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Pilot-Scale Testing of a Vibrating Electrostatic Separator for Fly Ash Decarbonization

Roe-Hoan Yoon[1], **Eric Yan**[1], **Oh-Hyung Han**[2], **Byung-Wook Park**[3]
[1] Minerals and Coal Technologies, Inc., Blacksburg, Virginia 24060, U.S.A.
[2] Chosun University, KwangJu 501-759, Korea
[3] Korea Fly Ash Cement Company, Ltd., Bo-Ryung, Chungnam, Korea

A new electrostatic separator has been developed for the removal of unburned carbon from fly ash. In this separator, a flowing film of fly ash is created on the surface of a vibrating electrode. Conducting particles such as unburned carbon acquire electrostatic charges and jump out of the flowing film so that they can be removed from the non-conducting fly ash particles moving forward. The new separator has been tested successfully using a pilot-scale test unit at 0.5 tons/hr capacity. Based on the successful test results, a larger unit is being constructed at the present time..

Keywords: Fly ash, Unburned carbon, Conductive induction, Vibrating electrostatic

Introduction

Fly ash is used to replace pozzolans in Portland cement and as fillers in plastic and asphalt manufacture. One of the problems in recycling fly ash as pozzolan is the amount of the unburned carbon left in it. Loss on ignition (LOI) is a common measure of the unburned carbon in fly ash, and the ASTM C114 describes a standard method of determining it. The unburned carbons in fly ash consume air-entraining agents used in concrete. They also affect pozzolanic reactivity and weaken the strength of concrete. Therefore, ASTM C-618-92a limits maximum LOI for Class F and C fly ashes to 6%. It is desirable, however, to further reduce the LOI of a fly ash preferably to below 3% using appropriate beneficiation methods to increase its marketability. In 2000, Korea produced a total of 4.4 million metric tons of fly ash, approximately 30% of which was recycled. In the same year, the U.S. produced 62.7 million short tons of fly ash, and 20.8 million tons of it was recycled.

Various separation methods are used to remove unburned carbons from fly ash. These include classification, electrostatic separation, and flotation, of which the last is most efficient. However, the *flotation* is a wet process, requiring the product to be dewatered before use. Dry cyclones are commonly used for the *classification*. The coarse fractions, which usually contain bulk of the unburned carbons, are rejected, while the fines fractions containing bulk of the fly ash are recovered. This process is advantageous over flotation in that it is a dry process and requires low capital and operating costs. However, it suffers from low separation efficiencies, particularly when the particle size is small. *Electrostatic separation* is also a dry process, and can be efficient depending on its design. For this reason, many investigators developed various electrostatic separators for fly ash decarbonization.

Electrostatic separation is widely used for the beneficiation of ores, plastics, and other recycled materials. Depending on the methods of charging the particles to be separated, electrostatic separators may be classified into three different types: i) electrodynamic (corona) separation, ii) true electrostatic (inductive) separation, and iii) triboelectrostatic separation (1,2). Of these, the triboelectrostatic separation has been studied most extensively for the decarbonization of fly ash (3-7). In this method, particles are contacted against a material whose work function lies in between the particles to be separated from each other. This will allow the particles to be charged oppositely. The charged particles are then separated from each other in an electric field.

Minerals and Coal Technologies (MCT) developed a new electrostatic separator that can be used for removing unburned carbons from fly ash (8). It is based on charging particles by conduction, i.e., by allowing a conductor such as carbon to be in contact with an electrode. In the present communication, the results obtained with this new electrostatic separator are presented. Both bench- and pilot-scale test results are given.

Experiment

Samples

All of the fly ash samples used in the present work were obtained from Korea Fly Ash Cement Company. Some of the laboratory tests were conducted using as-received samples, while others were conducted after removing the -200 mesh fraction. In pilot-scale tests, many of the tests were conducted on the rejects from a GE classifier.

Separator

Figure 1 is a schematic representation of the bench-scale test unit used in the present work. It consists of a negative electrode plate (10υ35-inch) and a set of V-shaped positive electrodes installed 1.25 inches above the negative electrode plate. (Only a part of the positive electrodes are shown in Figure 1.) The positive electrodes serve as collectors for charged particles. The electrode assembly is subjected to electromagnetic vibration so that the particles move forward in a flowing film while being agitated.

As the particles move forward along the surface of the negative electrode, conducting particles such as unburned carbons acquire negative charges by conduction. The charge density of the particles increases with increasing frequency of contacts with the negative electrode, which in turn is determined by the vibration frequency and the velocity at which the particles travel. When the particles acquire sufficient charges, they are repelled from the negative electrode and attracted by the positive electrodes above. This mechanism allows carbon particles jump into the V-shaped trough electrodes, as shown in Figure 1. Non-conducting particles such as fly ash would continue to move along the surface of the bottom electrode without being affected by the electric field..

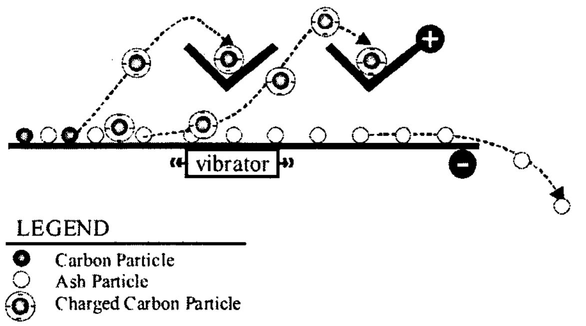

Figure 1. A schematic representation of the vibrating electrostatic separator.

The pilot-scale test unit used in the present work was similar to the laboratory unit, except that the negative electrode plate was 2-m long and 1-m wide. Also, the vibration was provided by an asymmetric motor rather than a magnetic vibrator. The pilot-unit was constructed as a triple deck, so that particles are given a total of 6 meters of travel distance.

Procedure

The process was sensitive to humidity; therefore, most of the tests were conducted at relative humidity of less than 40%. The two products and the feed were analyzed for LOI using the method described in ASTM C114. The results were used to determine the recoveries of fly ash using the three-product formula.

In laboratory tests, a given fly ash sample was passed through the separator several times to obtain a desired product. This was necessary because a single passage provided only a short travel distance, which was insufficient for charging all of the carbon particles present in a feed. A feed sample passing through the separator five times would be given a total of 4.4 meters of travel distance.

Results and Discussion

A. Laboratory Tests

Each test was conducted using a 100-g sample. All of the tests were conducted at a potential difference of 30 kV between the top and bottom electrodes.

1) Effects of Angle of Slope

Table 1 shows the results obtained by changing the angle of slope of the separator. As shown, the recovery of fly ash increased with increasing slope, which can be attributed to the increasing velocity of particles with increasing slope. At a higher particle velocity, fewer particles would be charged enough to jump out of the flowing film. Conversely, the lower the slope, the lower the product LOI and the fly ash recovery. At the lowest angle of slope of 11θ, the LOI of the fly ash product was reduced from 26.6 to 3.2% with a recovery of 68.0% after three passes. After four passes, the LOI was further reduced to 1.6% with a recovery of 65.9%. It should be noted here that the number of cleaning stages required to obtain a desired LOI should decrease, as the size of the separator becomes larger.

Table 1. Effects of Changing the Angle of Slope on the Separation of a +200 mesh Fly Ash Sample Assaying 26.6% LOI

Angle of Slope (deg)	3 Stages			4 Stages		
	Cumulative wt%			Cumulative wt%		
	Yield	Rec.	LOI	Yield	Rec.	LOI
11	49.4	68.0	3.2	49.2	65.9	1.6
16	52.8	69.5	3.5	50.1	66.7	2.2
18	54.8	71.4	4.4	51.0	67.4	3.0
21	57.2	74.0	5.0	51.9	68.5	3.2
23	59.3	75.4	6.7	54.1	70.6	4.3
26	73.2	86.7	13.0	62.3	78.7	7.3

2) Effects of Multi-Stage Processing

In this test, the +200 mesh fly ash sample was cleaned five times at 30 kV. The results, given in Table 2, show that the separation efficiency increased with increasing number of cleaning stages. This observation may be explained as follows. Although carbon is a conductor, the conductivity of the unburned carbon particles present in fly ash may be relatively low. The most likely reason for the low conductivity may be that the surface of the carbon particles may have been oxidized during the process of incomplete combustion in the furnace. The low conductivity may necessitate that unburned carbons have multiple contacts with the bottom electrode before they can be sufficiently charged. Furthermore, the probability of the particles contacting the negative electrode and being negatively charged would increase with increasing travel distance. After five passes, the LOI of the +200 mesh fly ash sample was reduced from 26.2 to 1.3% with a 65.9% recovery.

Table 2. Effects of Multi-Stage Cleaning of a +200 Mesh Fly Ash Sample

Stage	Cumulative wt%		
	Yield	Recovery	LOI
1	78.8	86.8	19.7
2	72.0	81.9	16.6
3	60.1	74.0	9.7
4	52.0	68.5	3.3
5	49.0	65.9	1.3

3) Effects of Pre-Charging

In this test, a fly ash sample from Korea Fly Ash Company was used without pre-screening. Two sets of tests were conducted. In one, the sample was charged before the separation tests, and in another it was fed to the separator without pre-charging. The pre-charging was achieved by passing the feed sample through an air cyclone that was made of Plexiglas. As the carbon particles contact the inner walls of the cyclone, electrons were transferred possibly from Plexiglas to carbon, thereby charging it negatively.

This negative charge may have shortened the time required for the carbon particles to acquire sufficient charges for effective separation. Consequently, the test results obtained with the pre-charged sample gave considerably better results.

Table 3. Effect of Pre-Charging a Fly Ash Sample Assaying 8.63% LOI Prior to the Electrostatic Separation

Stage	No charging			Pre-charging		
	Cumulative wt%			Cumulative wt%		
	Yield	Rec.	LOI	Yield	Rec.	LOI
1	88.3	91.9	5.0	92.0	95.9	4.8
2	82.5	87.0	3.7	88.6	93.5	3.6
3	79.5	84.1	3.2	86.2	91.4	3.1
4	76.3	80.9	3.1	84.1	89.3	2.9
5	74.0	78.6	3.0	81.1	86.3	2.8

As shown in Table 3, the LOI of the pre-charged sample was reduced to 2.9% after four stages of cleaning at 89.3% recovery. With no pre-charging, a 3% LOI product was obtained after 5 stages of cleaning with 80.1% recovery. Thus, a pre-charging technique using a triboelectrification method is helpful for improving the efficiency of the electrostatic separation method described in the present communication.

4) Effects of Feed Rate

Table 4 shows the results obtained with a +200 mesh fly ash sample, assaying 4.0% LOI, by changing the feed rate. In general, the product LOI decreased with decreasing feed rate. At a feed rate of 50 g/min, the LOI was reduced to as low as 1.3% with a recovery of 93.8% after five stages of cleaning. At 300 g/min, the product LOI was higher (2.1%), but the recovery was also higher (96.3%).

Table 4. Effect of Feed Rate on Processing of a +200 Mesh Fly Ash Assaying 4.0% LOI

Stage	50 g/min		200 g/min		300 g/min	
	Cum. wt%		Cum. wt%		Cum. wt%	
	Rec.	LOI	Rec.	LOI	Rec.	LOI
1	97.2	2.5	98.5	3.3	97.7	2.9
2	96.1	2.0	96.4	2.6	96.7	2.3
3	93.8	1.3	93.4	1.6	96.3	2.1

B. Pilot-Scale Tests

1) Effect of Applied Potential

Figure 2 shows the result obtained using the triple-deck vibrating electrostatic separator. The tests were conducted on a sample taken from the feed to a GE classifier at Korea Fly Ash Company. It assayed 4.34% LOI. The tests were conducted at 0.15 tons/hr capacity by changing the potential difference between the two electrodes in the range of 20 to 28 kV. The %LOI decreased with increasing potential difference. Note, however, that the decrease in LOI was achieved at the expense of yield (or recovery). At the highest applied potential of 28 kV, the LOI decreased from 4.34 to 2.98% with a recovery of 93%.

Figure 3 shows the result obtained on a reject stream from a GE classifier at Korean Fly Ash Cement Company. The sample assayed 6.95% LOI, and the tests were conducted by varying potentials in the range of 20 to 28 kV. As was the case with the feed sample (see Figure 2), the %LOI decreased with increasing potential. Note, here, that the unburned carbons were more readily removed from the reject stream than from the feed stream.
At 28 kV of applied potential, the %LOI was reduced from 6.95 to 1.63% with a recovery of 87.45%. The coarse particle size of the reject may be responsible for the higher separation efficiency observed.

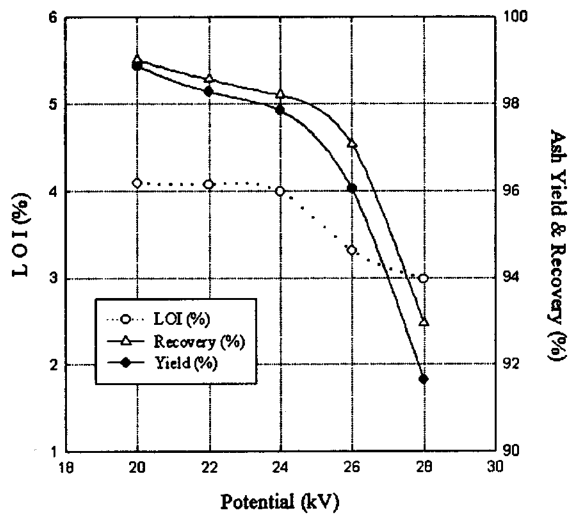

Figure 2. Effect of applied potential on the removal of unburned carbon from a feed to a GE classifier assaying 4.35% LOI.

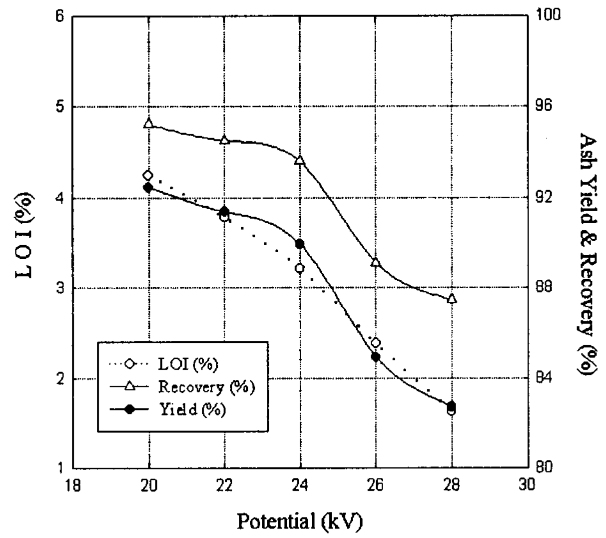

Figure 3. Effect of applied potential difference on the removal of unburned carbon from a reject stream from a GE classifier assaying 6.95% LOI.

2) Effects of Multi-Stage Cleaning

Figure 4. Effects of multiple-stages of cleaning of a classifier feed (4.35% LOI) using the triple-deck vibrating electrostatic separator. It was passed through the triple-deck vibrating electrostatic separator three times, so that the sample is given a total of 18-m of travel distance. The potential was set at 28 kV. The results showed that %LOI continue to decrease with increasing number of cleaning stages. After a single-stage of cleaning, the %LOI was reduced from 4.34 to 3.3%. With two more stages of cleaning, LOI was reduced to as low as 1.04% with 82% recovery. At a longer travel distance, unburned carbons are more fully charged and, hence, are more readily removed.

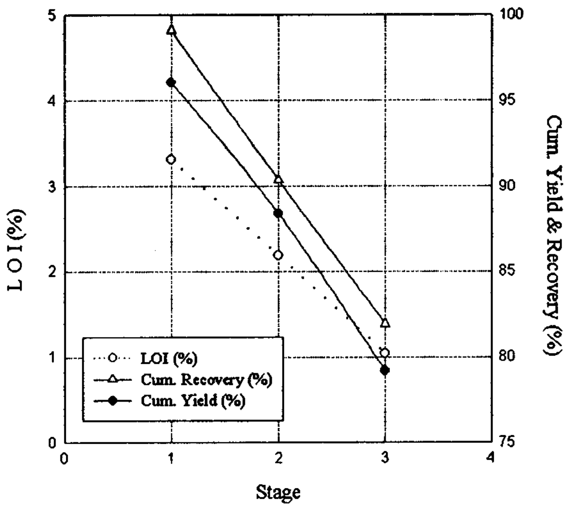

Figure 4 shows the result obtained on a feed to the GE classifier assaying 4.35% LOI.

Figure 5 shows the results obtained on a reject stream from a GE classifier assaying 6.95% LOI. The tests were conducted at 0.15 tons/hr and a potential difference of 28 kV. A single pass reduced LOI to 2.38%. After two more passes, LOI was further reduced to 0.9% at 75.1% recovery. Note that the reject stream can be more readily cleaned than the feed stream (Figure 4), which can be attributed to the larger particle size of the former

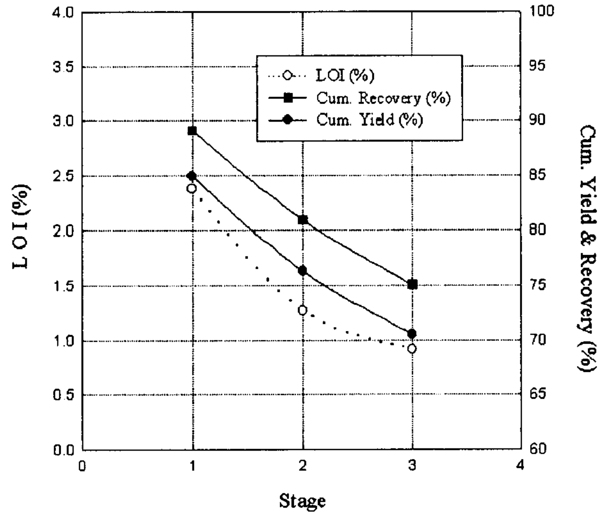

Figure 5. Effect of processing a classifier reject assaying 6.95% LOI using a triple-deck vibrating electrostatic separator.

3) Effects of humidity

Figure 6 shows the results obtained by controlling the relative humidity. The tests were conducted on a GE classifier reject stream assaying 7.15% LOI at 0.15 tons/hr throughput and 28 kV potential difference. All tests were conducted at single stage. At humidity below 50%, the LOI of the fly ash product was reduced to 3.15% with a recovery of 87%. At 70% relative humidity, the LOI was reduced to 4.40% at a recovery of 81%. The results show that the selectivity of the electrostatic separation deteriorates significantly with increasing humidity.

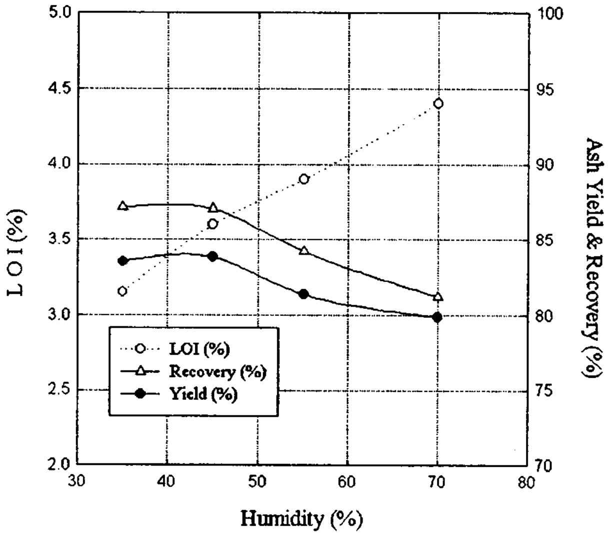

Figure 6. Effect of humidity on the (single-stage) processing of a classifier feed assaying 7.15% LOI.

4) Effect of Feed Rate

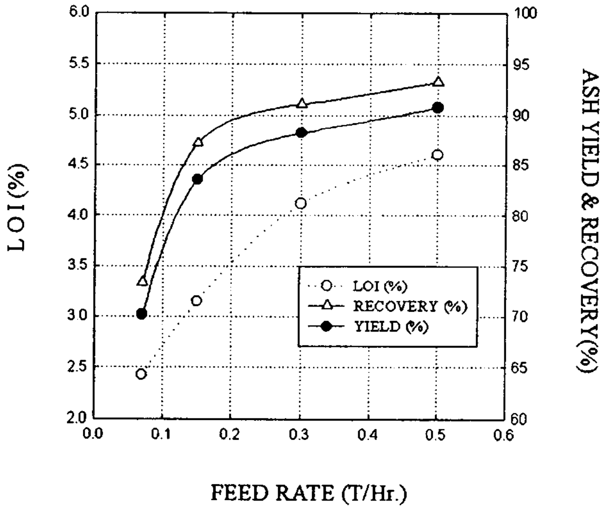

Figure 7. Effects of feed rate on the removal of unburned carbon from a classifier reject assaying 7.15% LOI.

A series of tests were conducted on a classifier reject, assaying 7.15% LOI, by changing feed rate. As shown in Figure 7, the %LOI of the product increased with increasing feed rate. At a feed rate of 0.15 tons/hr, the %LOI of the product was reduced to 3.15% with a recovery 81.1%. As the feed rate was increased to 0.5 tons/hr, the LOI increased to 4.60% with a recovery of 93.24%. At a higher feed rate, the thickness of the flowing film increased, which made it difficult for the unburned carbon particles to make contacts with the negative electrode surface and be charged sufficiently. Even if the particles are highly charged, they may be prevented from jumping out of the flowing film by the overlying particles.

Conclusion

A new vibrating electrostatic separator was developed for the removal of unburned carbons from fly ash. It is based on charging the carbon particles by conduction, and separating them from uncharged fly ash particles in an electric field. Based on the bench-scale test results obtained in the present work, a pilot-scale test unit was constructed. A series of pilot-scale tests were conducted by changing the feed rate in a range of 0.1 to 0.5 tons per hour. It was found that the efficiency of removing unburned carbons depends critically on electrode potential, particle size, feed rate, humidity, angle of slope, vibration frequency, and the length of the negative electrode on which the particles travel. The results obtained in the present work demonstrated that the vibrating electrostatic separator can be used to remove unburned carbon from fly ash to less than 3% LOI. Based on the results obtained in the present work, a 2 tons/hr unit is being constructed.

Acknowledgement

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