and fine particles during processing.

Currently, no clear explanation or understanding exists for unfavorable particle-particle interactions that affect ash recovery rates. However, several potential contributing factors can be listed because all particles have to proceed through charging, separation and collection stages. For example, one possible influence may occur during particle deflection toward the electrodes when small (say <15µm) particles are blocked or intercepted by large particles. Another possible influence is during deposition onto the electrodes during which time an incoming particle could "knock-off" particles already attached to the electrode. This effect would be greater for the larger sized particles. If a fly ash has a high quantity of large particles, the separation in the laboratory system may not be as effective because of the large particles tend to fall off the electrodes, i.e., off the vertically installed parallel copper plates, to the center filter. Since particle charging is the foundation of triboelectrostatic processing, it is also necessary to consider whether the charge on fine particles is changed by the presence of large particles. Although it is not likely that these influences all are of the same magnitude, the particle concentration in the flow during our testing was, on a theoretical basis, dilute enough to neglect particle-particle interactions within a first-order approximation.

The potential multiple functions of a size classifier are included in the design of a continuous triboelectrostatic separator design. The charging, beneficiating, and classifying may all contribute to the success of the processing at a reasonable cost. However, the classifier is not considered an absolute necessity for successful triboelectrostatic beneficiation.

Product Quality

A required product quality can be obtained by selecting the ash fraction from the separation system. An ash recovery curve, shown in Figure 4-2, is calculated and plotted from the data on separated fractions. The product quality can be selected from the x-axis and the corresponding ash recovery can be found from the vertical axis. For this sample, which was obtained from a utility boiler burning bituminous coal having a sulfur content near 2%, over 65% of the ash was recovered with a carbon content of less than 3%. The recovery curve can also be calculated and plotted for the carbon rich stream. For example, Figure 4-4 shows that about 50% of the carbon in the ash was recovered with a carbon content greater than 35% in the carbon-enriched ash fraction.

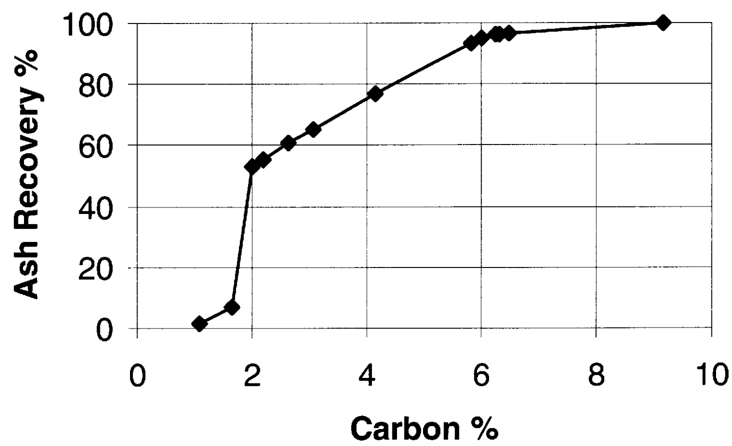

Figure 4-2
Ash recovery curve for fly ash.

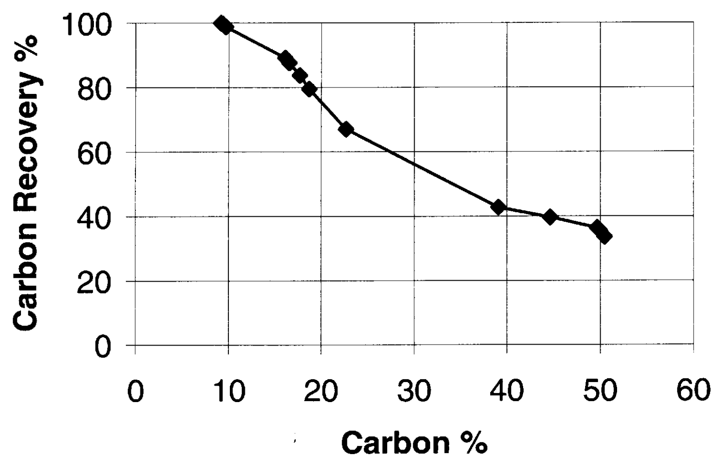

Figure 4-3
Carbon recovery curve for the ash from Figure 4-2.

Recycling

The performance of triboelectrostatic fly ash processing can be improved by recycling some of beneficiated product back to the inlet of the separation system. For example, when a middling product from the electrostatic separator was recycled, the ash recovery at ≤3% carbon increased from 36% to 53%, shown in Figure 4-4. The carbon recovery curves for this example are shown in Figure 4-5. These data also show that the recovery analysis presented in this report, although quantifying the performance of triboelectrostatic beneficiation, is representative of the recovery for only a single pass through the system. Such recycling has potentially significant consequences with respect to increasing the overall applicability of the processing as has been performed for this study.

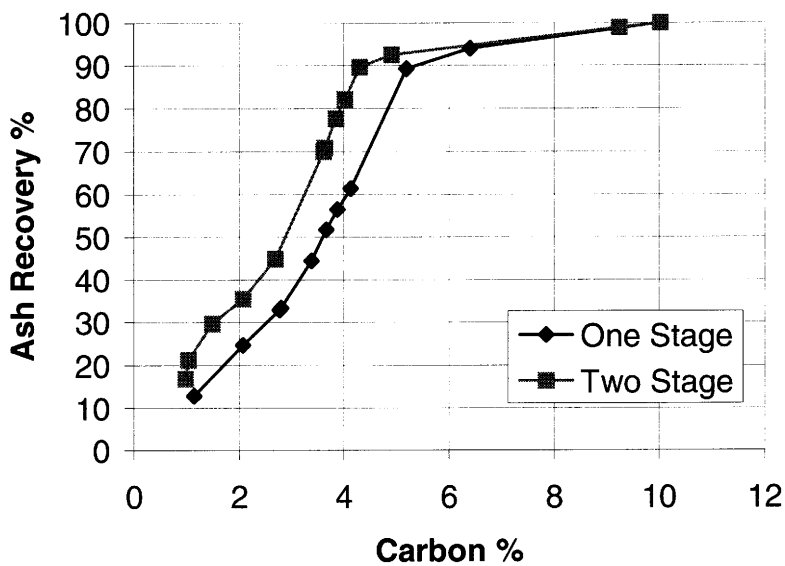

Figure 4-4
Ash recovery curves obtained during a single and double stage triboelectrostatic processing of a utility fly ash.

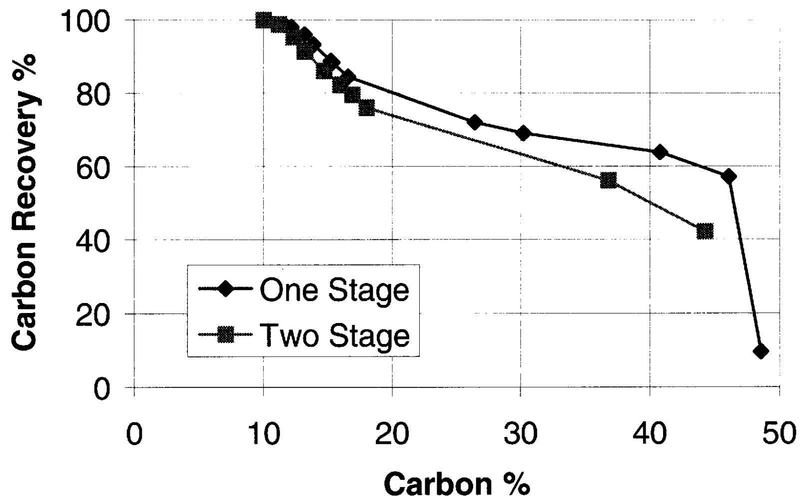

Figure 4-5
Carbon recovery curves obtained during a single and double stage triboelectrostatic processing of the utility fly ash from Figure 4-5.

SEM Results

The SEM pictures of beneficiated fly ash were taken for many of the samples. Differences between the carbon-rich products and the ash-rich products are obvious due to the great differences in particle shape, morphology and size. Ash particles are usually spherical; char particles are porous or skeletal, or broken into pieces from the skeleton shape.

Figure 4-6 is an SEM photograph of a beneficiated fly ash. The angular shaped particles are probably inertinite particles - unburned coal particles carried over to the ash collection system at the utility. A particle which is clearly melted and near spherical in shape but with little perforation is probably a char particle at an early combustion stage. Later combustion stage char particles are characterized by increased porosity. The most macroporous particles have a very skeletal shape, almost like a bird cage. Eventually, this skeletal structure breaks into pieces of smaller char particles during handling.

The char particles in the carbon-rich products from the triboelectrostatic system have different characteristics for many of the ashes which have been examined. Some samples have large, relatively non-porous carbon particles, while some ashes have many broken and skeleton pieces which produce a smaller carbon particle size distribution. It is possible that the presence of large, less porous char particles indicates insufficient exposure to combustion conditions as a consequence of insufficient retention time, insufficient air mixing, insufficient temperature, or a combination of these factors. During this study, a qualitative agreement was noted between the size distribution of carbon obtained from SEM data and measured from the wet sieving analysis.

Figure 4-7 is an SEM picture of fly ash #29. There is a relatively high concentration of large carbon particles , as shown in the SEM picture of the carbon-rich product in Figure 4-8. Comparing these data to that for the ash-rich product, the size of carbon particles were almost 10 times greater than the average size of the ash particles. This observation is consistent with the sieving analysis of the same ash. For this sample, it is possible that triboelectrostatic beneficiation may be affected by the presence of the large carbon particles. It is also possible that a size classifier incorporated into the processing scheme for this ash could make the beneficiation more efficient.

Figure 4-9 shows the carbon-rich product and the spherical ash particles of beneficiation for another fly ash. The carbon particles in this figure are much smaller than the carbon particles in Figure 4-8. It is possible that, for this sample, size classification would not improve significantly ash-carbon separation.

The SEM data also show the presence of very fine (<1μm) particles on the surface of the ash particles. The spherical surfaces of many ash particles, if carefully examined, are not smooth, but are coated with many small "dust" particles. These particles are more observable on the surface of the ash particles than on the carbon particles. The composition of these tiny particles is not known. The effect of coating a smooth surface with very fine particle on triboelectrostatic beneficiation is unknown but may be of importance.

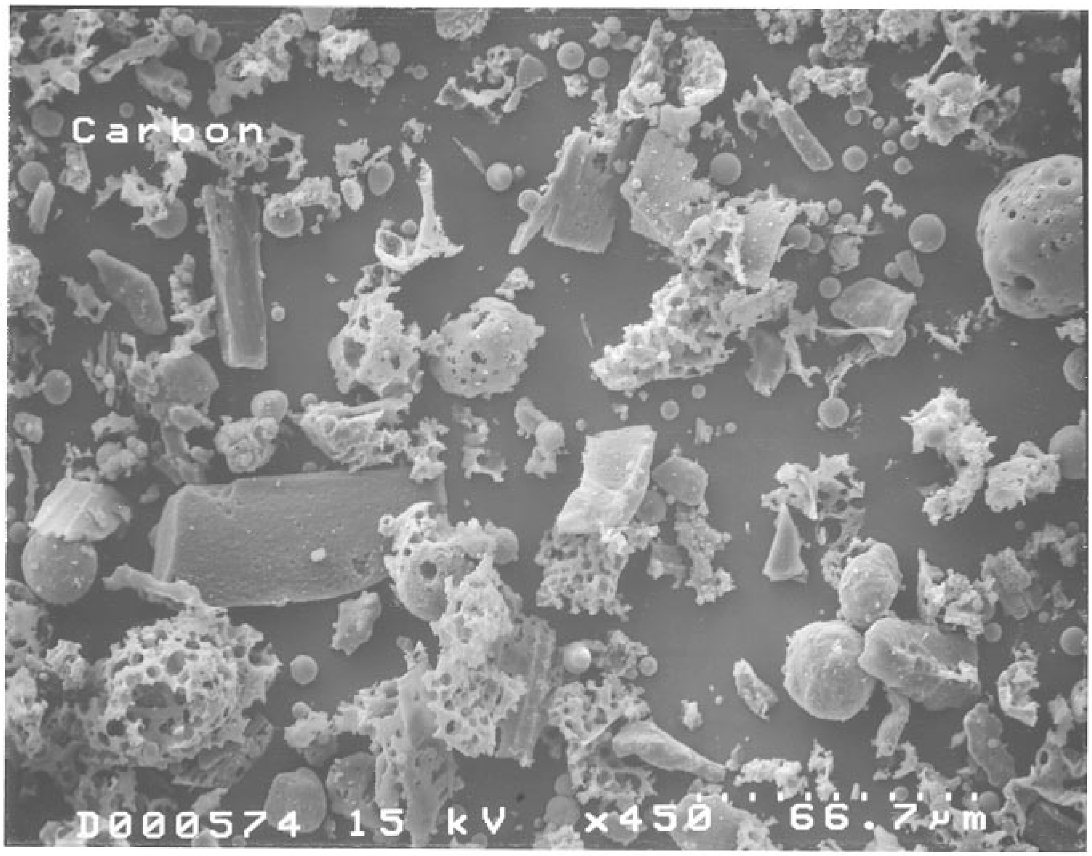

Figure 4-6
SEM picture of fly ash showing coal char at various combustion stages.

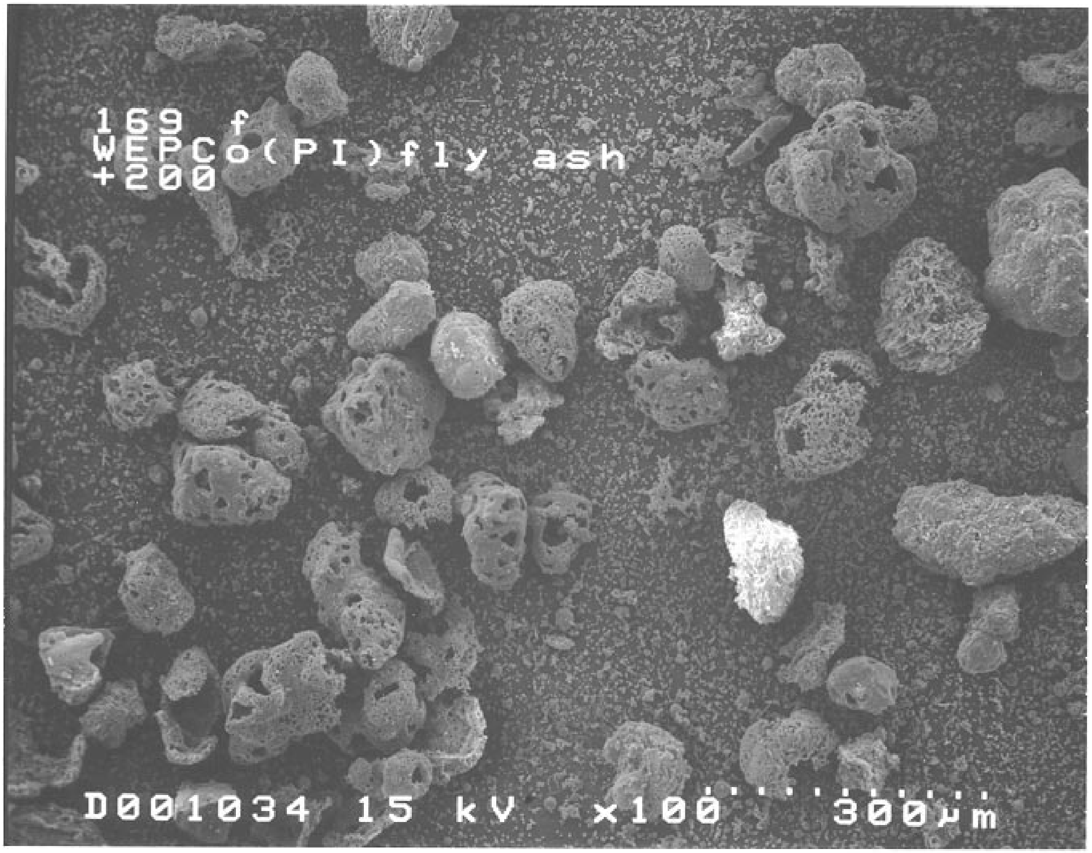

Figure 4-7
SEM picture of a fly ash having large carbon particles.

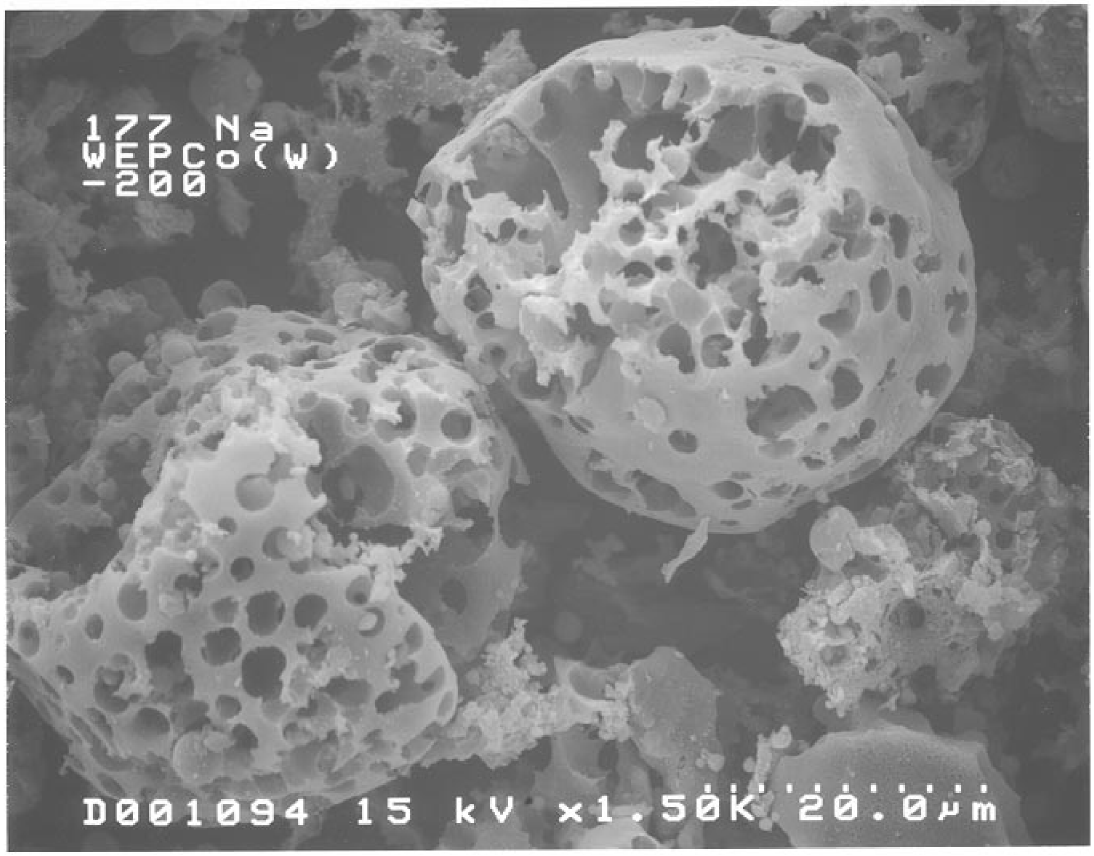

Figure 4-8
SEM picture of a carbon-rich product obtained by triboelectrostatic beneficiation which shows macroporous large carbon particles.

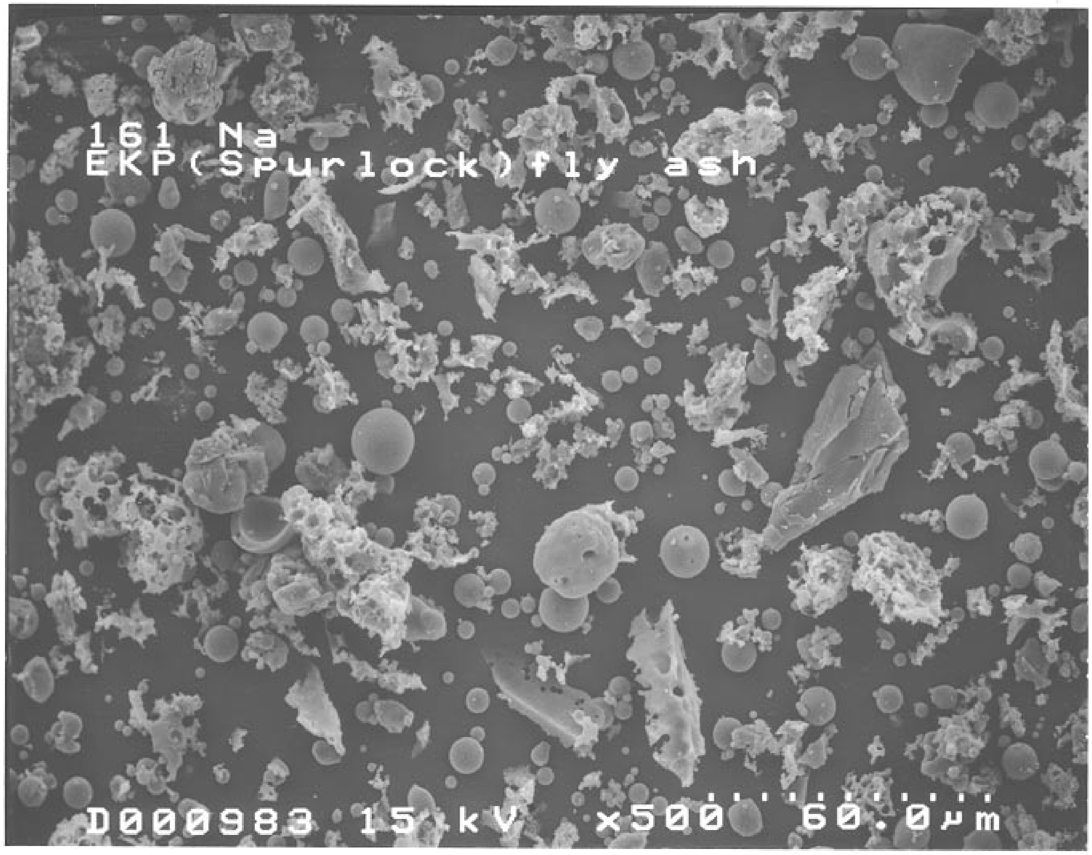

Figure 4-9
SEM picture of a fly ash sample showing fragmented carbon particles.

5

SUMMARY OF KEY FINDINGS AND CONCLUSIONS

An identical procedure was used in handling and processing each of twenty-nine fly ashes that were obtained from United States power stations burning various types of coals. Samples were received in five gallon, sealed containers. Triboelectrostatic beneficiation tests to separate unburned carbon from ash were performed on the 19 ashes with an initial carbon concentration > 3% to determine a general efficiency and applicability of the technique. The size distribution and the carbon distribution in the fly ash were analyzed to provide information on the behavior of carbon and ash particles during the processing.

The key observations and findings of this study are as follows:

- The physical characteristics of fly ashes are significantly different from one another. The carbon content in the ashes varied between 0.2-28 %. The particle size distributions were highly variable with approximately 60~90% of the mass in each of the samples below 45 μm in diameter; the size distribution of carbon was ash specific, and probably a result of coal characteristics and combustion conditions to which the samples were subjected. Another observation was that most of the carbon (~40-70%) was contained in the fine sized (<45 μm) particulate, yet the carbon percentage was usually the highest (>20%) in the largest sized (>115 μm) fraction; .

- With triboelectrostatic separation and no sieving to remove large particles, seven of the nineteen ashes evaluated had >50% recovery of low carbon (≤3%) ash.

- Twelve of the 19 ashes with <50% recovery of low carbon ash were dry sieved and then triboelectrostatically separated if necessary:

    - the fine fraction of 2 of the sieved ashes contained less than 3% carbon and the net low carbon ash recovered was > 50%. No triboelectrostatic separation was needed.

    - A low carbon ash recovery of >50% was achieved with six of the 10 remaining ashes.

- Three ashes of the 19 tested did not respond well to triboelectrostatic processing with a single pass through the separator or to mechanical pre-sieving (low carbon ash recoveries < 30%).

- Recycling the ash through the triboelectrostatic separator improved the total low carbon ash recovery.

The current findings, based on batch laboratory-scale testing, show that triboelectrostatic separation is a viable approach for reducing fly ash carbon. Pre-sieving of coarse ash fractions can further improve the overall performance of triboelectrostatic beneficiation of high carbon fly ash. Further work is needed to show that the triboelectrostatic separation process can be operated continuously and economically at a larger scale.

6

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