TECHNICAL PROGRESS REPORT

for the Fifth Quarter

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POC-SCALE TESTING OF A DRY TRIBOELECTROSTATIC SEPARATOR FOR FINE COAL CLEANING

by

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DISCLAIMER

Abstract

It is the objective of the present project to further develop the triboelectrostatic separation (TES) process developed at the Federal Energy Technology Center (PETC) and test the process at a proof-of-concept (POC) scale. This process has a distinct advantage over other coal cleaning processes in that it does not entail costly steps of dewatering. The POC-scale unit is to be developed based on i) the charge characteristics of coal and mineral matter that can be determined using the novel online tribocharge measuring device developed at Virginia Tech, and ii) the results obtained from bench-scale TES tests conducted on three different coals.

At present, the project is at the stage of engineering design (Task 3), which has three subtasks, i.e., Charger Tests (Subtask 3.1), Separator Tests (Subtask 3.2), and Final POC design (Subtask 3.3). Work accomplished during the current reporting period pertains to the first two subtasks. The results obtained to-date are summarized as follows:

- The charge densities of coal and mineral matter (represented by quartz) have been measured using the novel tribocharge measuring device. The results show that coal is positively charged, while mineral matter is negatively charged, which serves as the basis of the TES process.
- The difference between the charge densities of coal and mineral matter can be maximized by: i) decreasing particle size, ii) increasing particle (or compressed air) velocity, and iii) decreasing feed rate. These conditions can be used as the basis for selecting the optimum conditions for maximizing separation efficiency of the TES process.
- A series of laboratory scale TES tests have been conducted on a Pittsburgh coal by varying the potential difference between the two electrodes in the range of 20 to 70 kV. For

processing 200 mesh x 0 coal, the best results were obtained at 40 kV. The results obtained with the -140+200 mesh fraction tend to be inferior to those obtained with the 200 mesh x 0 coal, suggesting that the TES process becomes more efficient with finer particles.

- The TES tests were conducted using a new, improved triboelectrification device, which is different from the original design developed at FETC.

Both the Subtask 3.1 and Subtask 3.2 are continuing. The results obtained in these subtasks are essential for Subtask 3.3. Preparation is underway to conduct bench-scale tests on Elkhorn No. 3 coal and a low-rank coal.

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Executive Summary

The Pittsburgh Energy Technology Center (PETC) developed a triboelectrostatic separation (TES) process which is capable of removing mineral matter from coal without using water. A distinct advantage of this dry coal cleaning process is that it does not entail costly steps of dewatering which is a common problem associated with conventional fine coal cleaning processes. It is the objective of this project to conduct a series of proof-of-concept (POC) scale tests at a throughput of 200-250 kg/hr and obtain scale-up information. Prior to the POC testing, bench-scale test work will be conducted with the objective of increasing the separation efficiency and throughput, for which changes in the basic designs for the charger and the separator may be necessary. The bench- and POC-scale test work will be carried out to evaluate various operating parameters and establish a reliable scale-up procedure. The scale-up data will be used to analyze the economic merits of the TES process.

The work conducted during the current reporting period pertains to:

- charger test (Task 3.1) to study charge characteristics of coal and mineral matter, and
- bench-scale TES tests (Task 3.2) on a Pittsburgh coal.

In Task 3.1, a novel online tribocharge measuring device developed in the present work has been used to determine the charge characteristics of a clean Pittsburgh coal and quartz (representing mineral matter). The results are useful identifying conditions for troboelectrification process that can maximizing the charge difference between coal and mineral matter. In Task 3.2, a bench-scale TES unit developed in the present work was used to clean a Pittsburgh coal of its ash-forming minerals and inorganic sulfur under different conditions. The results obtained in these subtasks will be used for designing the POC unit.

INTRODUCTION

Numerous advanced coal cleaning processes have been developed in recent years that are capable of substantially reducing both ash- and sulfur-forming minerals from coal. However, most of the processes involve fine grinding and use water as cleaning medium; therefore, the clean coal products must be dewatered before they can be transported and burned. Unfortunately, dewatering fine coal is costly, which makes it difficult to deploy advanced coal cleaning processes for commercial application.

As a means of avoiding problems associated with the fine coal dewatering, the Pittsburgh Energy Technology Center (PETC) developed a dry coal cleaning process, in which mineral matter is separated from coal without using water. In this process, pulverized coal is subjected to triboelectrification before being placed in an electric field for electrostatic separation. The triboelectrification is accomplished by passing a pulverized coal through an in-line mixer which is made of copper, whose work function lies in-between those of carbonaceous material (coal) and mineral matter. Thus, coal particles impinging on the copper wall loses electrons to the metal, thereby acquiring positive charges, while mineral matter impinging on the wall gains electrons to acquire negative charges. The triboelectrostatic separation (TES) process has been tested successfully on bench-scale. The results obtained at PETC showed that it is capable of removing more than 90% of the pyritic sulfur and 70% of the ash-forming minerals from a number of eastern U.S. coals. It is necessary, however, to test the process on a proof-of-concept scale so that appropriate scale-up information is obtained. Furthermore, it is necessary to increase the throughput of the TES process by improving the design for the electrostatic separation system.

The laboratory-scale batch TES unit used by PETC relied on adhering charged particles on parallel electrode surfaces and scraping them off. Therefore, its throughput will be proportional to the electrode surface area. If this laboratory device is scaled-up as is, it would suffer from low throughput capacity and high maintenance requirement. In general, surface area-based separators (e.g., shaking tables, magnetic drum separator, electrodynamic separator, etc.) have lower throughput capacities than volume-based separators (e.g., flotation cell, dense-medium bath, cyclones, etc.) by an order of magnitude. Furthermore, the electrodes of the laboratory unit need to be cleaned frequently, creating a high-degree of maintenance requirement if it is scaled-up to a commercial unit. The bench-scale continuous TES unit developed at PETC, on the other hand, separates positively and negatively charged particles by splitting the gaseous stream containing these particles in an electric field by means of a flow splitter, so that the oppositely charged particles can be directed into different compartments. This device is fundamentally different from the laboratory unit in that the former is a volume-based separator, while the latter is a surface area-based separator. The bench-scale unit is referred to as *entrained flow* separator by the in-house researchers at PETC. Thus, the entrained flow TES unit is a significant improvement over the laboratory unit with regard to throughput capacity.

In the present work, the entrained flow separator will be scaled-up to proof-of-concept POC-scale. However, the parallel plate electrodes will be replaced by a pair of circular electrodes, for which there are two advantages. First, the circular electrodes provide a non-uniform electric field (and, hence, a field gradient), which will be conducive for improving the separation of oppositely charged particles from each other. Second, the electrode will be rotated so that fresh electrode surfaces can be exposed. This new design is similar to the open-gradient magnetic separator developed by Oak Ridge National Laboratory during the early 1980s. Therefore, the new design may be referred to as *open-gradient* triboelectrostatic separator.

OBJECTIVES

It is the objective of the project to further develop the TES process developed at PETC through bench- and POC- scale test programs. The bench-scale test program is aimed at studying the charging mechanisms associated with coal and mineral matter and improving the triboelectrification process, while the POC-scale test program is aimed at obtaining scale-up information. The POC-scale tests will be conducted at a throughput of 200-250 kg/hr. It is also the objective of the project to conduct cost analysis based on the scale-up information obtained in the present work.

Specific objectives of the work conducted during the current reporting period were: i) to study the triboelectrification mechanism of coal and ash-forming minerals using an on-line tribocharge analyzer with the objective of identifying conditions for maximizing separation efficiency (Subtask 3.1), and ii) to conduct bench-scale TES tests on U.S. coals with an emphasis on maximizing the BTU recovery and pyritic sulfur rejection (Subtask 3.2).

WORK DESCRIPTION

Task 3.1: Tribocharger Tests

Separation efficiency of the TES process depends critically on the surface charges of the particles involved. In general, the larger the difference between the charges of particles to be separated, the higher the separation efficiency. It is, therefore, the objective of this subtask to design efficient charger for the triboelectrostatic separator.

Apparatus for Charge Measurement

During the current reporting period, charging mechanisms have been studied to evaluate the efficiency of the static mixer charging system using the on-line tribocharge analyzer developed in the present work and described in the previous quarterly report. Four parameters affecting the charging mechanisms were examined during this quarter. These include: i) air velocity, ii) feed rate, iii) temperature, and iv) particle size. The on-line tribocharge analyzer was used to measure the charges of both coal and mineral matter. As will be shown later in this report, temperature is a very important parameter in tribocharging mechanism. Therefore, the charge measuring system has a provision to maintain the temperature of the system at a desired level (see Figure 1). In a given experiment, a sample is preheated in an oven at a desired temperature before being placed on the sample hopper. The sample is fed to the on-line charge analyzer by means of a compressed air, which is heated by means of a heating tape before entering the system. The system temperature is monitored by means of a thermometer located between the air inlet and the charger. The rest of the charge measuring system was described in our previous report.

Sample Preparation

For the charge measurement, a Pittsburgh No. 8 coal sample was crushed in a jaw crusher and then in a roller mill. The crushed coal samples were then pulverized to -40 mesh in a hammer mill. The pulverized coal was dry-screened to obtain three different size fractions, namely: -40+65, -65+100, and -100+200 mesh. In order to obtain information on the charging mechanisms of the ash-forming minerals present in the coal sample, a quartz (SiO_2) sample was purchased from Fisher Scientific Co. Two different size fractions, i.e., -40+65, and -65+100 mesh, were used for the charge measurement. The origin of this quartz sample was not provided by Fisher Scientific.

Effects of Air Velocity and Particle Size

Table I-II, Appendix I, show all of the test results obtained during this reporting period. At a given test condition, the measurement was repeated at least three times and the results were averaged. Figure 2 shows the results plotted vs. the velocity of the compressed air. The measurement was conducted at temperatures in the range of 28-30 ^{o}C and at an air pressure of 40 psi. The feed rate of the samples were 0.2 kg/min in average. As shown, the coal particles are positively charged, while the quartz particles are negatively charged. The fact that coal and quartz (representing the behavior of the mineral matter in coal) particles are oppositely charged serves as the basis for the TES process in cleaning coal of its mineral matter.

The results given in Figure 2 shows that the magnitude of the charge density increases with increasing air velocity regardless of particle size. As discussed in our previous report, the charge of a particle may increase with increasing velocity of the particles impinging on the copper walls and the blades of the in-line mixer charger. Note that the charge density difference between the coal and quartz particles increases with increasing air velocity and with decreasing particle size. Thus, the separation efficiency of the TES process should increase with increasing air velocity and decreasing particle size. The latter may be regarded as a distinct advantage of the TES process. With other processes, separation efficiency decreases with decreasing particle size in general.

Effects of Feed Rate and Particle Size

Figure 3 shows the results of the charge measurements conducted on the Pittsburgh No. 8 coal sample and the quartz sample obtained from Fisher Scientific. All of the measurements were conducted at an air velocity of 1.9 m/sec. For both coal and quartz, the magnitudes of the charge density decreased with increasing feed rate regardless of particle size. This observation may be attributed to the decrease in particle velocity with increasing feed rate. At a given air velocity, the velocity of particles should decrease with increasing feed rate. The results given in Figure 3 show also that finer particles exhibit higher charge densities, which can simply be attributed to the high surface area-to-mass ratio of the former.

The most important aspect of the result shown in Figure 3 is the fact that coal particles are positively charged while the quartz particles are negatively charged, which serves as the basis for TES separation. It is interesting to note here that the coal and quartz particles exhibit the maximum difference in charge densities at the lowest feed rate. One should, therefore, expect that the separation efficiency can be maximized at the lowest feed rate.

Figure 4 shows the effect of temperature on the charge density of coal particles (-40+200 mesh). The charge measurements were conducted at an air velocity of 1.9 m/sec and at a feed rate of 0.2 kg/min. The results show that the charge density increases with increasing temperature. It is well known that humidity control is critical in electrostatic separation in general. Under humid environment, charges created by triboelectrification mechanism dissipate quickly to other particles due to the surface conductivity created by the surface moisture. Note that the charge density increases sharply above 60 ^{o}C, which may be an important information in designing a TES unit.

The results obtained from the charge measurement will be subjected to statistical analysis in order to obtain scale-up information for charger design. Central-composite experimental design technique will be applied to study the optimization of the bench-scale TES unit. The test matrix will include four operational parameters (i.e., air velocity, particle feed rate, particle size and temperature) and the geometry, namely, the L/D ratio of the tribocharger. These parameters will be varied at three levels (low, intermediate, and high) representing a wide range of operating conditions. Once the optimum geometry has been established, tribochargers will be constructed with at least two different materials, e.g., copper, stainless steel and/or plexiglass. The tribocharger that gives the maximum charge difference between coal and mineral matter will be chosen as the charger to be scaled-up for the POC unit.

Task 3.2 Separator Tests

The primary objectives of this Subtask are i) to evaluate different bench-scale designs for the triboelectrostatic separator, and ii) to investigate the various operating parameters on separator performance. The information obtained from this task will be used for obtaining engineering guidelines for the design, manufacture, operation and optimization of the 200-250 Kg/hr POC unit. The bench-scale tests will be conducted using two different separators having nominal capacities of 1 kg/hr and 10-20 kg/hr. The performance data obtained for these units will be used to develop scale-up criteria for POC unit.

Sample Preparation

During the current reporting period, bench-scale TES tests have been conducted on a Pittsburgh No.8 coal sample. The coal sample was a clean coal product from a coal preparation plant, CONSOL, Inc. (This company does not wish to identify the plant where this coal originated.) Original plan was to use a run-of-mine (ROM) coal, but a decision was made to test a clean coal. The reason behind this decision was that, if the current project is successful, eventual commercial unit would be used in utilities where clean coal is burned. It should be noted, however, that better separation efficiencies can be obtained with ROM coals.

The Pittsburgh coal sample was crushed in a jaw crusher and then in a roll mill. The crushed coal was then pulverized in a hammer mill to -140 mesh. The pulverized coal was dry-screened to obtain two different size fractions, namely: -140+200 and -200 mesh. The samples prepared as such were kept in an oven at 112°C overnight to remove the moisture from the surface of the coal particles. The sample preparation was done one day before each test program to minimize possible surface oxidation.

Improvements in the Laboratory TES Unit

Heating Device Earlier tests showed that separation efficiency deteriorates when the tests were run on cold or humid days. It was considered that the poor performance was due to the surface moisture on the coal particles. The importance of controlling temperature, which in turn controls the surface moisture, is shown in Figure 4, in which the charge density on coal particles is shown to increase sharply above 60°C. For this reason, a heating system was installed so that tests could be run under conditions of controlled temperature (and hence humidity).

Charger Design Initial tests were run using an in-line mixer charger made of copper. The dimension of the mixer were ½-inch diameter and 6-inches in length. It was a four-stage mixer, of Koflo design, i.e., the mixer was equipped with four blades inside the tubing. It was soon found that the mixer was clogging, possibly because of excess number of blades in the tubing, and the separation efficiencies were low. It was, therefore, decided to run tests with a plexiglass tubing without any blade inside. The use of a straight plexiglass tubing not only eliminated the clogging problem but also improved the separation efficiency (see Table III). This finding is consistent with the experience at FETC, where nylon was found to be a better charging material than copper (Link, 1996). The dimension of the plexiglass charger installed as part of the laboratory TES unit were: 1-inch in diameter and 16-inch in length. It is not certain at this point whether the plexiglass charger will work better with blades and, if so, how many. This question will be answered during the next quarter. It should be noted, here, that the new TES units being developed at FETC also use the straight copper tubings without inline mixer blades (Finseth, 1997).

Separator Test Results

a) *Entrained Flow Separator vs. Plate Separator*

The last quarterly report described the design of the bench-scale TES separator that has been used during the current reporting period. It is based on the entrained flow (or open-gradient) concept, which differs from the original FETC separator. In the latter, positively and negatively charged particles are collected on negatively and positively charged electrode, respectively. There are several problems associated with the original design, which include:

- difficulty in removing the particles collected on electrodes,
- throughput being limited to the surface area of the electrodes,
- loss of particles in the bypass stream (i.e., the particles not collected on the electrodes).

The entrained flow separator can overcome all of these deficiencies. However, it has one drawback, that is, the quality of the clean coal products will not be as good as those obtained using the original separator, simply because there are no byproduct stream.

Figure 5 shows the results obtained on the Pittsburgh No. 8 coal using the bench-scale TES unit, which is an entrained flow separator. The test was conducted with positive electrode at 40 kV and with the other electrode grounded. The feed coal assayed 5.86% ash and 1.63% S. After the first pass, the clean coal assayed 3.91% ash and 1.35% S with 52.4% yield, while the reject stream assayed 8.62% ash and 1.96% S. These results gave a combustible recovery of

58.6%. The two product streams were then subjected to recleaning, as shown in flowsheet given in Figure 5.

Although the laboratory TES unit is an entrained flow separator, it has been found that considerable amounts of particles adhere on the surfaces of the drum electrodes. After running the separator, typically for 20 to 30 minutes, the materials remaining on the drum surface were scraped off, weighed, and assayed. The results are shown in Figure 6. The data shown in this figure essentially represent the original TES separator based on collecting materials on electrode surfaces.

The data sets given in Figures 5 and 6 have been plotted in Figure 7 and 8 for ash and sulfur, respectively. It may appear that the original TES separator gives significantly better results than the entrained flow separator. It should be noted, however, that the amount of materials collected on the drum electrode surfaces were less than 1% of the total feed used in a given experiment. The reason is that the particles collected on the electrodes surfaces were continuously removed by means of brushes during the entire course of a test. Nevertheless, it is interesting to see that the material collected on electrode surfaces are of higher quality than those collected in the entrained flow separator.

The recovery vs. grade curves shown in Figures 9 and 10 give valuable information in designing POC module in Subtask 3.3. One can predict the product quality in terms of ash and sulfur contents at given combustible recovery.

b) *Grade vs. Recovery Curves Pittsburgh Coal*

A series of tests were conducted on the Pittsburgh coal using the bench-scale TES unit. Tests were conducted by varying electrode potentials at a feed rate 4 kg/hr. Most of the tests were conducted with the -200 mesh fraction during the current reporting period, but one set of tests were conducted on the -140+200 mesh fraction to see the effect of particle size.

As shown in the preceding section, the TES process is capable of producing very clean products in the first stage but at relatively low combustible recoveries. It may be possible to improve the design of the separator, and increase the recovery while maintaining the product quality. Until this becomes a reality with further research, one may consider increasing the recovery by feeding the reject stream containing unrecovered coal to another separator. Since only one separator is available for this project, the reject stream was collected, and reprocessed using the same separator. Tables IV, V and VI show the results obtained in this manner with the -200 mesh fraction at 20, 40 and 70 kV, respectively. It is noted, here, that in the test conducted at 70 kV the clean coal product obtained from the first stage was recleaned to further improve the product quality. The data given in this table have been plotted in Figures 9 and 10 in the form of recovery vs. grade curves for ash and sulfur, respectively.

The results given in Figures 9 and 10 show that the grade vs. recovery curves shift considerably depending on the potential applied to the electrodes. It appears that the electrode potential of 20 kV is not strong enough to pull the charged particles toward the electrodes. The best results were obtained at 40 kV. The results obtained at 70 kV are slightly inferior to those obtained at 40 kV, which may be attributed to entrainment. At very high electrode potentials, particles may move so quickly toward the oppositely charged electrode that some of the adversely (or less strongly) charged particles can report to the same product stream, thereby contaminating the product quality (or shifting the grade vs. recovery curve to the right).

Table VII and Figures 11 and 12 show the result obtained with the -140+200 mesh fraction of the Pittsburgh coal. The test was conducted at 70 kV. Work is currently under progress to obtain data at 40 and 20 kV. Although this particular series of tests have not been completed as yet, the results obtained with this coarser size fraction are inferior to those obtained with the -200 mesh fraction. Two reasons may be given for the inferior results obtained with the coarser size fraction. First, the coarser particles would have lower degree of liberation. Second, the coarser particles have lower charge-to-mass ratio, as shown in Figures 11 and 12, causing a difficulty in separating particle in an electric field.

The results obtained with the -200 mesh fraction demonstrated that electrode potential plays an important role in determining the separation efficiency. Perhaps a more important parameter affecting the separation efficiency would be the charge density of the particles. By maximizing the charge difference between the coal and the mineral matter, one should be able to shift the grade vs. recovery curves more to the left. Although the bench-scale test work was conducted using an improved charger, further improvement in the charger design should be possible. It should also be noted, here, that the data presented in this report were obtained without using a pulverizer installed as part of the bench-scale TES unit. As has been noted, the coal samples were pulverized one day prior to each test. If the separation test had been conducted with freshly pulverized coal samples, the particles could have exhibited higher charge densities, which would have increased the separation efficiency. The laboratory-scale pulverizer was received only several weeks prior to the writing of this report from University of Kentucky. The pulverizer is currently being incorporated into the TES unit.

SUMMARY AND CONCLUSION

The work performed during the current reporting period was concerned with Task 3:

Engineering Design. As part of Subtask 3.1, four parameters affecting triboelectrification mechanisms were investigated. These include: i) particle size, ii) temperature, iii) air velocity, and iv) feed rate. The charge measurements were conducted on coal and quartz samples. The results show that charge density increases with:

- increasing air (or particle) velocity for all particle sizes studied,
- decreasing particle size,
- decreasing feed rate, and
- increasing temperature.

These findings will be useful for improving the design of the bench-scale TES unit and subsequently that of the POC unit. The fact that the difference between the charges of coal and mineral matter is maximized with decreasing particle size suggests that the TES process is ideally suited for processing finer particles, e.g., fly ash. On the other hand, the observation that charge density decreases with increasing feed rate may impose a serious limitation to the throughput of a triboelectrostatic separator. The temperature effect may be related to the control of the surface moisture for the particles in the feed stream.

In Subtask 3.2, the bench-scale TES unit was used to clean a Pittsburgh coal. The coal sample used for the tests was a clean coal product assaying 5.6% ash and 1.67% sulfur. During the current reporting period, the tests were run by varying the potential difference between the electrodes in the range of 20 to 70 kV at a throughput of 4 kg/hr. The best result were obtained at 40 kV. According to the grade vs. recovery curve obtained at this potential, the ash content can be reduced to 3.7% at 80% Btu recovery and 4.3% at 90% Btu recovery. As for sulfur, the total sulfur content can be reduced to 1.2% at 80% Btu recovery and 1.25% at 90% Btu recovery. The samples are being analyzed for pyritic sulfur at the moment of writing this report.

The bench-scale TES unit was equipped with a new charger made of plexiglass. It was found that use of a 4-stage inline mixer made of copper created clogging problems at high feed rates, and the separation efficiencies were poor. The new charger is a simple plexiglass tubing with dimensions of 1-inch diameter and 16-iches in length. The in-house researchers at FETC also found that it is not necessary to use inline mixers to create charges, and that non-metals may be better suited for making tribochargers.

The bench-scale TES tests were conducted at 4 kg/hr capacity. It is possible to increase it considerably by simply installing multiple chargers. During the next quarter, tests will be conducted at higher capacities to collect scale-up information.

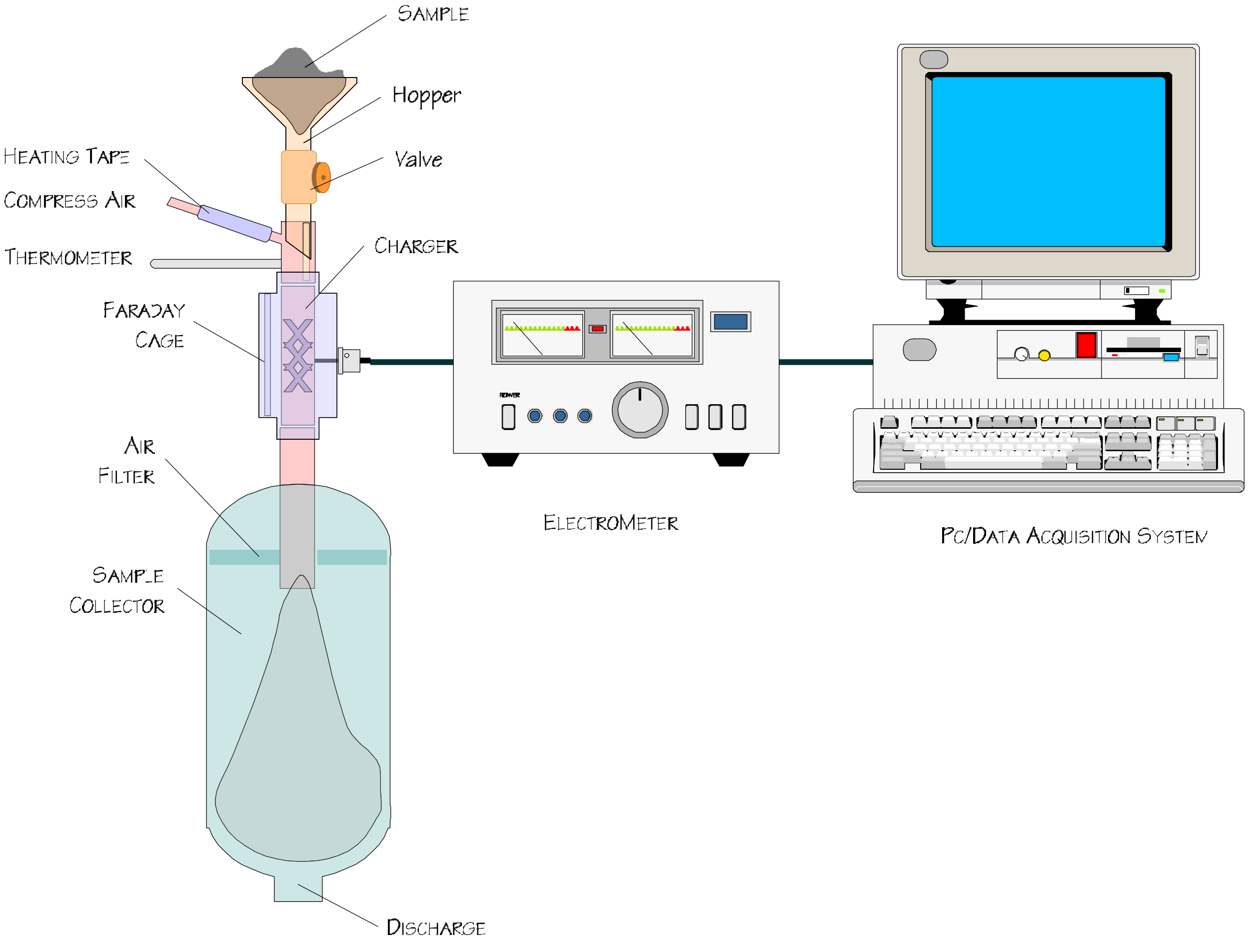

Figure 1. Schematic representation of the on-line charge measurement device with heating system and temperature sensor for studying tribocharging mechanism used in the present work.

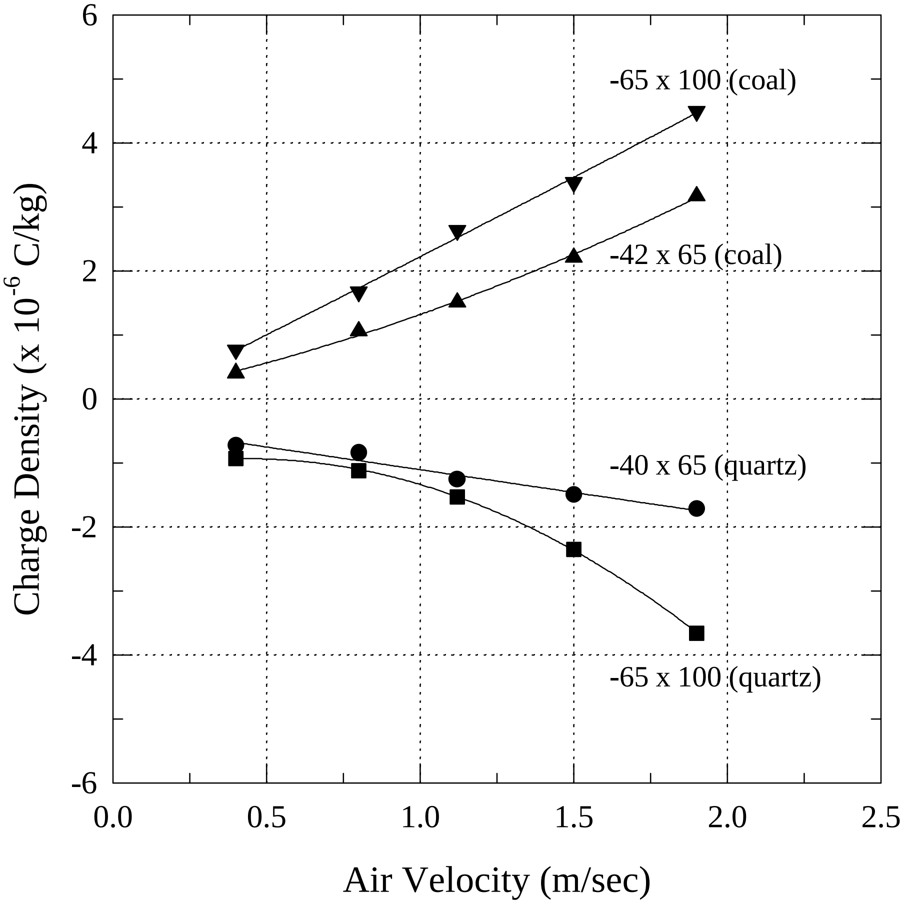

Figure 2. Effect of air velocity on charge density using Pittsburgh No.8 clean coal sample and quartz with a variety of particles sizes.

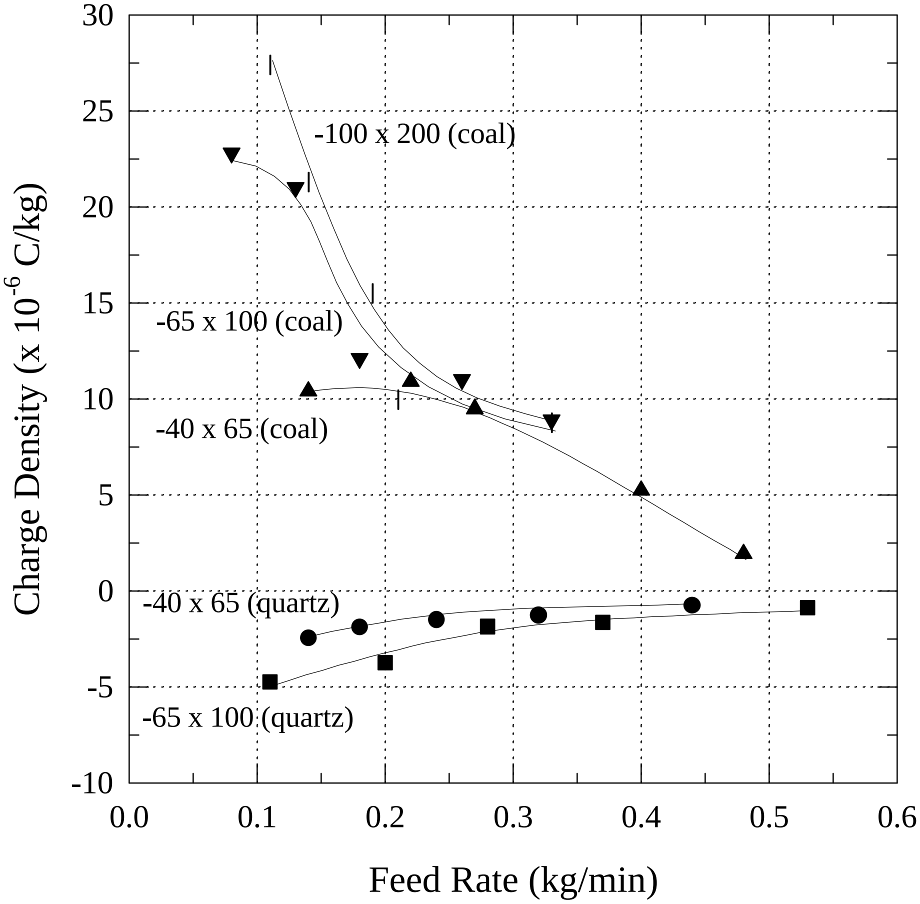

Figure 3. Effect of particle feed rate on charge density using Pittsburgh No.8 clean coal and quartz samples with a variety of particle size.

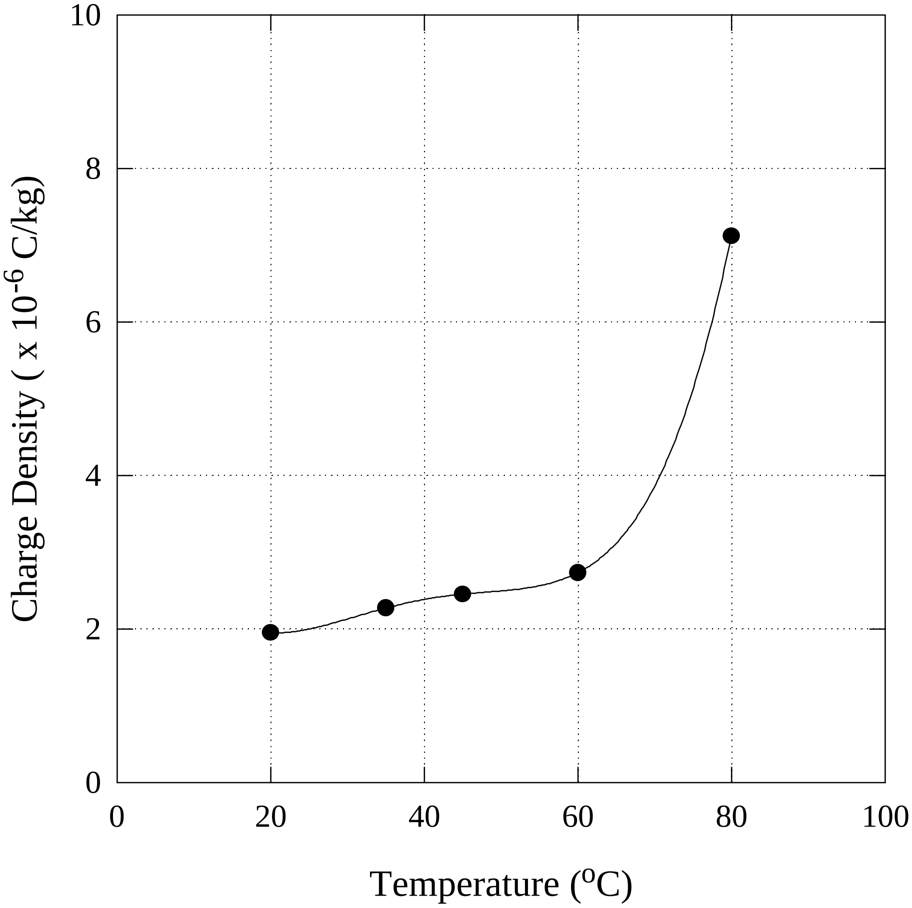

Figure 4. Effect of temperature on charge density. The results were obtained on Pittsburgh No. 8 coal sample with a 200 g/min feed rate.

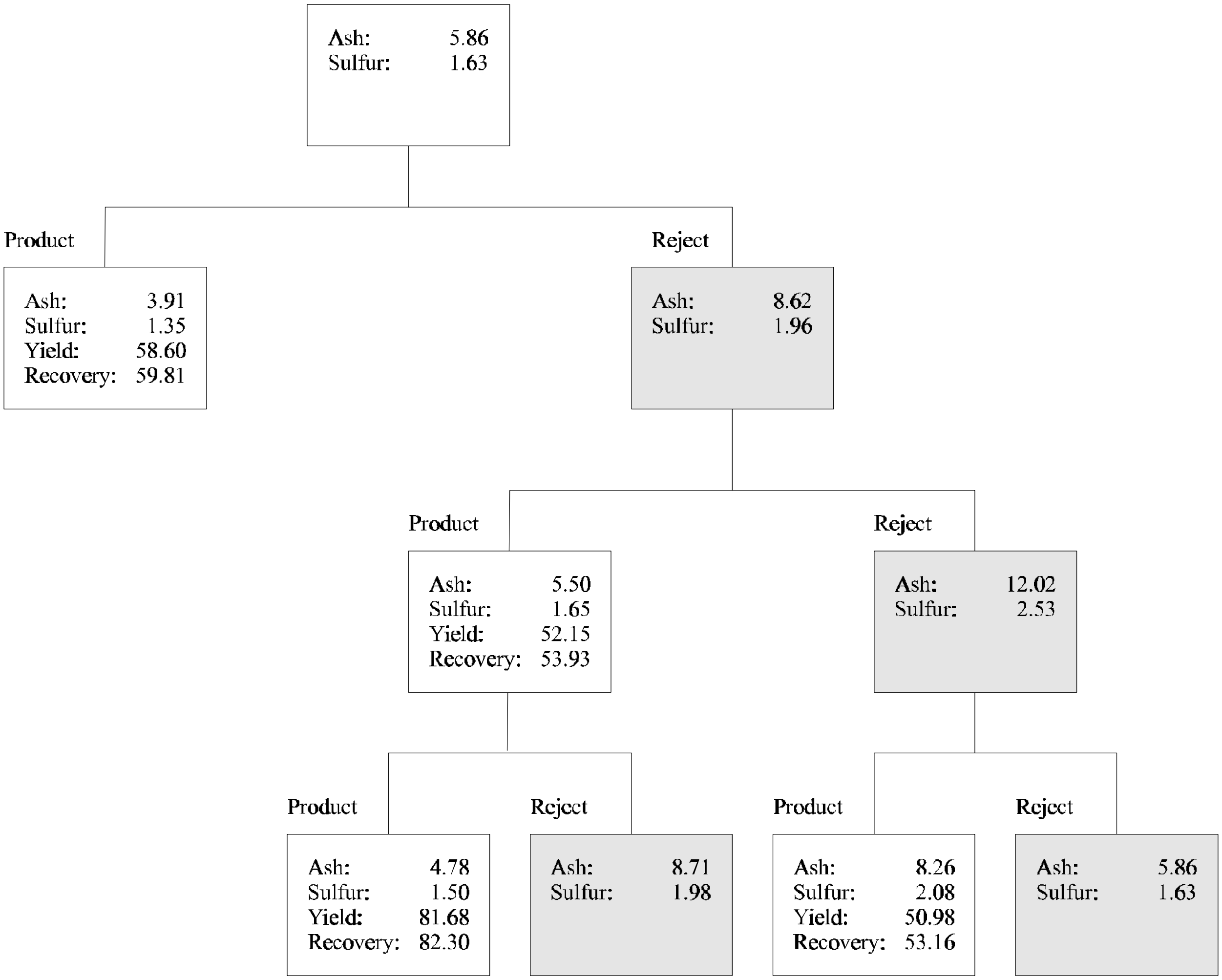

Figure 5. Separation test flowsheet for the bench-scale TES unit. The results were obtained with a Pittsburgh No.8 clean coal sample at electrode potential of 70 kV. Assays for each of the test were measured from the bulk sample.

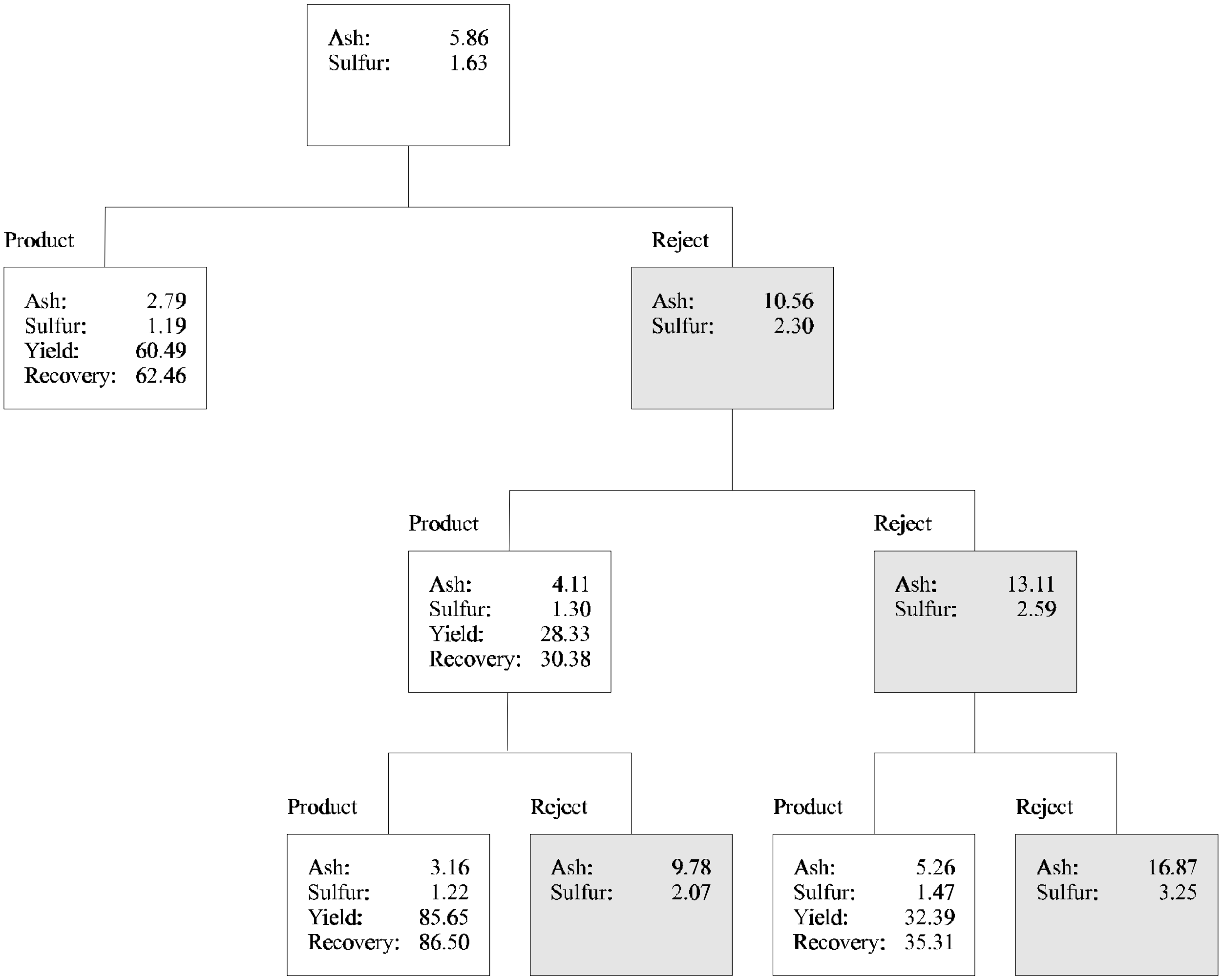

Figure 6. Separation test flowsheet for the bench-scale TES unit. The results were obtained with a Pittsburgh No.8 clean coal sample at electrode potential of 70 kV. Assays for each of the test were measured from the sample scraped from the drum electrodes.

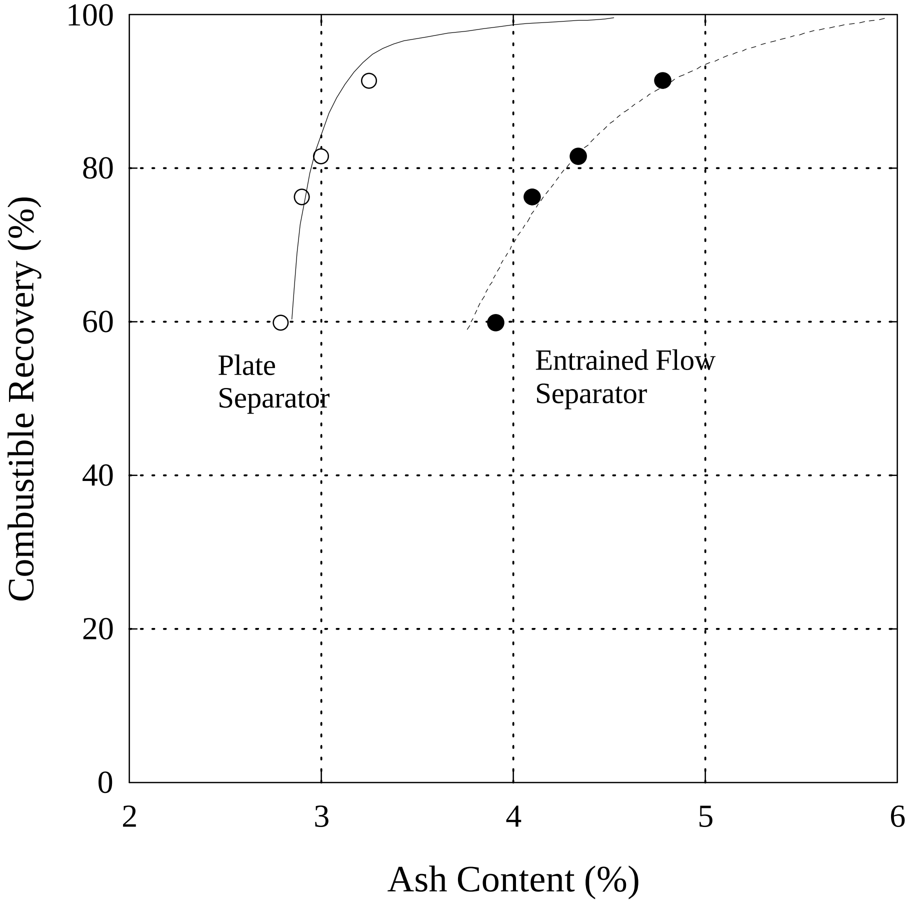

Figure 7. Product ash content as a function of combustible recovery. The results were obtained on Pittsburgh No. 8 clean coal sample in the TES bench-scale Unit separation study.

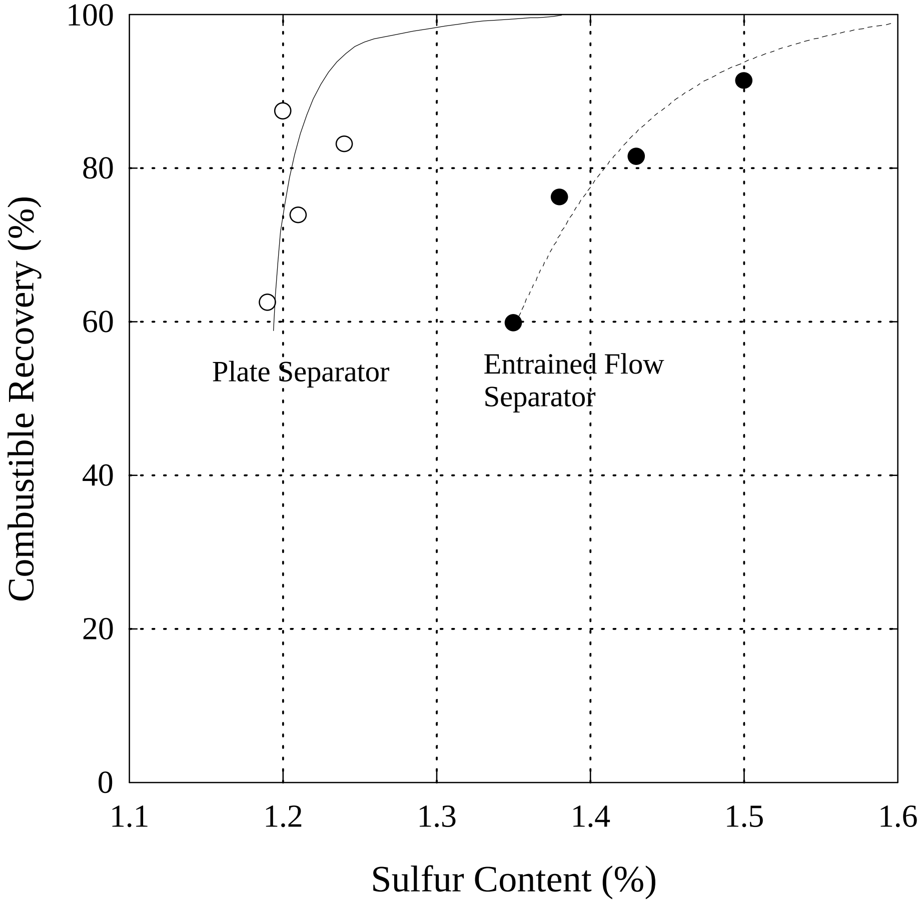

Figure 8. Product sulfur content as a function of combustible recovery. The results were obtained on Pittsburgh No. 8 clean coal sample in the TES bench-scale Unit separation study

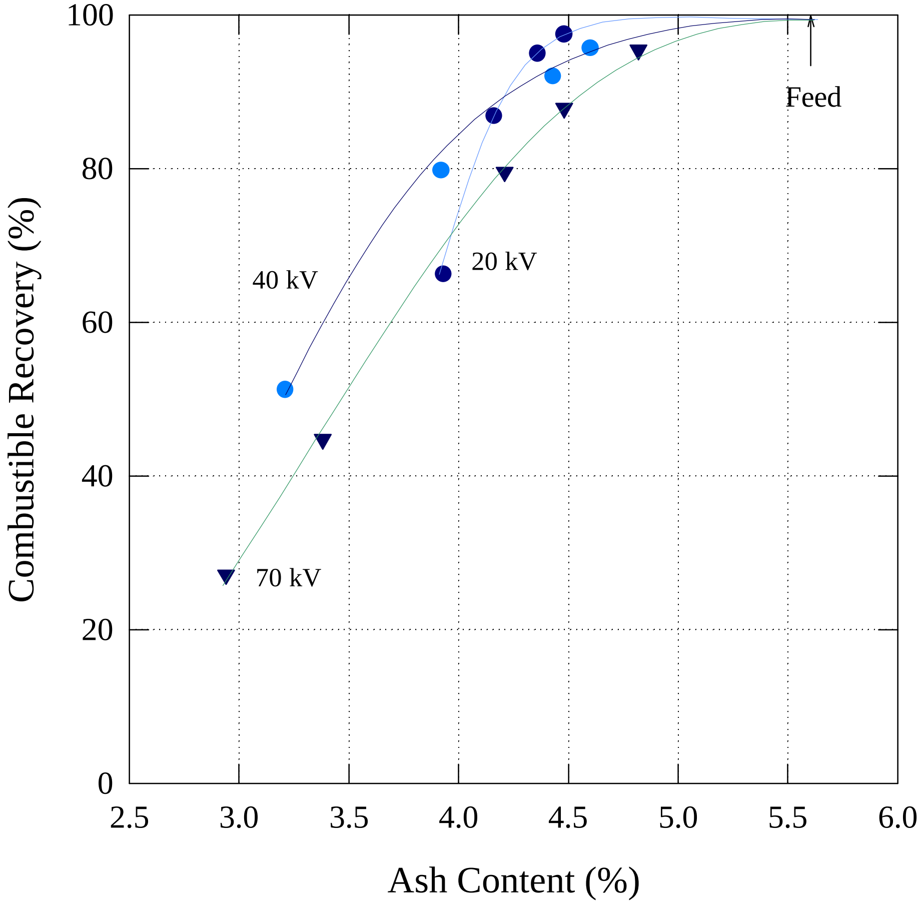

Figure 9. Grade vs. Recovery curves of the bench-scale TES unit. The results were obtained on -200 mesh Pittsburgh No. 8 clean coal samples with 20, 40, and 70 kV electrode potential settings.

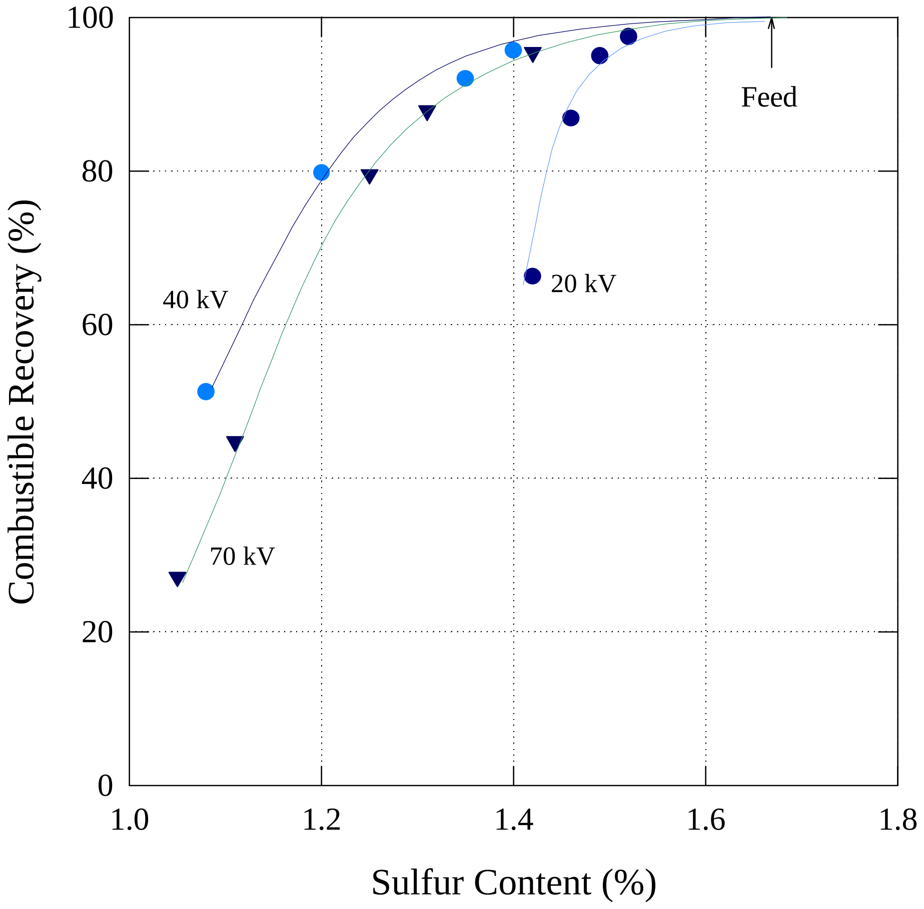

Figure 10. Grade vs. Recovery curves of the bench-scale TES unit. The results were obtained on -200 mesh Pittsburgh No. 8 clean coal samples with 20, 40, and 70 kV electrode potential settings

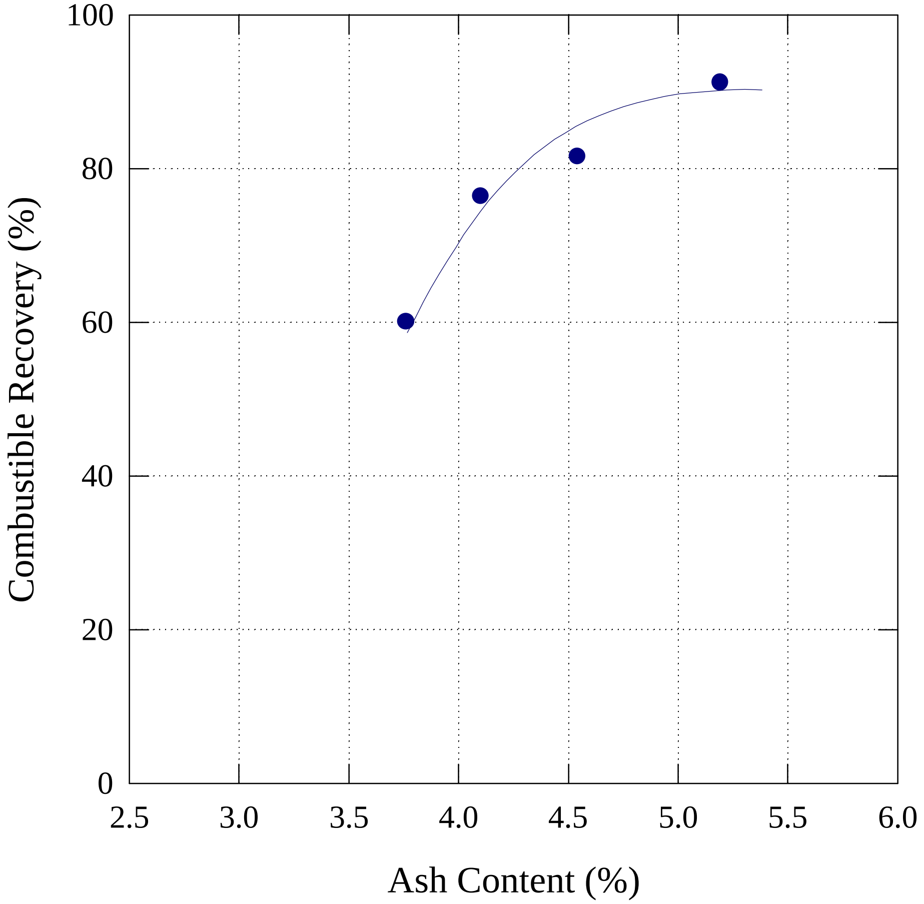

Figure 11. Grade vs. Recovery curve of the bench-scale TES unit. The results were obtained on -140+200 mesh Pittsburgh No. 8 clean coal samples with a 70kV electrode potential

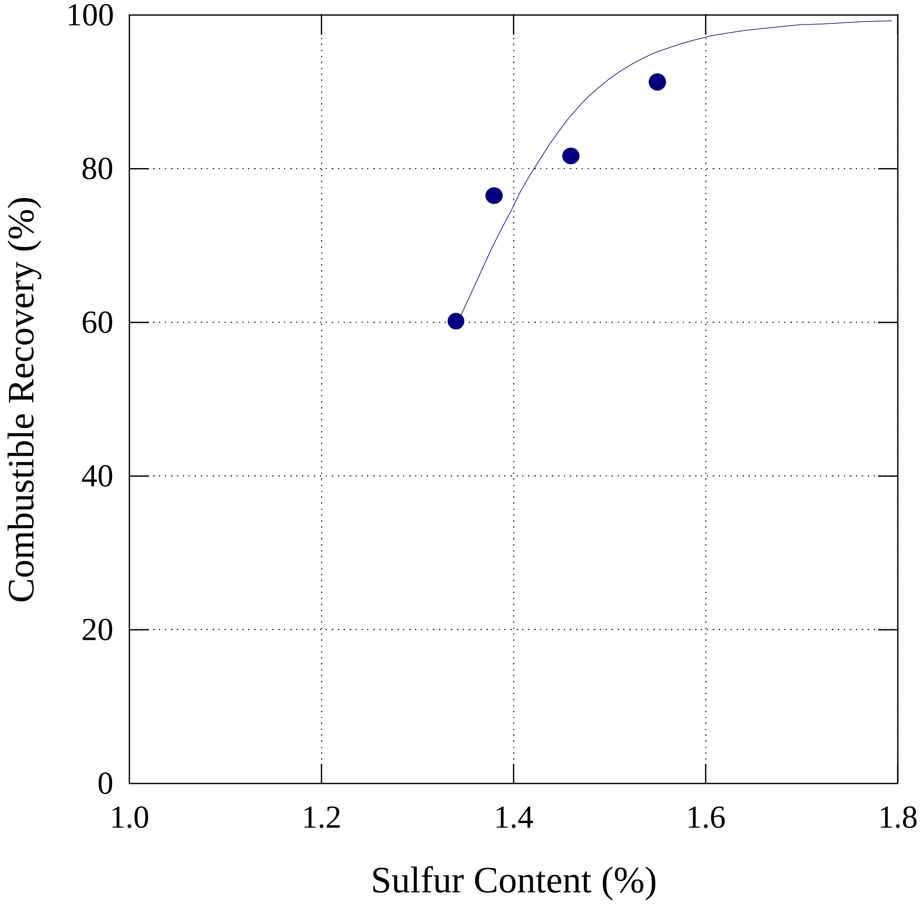

Figure 12. Grade (sulfur content) vs. Recovery curve of the bench-scale TES unit. The results were obtained on -140+200 mesh Pittsburgh No. 8 clean coal samples with electrode potential at 70 kV

Table I	Effect of air velocity on particle charge mechanism test results using Pittsburgh No. 8 coal and quartz sample

Sample	Size (mesh)	Air (m/sec)	Charge Density, σ (x 10^{-7} C/Kg)
quartz	-40 x 65	0.40	-7.27
		0.80	-8.43
		1.12	-12.60
		1.50	-15.00
		1.90	-17.20
	-65 x 100	0.40	-9.30
		0.80	-11.20
		1.12	-15.30
		1.50	-23.50
		1.90	-36.60
coal	-40 x 65	0.40	4.05
		0.80	10.60
		1.12	15.10
		1.50	22.10
		1.90	31.70
	-65 x 100	0.40	7.68
		0.80	16.70
		1.12	26.30
		1.50	33.80
		1.90	44.90

Table II Effect of particle feed rate on particle charge mechanism test results using Pittsburgh No. 8 coal and quartz sample

Sample	Size (mesh)	Feed Rate (kg/min)	Charge Density, σ (x 10^{-7} C/Kg)
quartz	-40 x 65	0.14	-24.70
		0.18	-18.90
		0.24	-15.20
		0.32	-12.80
		0.44	-7.65
	-65 x 100	0.11	-47.30
		0.20	-37.40
		0.28	-18.60
		0.37	-16.40
		0.53	-8.73
coal	-40 x 65	0.48	19.40
		0.40	52.40
		0.27	94.90
		0.22	109.00
		0.14	104.00
	-65 x 100	0.33	89.10
		0.26	110.00
		0.18	121.00
		0.13	210.00
		0.08	228.00
	-100 x 200	0.33	87.60
		0.21	99.60
		0.19	155.00
		0.14	213.00
		0.11	274.00

Table III Comparison of TES bench-scale unit test results with tribocharger made of different materials.

	Copper			Plexiglass		
	Feed	Product	Reject	Feed	Product	Reject
Ash	21.88	17.44	24.87	22.57	14.65	29.10
Sulfur	3.06	2.74	3.28	2.97	2.33	3.50
Yield (%)	40.24			45.19		
Recovery (%)	42.53			49.81		

Table IV Effect of applied electrode potential study on the TES bench-scale unit. Test results were obtained with Pittsburgh No. 8 clean coal sample at a 20 kV applied voltage

Sample: Pittsburgh N0.8 clean coal, -200 mesh

Applied Voltage: 20kV

Feed Rate: 4.0 kg/hr

Air Velocity: 8 l/min

Hot Air Temperature (^{o}C): 55

Stage	Ash			Sulfur			Individual		Cumulative			
	Feed	Product	Reject	Feed	Product	Reject	Yield	Recovery	Ash	Sulfur	Yield	Recovery
1	4.68	3.93	6.12	1.58	1.42	1.87	65.75	66.27	3.93	1.42	65.75	66.27
2	6.12	4.89	7.98	1.87	1.58	2.29	60.19	60.98	4.16	1.46	86.37	86.84
3	7.98	6.51	10.07	2.29	1.86	2.88	58.71	59.65	4.36	1.49	94.37	94.69
4	10.07	8.31	11.90	2.88	2.36	3.42	50.97	51.97	4.48	1.52	97.24	97.45

Table V Effect of applied electrode potential study on the TES bench-scale unit. Test results were obtained with Pittsburgh No. 8 clean coal sample at a 40 kV applied voltage.

Sample: Pittsburgh N0.8 clean coal, -200 mesh

Applied Voltage: 40kV

Feed Rate: 4.0 kg/hr

Air Velocity: 8 l/min

Hot Air Temperature (^{o}C): 55

Stage	Ash			Sulfur			Individual		Cumulative			
	Feed	Product	Reject	Feed	Product	Reject	Yield	Recovery	Ash	Sulfur	Yield	Recovery
1	4.99	3.21	6.79	1.53	1.08	1.99	50.28	51.22	3.21	1.08	50.28	51.22
2	6.79	5.16	9.00	1.99	1.41	2.79	57.55	58.56	3.92	1.20	78.89	79.79
3	9.00	7.61	11.04	2.79	2.28	3.54	59.48	60.38	4.42	1.35	91.45	91.99
4	11.04	8.67	12.97	3.54	2.56	4.35	44.88	46.08	4.60	1.40	95.29	95.68

Table VI Effect of applied electrode potential study on the TES bench-scale unit. Test results were obtained with Pittsburgh No. 8 clean coal sample at a 70 kV applied voltage.

Sample: Pittsburgh N0.8 clean coal, -200 mesh

Applied Voltage: 70kV

Feed Rate: 4.0 kg/hr

Air Velocity: 8 l/min

Hot Air Temperature (^{o}C): 55

Stage	Ash			Sulfur			Individual		Cumulative			
	Feed	Product	Reject	Feed	Product	Reject	Yield	Recovery	Ash	Sulfur	Yield	Recovery
1	5.10	3.38	6.45	1.51	1.11	1.81	43.97	44.77	3.38	1.11	43.97	44.77
2	6.45	5.28	8.33	1.81	1.42	2.43	61.64	62.41	4.22	1.25	78.51	79.24
3	8.33	7.05	9.18	2.43	1.97	2.74	39.91	40.46	4.49	1.32	87.08	87.64
4	9.18	8.74	9.90	2.74	2.69	2.83	62.07	62.37	4.85	1.43	95.10	95.35

Table VII Effect of applied electrode potential study on the TES bench-scale unit. Test results were obtained with Pittsburgh No. 8 clean coal sample at a 70 kV applied voltage.

Sample: Pittsburgh N0.8 clean coal, -140x200 mesh

Applied Voltage: 70kV

Feed Rate: 4.0 kg/hr

Air Velocity: 8 l/min

Hot Air Temperature (^{o}C): 55

Stage	Ash			Sulfur			Individual		Cumulative			
	Feed	Product	Reject	Feed	Product	Reject	Yield	Recovery	Ash	Sulfur	Yield	Recovery
1	6.16	3.76	9.06	1.70	1.34	2.22	58.60	60.10	3.76	1.34	58.60	60.10
2	9.06	6.65	12.87	2.22	1.77	3.02	52.15	53.53	4.54	1.46	80.19	81.58
3	12.87	10.41	15.60	3.02	2.33	3.68	50.98	52.42	5.19	1.55	90.29	91.22
4	6.65	5.35	9.71	1.77	1.54	2.21	81.68	82.82	4.10	1.38	74.78	76.42