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Pittsburgh Energy Technology Center
Pittsburgh, Pennsylvania

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INITIAL STUDY OF DRY ULTRAFINE COAL BENEFICIATION UTILIZING TRIBOELECTRIC CHARGING WITH SUBSEQUENT ELECTROSTATIC SEPARATION

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ABSTRACT

A novel, dry process using electrostatics to beneficiate ultrafine coal is being developed by the Coal Preparation Division at the Pittsburgh Energy Technology Center. The historical concept of triboelectricity and its eventual use as a means of charging coal for electrostatic separation will be discussed.

Test data from a first-generation and a second-generation Tribo-Electrostatic separator are presented showing the effects of feed particle size, separator voltage, solids concentration in air, and particle velocity on separation performance.

BACKGROUND

History of Electric Charging

All of us, at one time or another, have observed both the crackling and sparking that takes place when a comb is briskly pulled through one's hair in cold, dry weather and the ability of the comb to pick up (attract) small bits of paper. These phenomena are due to static electricity, which is dependent upon an imbalance of either positive or negative electric charges. This charge imbalance can be produced in several ways: a direct contact with an electrical source; the disruption of polarized liquid films; or the rubbing together of two materials to produce a transfer and separation of static electric charge. The last phenomenon is referred to as "triboelectrification."

The earliest observations of electrical effects other than those due to atmospheric electricity were made by Thales of Miletus[1] around 600 B.C. He noted that amber that had been rubbed with silk would attract bits of straw, lint, and other materials. Nearly all substances are now known to possess this triboelectric effect to some extent; however, the ancients knew of only two -- electron (amber) and lyncurium (topaz or tourmaline). Because the effect was erratic and short-lived, and had no practical applications, it remained a curiosity until around 1600 A.D. It was then that William Gilbert, the "father of electric and magnetic science,"[1] published "de Magnete." This work revealed the first insights on the nature and universality of electricity. One of his most important discoveries was that substances other than amber could acquire the power of attraction by rubbing. His invention of the versorium, a simple form of electroscope, allowed him to make observations and predictions about electrical phenomena. He called substances that could be electrically charged "electrics," and those that could not, "nonelectrics." His observations convinced him that "all bodies are attracted by electrics save those which are afire or flaming, or extremely rarefied."

Early investigators of static electricity devoted much time arranging lists of materials into the electrostatic series. In Ganot's Physics[2] one finds the following list:

1. Catskin
2. Flannel
3. Ivory
4. Rock crystal
5. Glass
6. Cotton
7. Silk
8. The hand
9. Wood
10. Metals
11. India rubber
12. Sealing wax
13. Resin
14. Sulphur
15. Gutta-percha
16. Guncotton

These substances are arranged in such an order that each becomes positively charged when rubbed with any material following it but negatively charged when rubbed with materials preceding it. Highest charges were obtained when the two substances were far apart in the series.

Although materials in the electrostatic series behaved, in general, according to the rule, some remained neutral after rubbing or showed a reversed sign under certain conditions. Vieweg[3] pointed out that many substances--fur, paper, wool, and cloth--could not be described accurately and therefore would not give reproducible results. For this reason, he began arranging a new series composed of pure chemical compounds, elements, and crystals. When bringing two substances together, he found that the most consistent results were obtained when pressure was applied. He attributed this to the fact that most surfaces absorb films of gas or water vapor and that these are removed by brisk rubbing. This was in agreement with the work done by Shaw and Jex,[4] who postulated that surfaces could be modified in two ways: (1) adsorbed films of water vapor or gas, or (2) physical changes caused by strains or reorientation of surface particles.

Explanation of Triboelectrification

Other investigators thought that other forces could explain how electrification was taking place. Richards[5] believed that when bodies collided, electricity separated, and the bodies became charged. Tagger[6] also experimented with this impact theory and carefully measured velocity and masses of colliding bodies. These tests showed that only a small part, less than 1%, of the transferred energy was available as electrical charge. Richards also thought that pressure could explain the charging process. By pressing together optically flat surfaces of glass and steel, he found that the charge formed was independent of friction. Once intimate contact was developed, however, the charge was proportional to the area of contact.

In working with frictional electricity, Naylor and Ramsey[7] came to a profound conclusion when they state "Friction has been merely the means of securing intimate contact, which has been immediately followed by separation, causing such an increase in potential as made the charge readily evident." The impact of this statement regarding separation is made quite clear when one follows some basic electrical relationships:

$$E = \frac{Q}{C}\ , \text{ and } C = K\frac{A}{X}\ ; \quad \text{therefore, } E = X\frac{Q}{AK}\ .$$

E = potential difference in volts
Q = quantity of charge in coulombs
C = capacity in farads
X = thickness in centimeters of the distance between charged surfaces
A = cross-sectional area of space between charged surfaces
K = constant dependent on dielectric

Since A, K, and Q can be regarded as constants, the voltage is then directly proportional to the separation distance between the charged surfaces. This then explains very nicely the static electricity that is produced when fracturing occurs along the cleavage planes of crystalline or laminated bodies (including coal). Before their separation, these surfaces have been in intimate contact, and electrical polarization has taken place along these interfaces. Fracturing or cleavage, therefore, is not the initial cause of charge transfer but merely manifests this charge when separation provides it with greater potential energy.

An accurate description of the triboelectrification process awaited the advent of modern solid-state physics. The principle, illustrated in Figure 1, shows that when materials with different work functions (defined

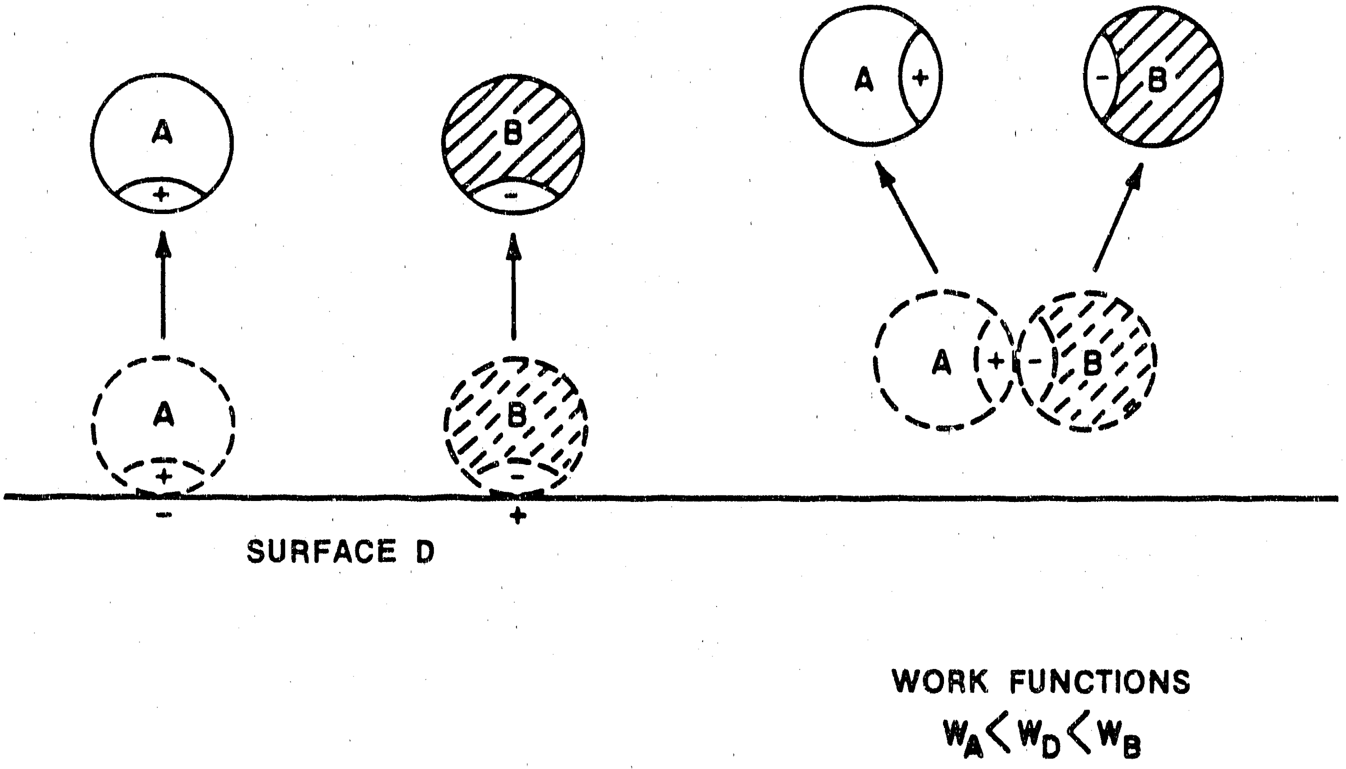


FIGURE 1. TRIBOELECTRIFICATION BETWEEN PARTICLES A AND B AND SURFACE D.

as the difference between the energy of an electron at the Fermi level inside the surface of the solid and an electron at rest outside the surface of the solid) are brought into contact, a transfer of electrons takes place at the interface. This transfer occurs because the Fermi levels of particles in contact must equilibrate. Upon rapid separation of the materials, the charge remains, producing particles with opposite charges.

Triboelectrification is, therefore, the cause of electrical charge transfer between materials in contact. Friction, pressure, and impact are merely the forces used to bring particles into intimate contact so that electron transfer can take place. Rapid separation of the particles or the fracturing of materials that have been in contact for long periods of time serves to manifest the charging that has taken place.

RESULTS AND DISCUSSION OF PREVIOUS WORK WITH COAL

The earliest experiments with the electrification of coal were performed by Blacktin and Robinson[8] in 1928. Explosions were prevalent in the coal mining industry, and most of them were attributed to dust. Their objective then was to ascertain if the dust clouds produced in handling coal could become sufficiently charged with static electricity to cause a discharge capable of igniting the dust. An apparatus, illustrated in Figure 2, was constructed in which mixtures of coal dust and air could be blown at high velocities through a large-diameter iron pipe. The coal used in the experiments was dry and sieved through a 200-mesh screen. Three feed rates at a velocity of 450 linear feet per minute were tested and provided voltages of 4,000 volts at the lowest feed rate, 5,800 volts when the rate was doubled, and 7,000 volts when the rate was quadrupled. Potentials as high as 20,000 volts were eventually obtained when the linear velocities were increased to 2,600 feet per minute. Although they were unable to ignite dust by this means unless methane was present, they did demonstrate the high potentials that could be obtained when coal is triboelectrically charged.

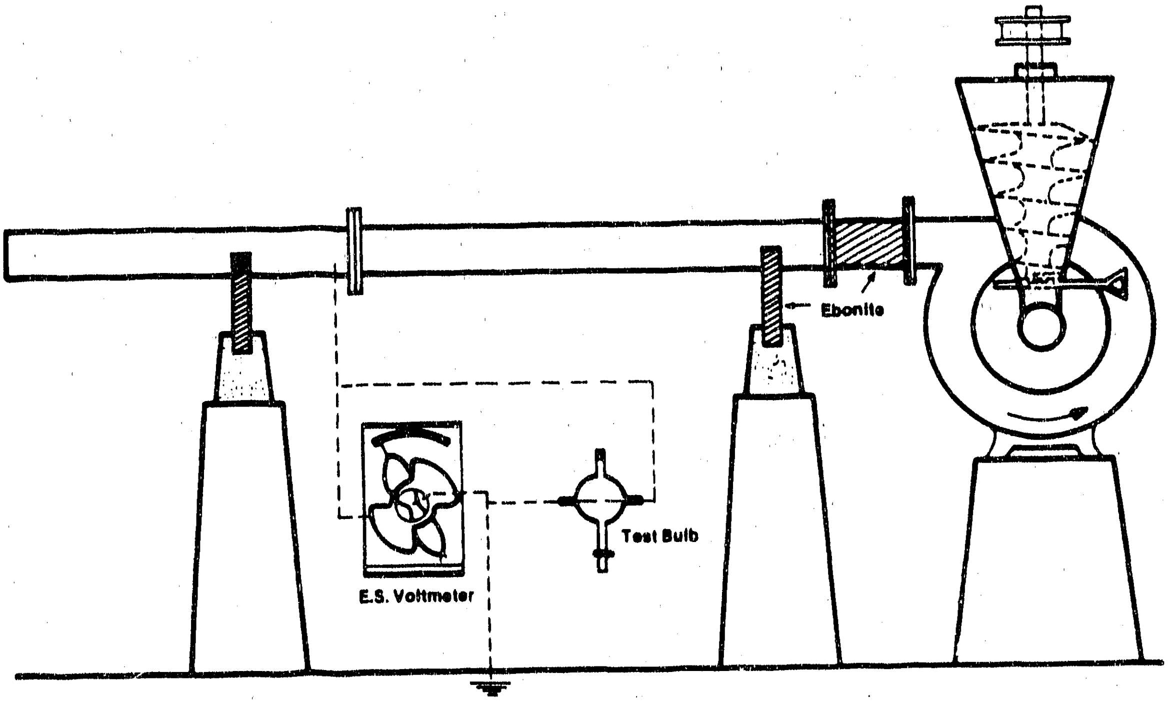


FIGURE 2. DIAGRAM SHOWING LAYOUT OF LARGE-SCALE APPARATUS USED IN INVESTIGATING SELF-ELECTRIFICATION OF COAL-DUST CLOUDS.

In 1961, Battelle Memorial Institute was commissioned by Bituminous Coal Research, Inc., to work on a project entitled "Electrostatic Separation of Pyrite From Coal."[9] The objective was to determine if pyritic material could be removed from pulverized coal (50-70 percent minus-200 mesh) by electrostatic techniques. A triboelectric separator, illustrated in Figure 3, was used for the experiments, and some typical results are listed in Table 1. Since their main objective was pyrite removal, their results indicated that a large number of cycles would be necessary before a sufficiently concentrated pyrite-rich fraction could be collected and economically discarded. Unfortunately, their findings of high concentrations of mineral matter (ash) in some of the collected fractions, and their mention that further study might be worthwhile, were not investigated further.

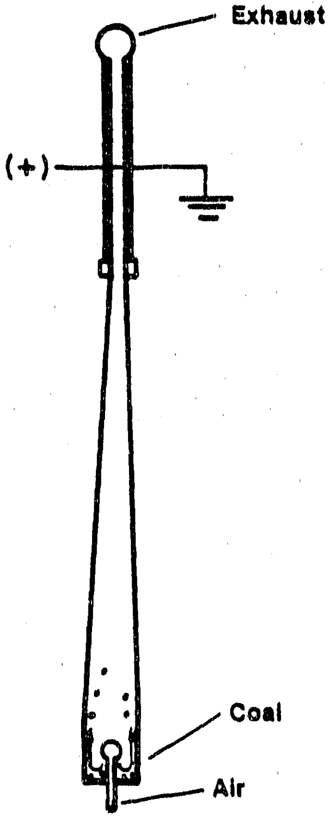


FIGURE 3. TRIBOELECTRIC SEPARATOR WITH PARALLEL PLATES.

Table 1. TRIBOELECTRIC SEPARATION OF WEST VIRGINIA PITTSBURGH SEAM COAL

Collector Fraction	Wt.%	Pyritic Sulfur %	Ash %
Ground Plate	44.9	1.5	6.9
(+) Plate	25.3	4.3	16.7

Note: Feed was 77.5% minus-200-mesh coal, containing 2.37% pyritic sulfur.

During the 1970's, Bergougnou[10] and his co-workers at the University of Western Ontario were actively investigating the use of electrostatics as a means for beneficiating coal. Two different electrostatic separators--a Separation Tower, illustrated in Figure 4, and a Dilute-Phase Electrostatic Loop, illustrated in Figure 5--were constructed for their experiments. Coal for their tests was ground to a top size of 200 mesh in a specially designed ball mill and then dried in a vacuum oven at 50°C for 12 hours. The dried coal was then fluidized, triboelectrically charged over a copper honeycomb, and separated in the two units. They were able to obtain significant reductions of both pyritic sulfur and ash in their experiments, and comparisons of the results from both units are illustrated in Figure 6. They concluded that further research was needed and were working to demonstrate these techniques on a pilot-plant scale involving multiple recycling of fractions when funding for the project was terminated.

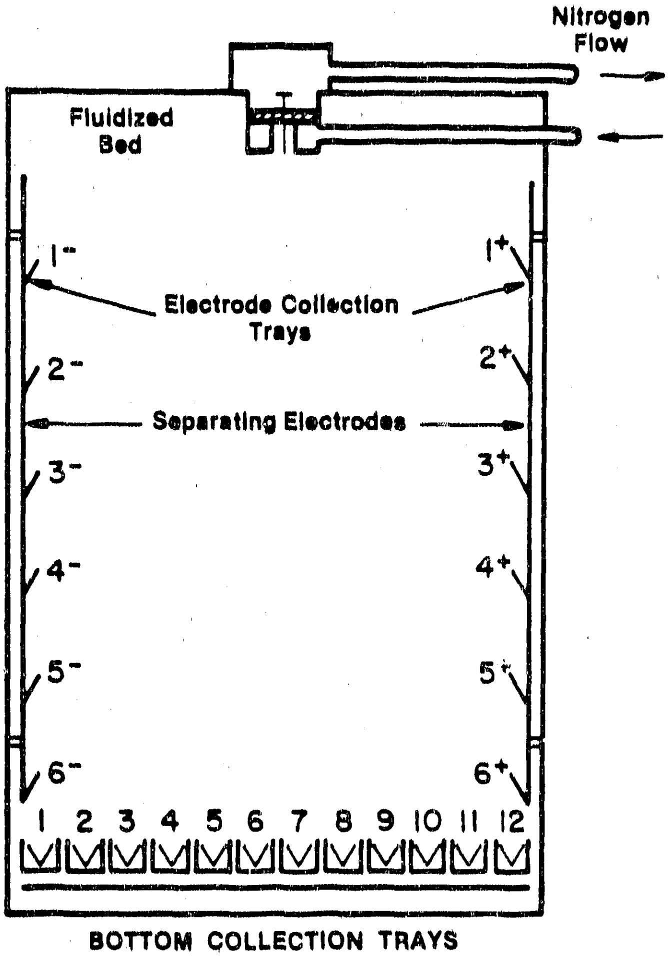


FIGURE 4. ELECTROSTATIC SEPARATION TOWER.

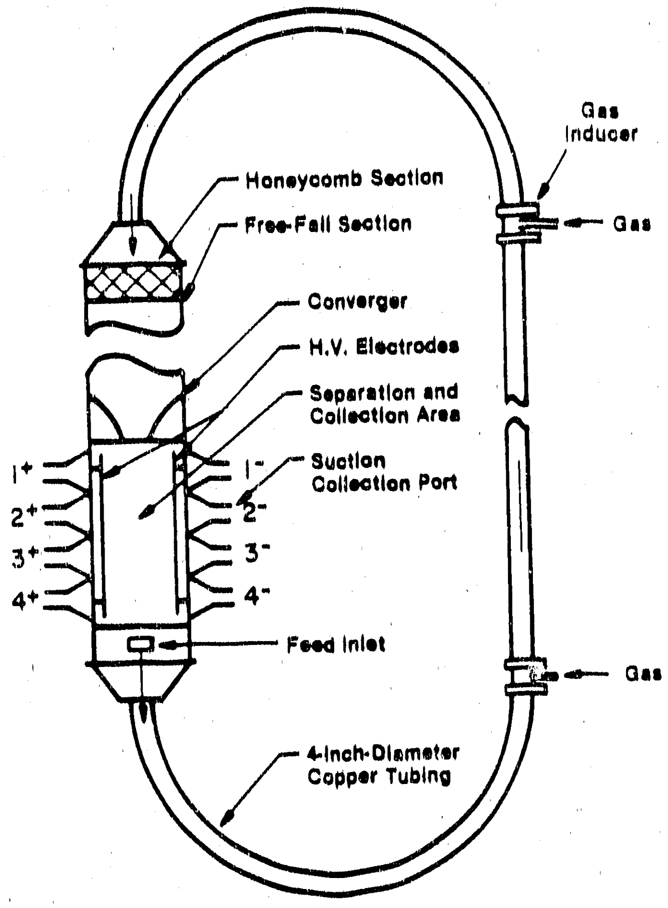


FIGURE 5. DILUTE-PHASE ELECTROSTATIC LOOP.

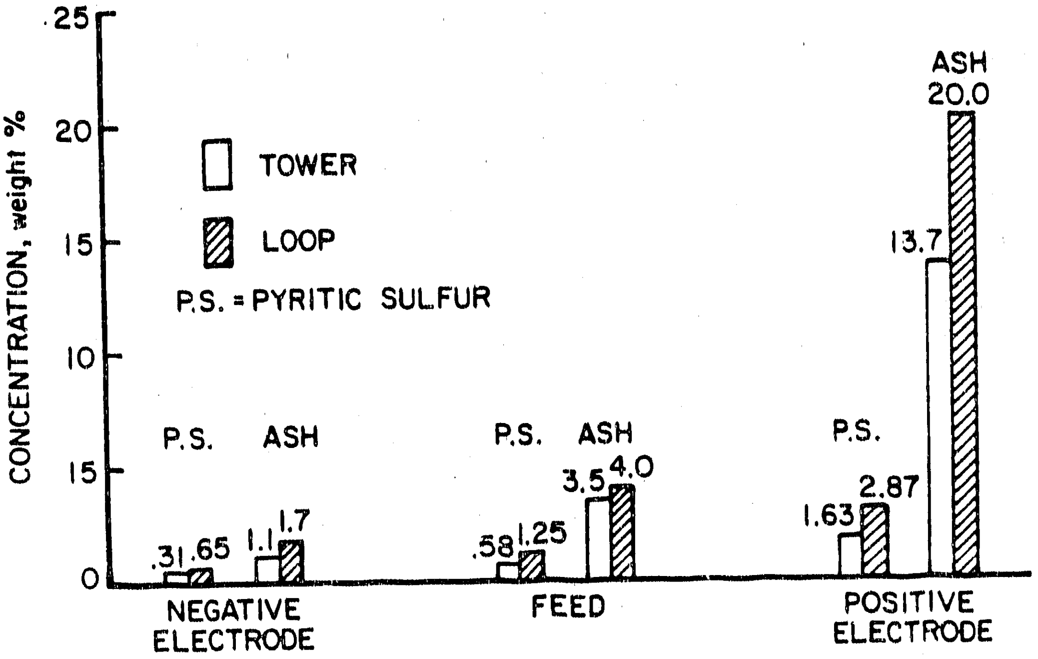


FIGURE 6. COMPARISON OF RESULTS FROM THE ELECTROSTATIC TOWER AND DILUTE PHASE ELECTROSTATIC LOOP BY X-RAY ANALYSES OF THE COLLECTED COAL FRACTIONS.

At the same time that the work was going on in Ontario, Advanced Energy Dynamics (AED) in Massachusetts was actively pursuing a research program aimed at the commercialization of a dry electrostatic beneficiation process for coal. They developed two different processes for charging and separating coal from mineral matter. The "Fine Coal Cleaning" system (FC) was based on an improved version of a drum-type electrostatic separator, illustrated in Figure 7, utilizing a high-voltage corona discharge as a means of charging. Dry coal particles ranging in size from 60 to 400 mesh are laid down in a monolayer on the grounded rotating drum while passing through a high-voltage corona field. Coal and its mineral matter are both negatively charged; however, the mineral matter, which is a good conductor, gives up its charge to the grounded drum and is thrown off. The coal, an insulator or semiconductor, does not give up its charge readily and remains adhered to the drum and is later scraped off. A 10-tph commercial-scale unit was tested at the Picway Station Power Plant in Columbus, Ohio. The system could not handle 400 mesh and lower size material, and was put on hold in the summer of 1985.

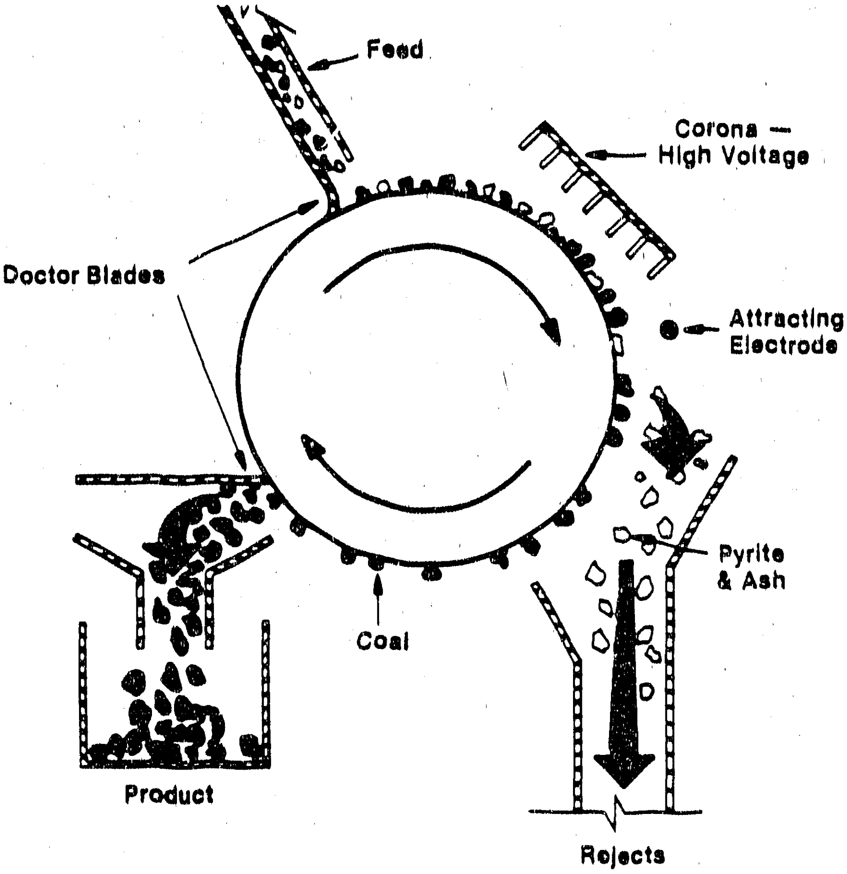
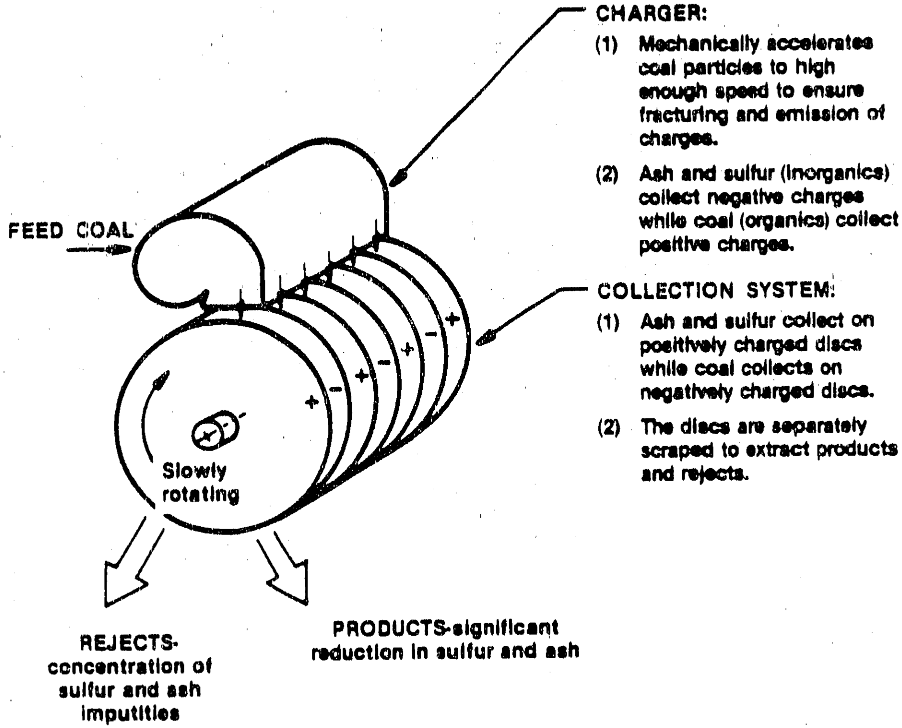


FIGURE 7. PRINCIPLE OF OPERATION: FC MODEL.

The other process, an "Ultrafine Coal Cleaning" system (UFC), beneficiated coal ground to 400 mesh x 0. This process, illustrated in Figure 8, featured what they called "fracto-charging" as a means of obtaining high charges on the coal particles. Coal is accelerated at velocities high enough to ensure fracturing of the coal particles, producing a charge. Advanced Energy Dynamics is currently involved in a research effort to develop a belt cleaning system as an alternative device in the "UFC" system.



CHARGER:
1. Mechanically accelerates coal particles to high enough speed to ensure fracturing and emission of charges.
2. Ash and sulfur (inorganics) collect negative charges while coal (organics) collect positive charges.

COLLECTION SYSTEM:
1. Ash and sulfur collect on positively charged discs while coal collects on negatively charged discs.
2. The discs are separately scraped to extract products and rejects.

FIGURE 8. PRINCIPLE OF OPERATION: UFC MODEL.

NEED FOR A DRY COAL CLEANING PROCESS

The Arab oil embargo and the corresponding high increases in the cost of energy, as well as recent problems in the nuclear industry, show the need for producing low-ash and low-sulfur fuels from coal, our most abundant energy supply. To produce the high-quality fuels required to meet stringent emission standards, coal cleaning technology may have to be directed toward the cleaning of micron-size coal (0-30 microns). Microscopic analysis has shown that complete liberation of mineral matter may occur only in the micron-size range for most coals. Most of the current fine-coal-cleaning technologies -- froth flotation, dense-medium cycloning, and heavy-liquid cycloning -- do not have the ability to clean coal in the micron-size range; they begin to become inefficient when particle size drops below 74 microns (200 mesh). In addition, any wet process faces an increasingly difficult dewatering task as the particle size decreases.

Reduction in size to 30 microns causes extremely difficult handling and cleaning problems. However, the corresponding reduction in mass with decreasing size offers the possibility that electrostatic and magnetic fields could be used as a means for beneficiating coal of this size if sufficiently high electrical charges could be placed on the particles. With these ideas in mind, a project was initiated at PETC's Coal Preparation Division in FY1985 to develop a dry beneficiation process for coal called TriboElectrostatic Separation. This report will present and discuss the initial work that was conducted through the end of 1986.

DESIGN AND CONSTRUCTION OF PETC'S TRIBOELECTROSTATIC SEPARATOR

Conceptual ideas for the operation of an electrostatic separation process were predicated on four important criteria: (1) capabilities for handling micron-size coal, (2) minimum drying and sample preparation requirements, (3) charging and separation of sample in a single pass, and (4) selective particle charging. Initial design and fabrication of a lab-scale unit began in October 1984 with the separator system illustrated in Figure 9. Ultrafine coal would be suspended in a high-velocity air stream,

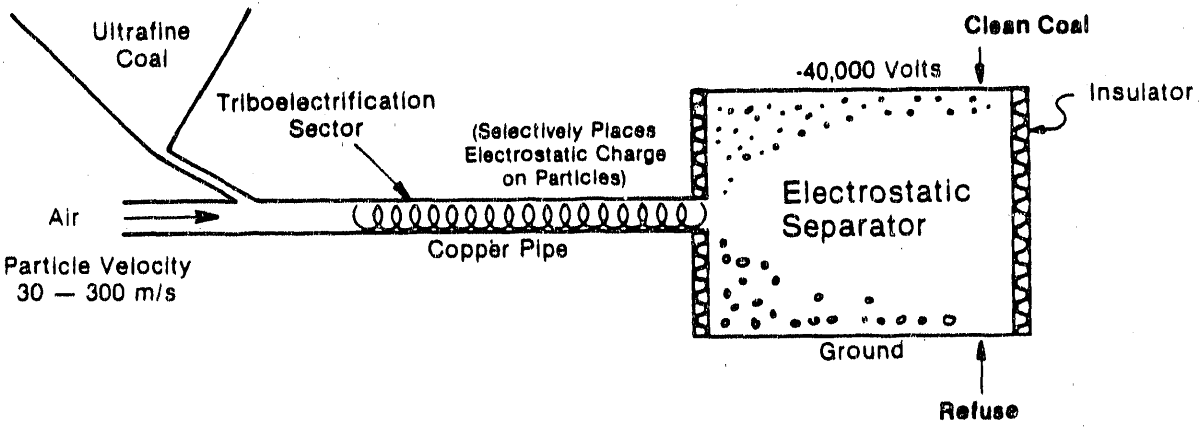


FIGURE 9. SIMPLIFIED DIAGRAM OF TRIBOELECTRIC CHARGER AND ELECTROSTATIC SEPARATOR.

triboelectrically charged, and then separated on the plates of an electrostatic separator at a potential of 40,000 volts. The triboelectrification sector was constructed of copper, since it proved to be an effective material for selectively placing positive charges on coal and negative charges on the mineral matter. To ensure high and efficient charging of the particles, the half-inch copper tube was formed into a helix to create a turbulent flow of the suspension. This ensured that the coal particles would have many contacts with the copper surface, thus providing high charging. High velocities would be required within the tribocharger; however, slower velocities were desirable in the high-voltage plate area to allow longer charged-particle residence times in the separation sector. For this reason, 12-inch by 10-inch plates were spaced 4 inches apart, thereby creating a cross-sectional area greater than 60 times that of the copper tube.

SAMPLE SELECTION, PREPARATION, AND ANALYSIS

Three different coal seams--Pittsburgh, Illinois No. 6, and Upper Freeport--were chosen for testing because of their commercial importance, high ash and sulfur contents, and their different cleanabilities. Coals were either run-of-mine or channel samples that were naturally air dried for three days, crushed to 28 mesh by 0, and stored under argon in the coal repository.

To obtain consistent and repeatable results, all samples and products were prepared, handled, and analyzed in the same way for each test. Grinding to a top size of either 200 mesh by 0 or 400 mesh by 0 was carried out directly before a test in a Mikro-Pulverizing unit, and the sample was checked for particle size distribution in a Leeds and Northrup model 7995 Microtrac Particle Size Analyzer. Sulfur and ash determinations for the feed coals, cleaned coals, and reject products were measured on a Leco SC32 Sulfur Determinator and a Leco MAC-400 Proximate Analysis Determinator.

PRELIMINARY EXPERIMENTAL TESTS AND RESULTS

Preliminary experiments were conducted in a manner that would evaluate the anticipated improvement in electrostatic separation performance with particle top size reduction, and in addition, particle charging characteristics could be estimated by the amount of material collected on the plates of the separator.

After grinding to top sizes of both 200 and 400 mesh, the coals were fed into the TriboElectrostatic Separator at a rate of 8 to 10 grams per minute and suspended in air with the air velocity at 40 feet per second. Separator voltage was set at 40,000 volts. Results of the tests tabulated in Table 2 show significant improvements in the clean-coal yield/ash relationship for all three coals, with reduction in top size from 200 mesh down to 400 mesh. Clean-coal weight recoveries increased by up to 112% while ash content decreased. More important was the fact that at 400 mesh, greater than 89% of the feed coal was being recovered from the plates of the separator. This indicated that very efficient particle charging was taking place within the triboelectric charger.

Table 2. PRELIMINARY ELECTROSTATIC SEPARATION PERFORMANCE

Coal	Size	Wt.%	Ash%	S%
		FEED		
Pittsburgh	200 x 0	100	15.6	4.2
	400 x 0	100	15.6	4.2
Illinois No. 6	200 x 0	100	14.5	5.6
	400 x 0	100	14.5	5.6
Upper Freeport	200 x 0	100	24.4	1.4
	400 x 0	100	24.4	1.4
		NEGATIVE PLATE (Clean Coal)		
Pittsburgh	200 x 0	30.0	6.6	2.9
	400 x 0	63.7	6.3	2.9
Illinois No. 6	200 x 0	38.4	8.8	4.4
	400 x 0	60.2	6.1	4.0
Upper Freeport	200 x 0	33.0	9.6	0.9
	400 x 0	61.0	8.8	0.8
		GROUND PLATE (Refuse)		
Pittsburgh	200 x 0	36.6	26.6	6.1
	400 x 0	32.9	33.7	8.2
Illinois No. 6	200 x 0	32.8	19.5	6.5
	400 x 0	28.8	28.6	9.6
Upper Freeport	200 x 0	35.0	40.2	2.4
	400 x 0	32.0	50.6	2.8

Results of these tests indicated the potential of the process; however, it was important to know whether the experiment could be repeated with regularity. Over a five-day period, different lots of Pittsburgh seam coal were ground to 400 mesh x 0, tribocharged, and separated. The data tabulated in Table 3 showed that consistent products could be obtained under constant operating parameters.

Table 3. TRIBOELECTROSTATIC SEPARATION REPEATABILITY EXPERIMENTS WITH PITTSBURGH SEAM COAL

	Feed		Negative Plate (Clean Coal)			Ground Plate (Refuse)		
Run #	Ash %	S %	Wt.%	Ash %	S %	Wt.%	Ash %	S %
1	15.6	4.2	61.5	5.4	2.8	30.5	29.3	6.4
2	15.6	4.2	60.2	5.9	3.0	31.1	28.6	6.5
3	15.6	4.2	60.5	5.5	2.9	30.9	27.8	6.4
4	15.6	4.2	62.0	6.1	3.0	30.3	29.8	6.7
5	15.6	4.2	60.2	6.3	3.0	31.0	28.7	6.9
Average			60.9	5.8	2.9	30.8	28.9	6.6

Clean-coal products and refuse products from the previous experiments were saved and utilized to test the recleaning capabilities of the system. Both products were independently refed through the separator, and the results of those tests are shown in Table 4. Clean-coal ash and sulfur values were further reduced, and the refuse product now contained 53% ash and 9% sulfur. A middlings product containing 11% ash and 3.6% sulfur was also produced from the recleaning step.

Table 4. TWO-STAGE TRIBOELECTROSTATIC RESULTS USING PITTSBURGH SEAM COAL

	Feed		Negative Plate (Clean Coal)			Ground Plate (Refuse)		
First Stage Product	Ash %	S %	Wt.%	Ash %	S %	Wt. %	Ash %	S %
Negative Plate	5.8	2.9	62.5	3.7	2.7	31.1	10.1	3.5
Ground Plate	28.9	6.6	60.3	11.8	3.7	27.9	52.6	8.9

During the testing period, some coals that had been ground days earlier and used for tests did not produce results as good as those for freshly ground coal. Oxidation of the surfaces was thought to be hindering the tribocharging process; therefore, an experiment was set up to verify this fact. A batch of Pittsburgh seam coal was freshly ground, enough coal was removed from it for one experiment, and the remainder was exposed to the air in a large pan. The results tabulated in Table 5 clearly show the degradation in performance with elapsed time between grinding and electrostatic separation. From this point on, all further testing was done with freshly ground coal.

Table 5. EFFECT OF OXIDATION ON TRIBOELECTROSTATIC SEPARATION USING PITTSBURGH SEAM COAL

Time After Grinding	Feed		Negative Plate (Clean Coal)			Ground Plate (Refuse)		
	Ash %	S %	Wt.%	Ash %	S %	Wt.%	Ash %	S %
5 min	15.6	4.2	55.3	3.6	2.7	31.2	30.2	6.0
6 days	15.6	4.2	52.6	6.6	2.9	28.1	26.6	6.1
19 days	15.6	4.2	51.9	7.6	2.9	27.8	25.4	5.8

EXPERIMENTAL MATRIX DESIGN FOR OPERATING PARAMETERS

The results of this early testing had clearly shown the capabilities of the first-generation electrostatic separator; however, there were some difficulties encountered with the unit. Sample size was inadequate, access to products was difficult, leakage was a problem, and no provision was made to capture material passing through the system. Careful observations of particle movement between the separator plates also indicated that longer residence times in the separator would produce improved results. Consequently, a second-generation unit with 60% larger plate area and other improvements was constructed (see Figure 10).

All testing prior to the construction of the new unit had been run at a fixed set of parameters that were never optimized. Conditions for the new unit would certainly be different than those for the old unit; therefore, a statistically designed experimental matrix was utilized to determine the best basic operating parameters. Four variables were investigated:

1. Velocity of the air/solids suspension
2. Concentration of solids in air
3. Separator voltage
4. Plate solids loading

The suspension velocity and solids concentration were not the measured parameters in this experiment but were calculated from measured values of air volume and coal feed rate. The suspension velocity is directly related to volumetric flow rate in that 100 liters per minute equals 40 feet per second, and solids concentration is calculated from the feed rate and volumetric flow rate.

The matrix experiment was carried out as two independent series and utilized freshly ground Upper Freeport coal from Indiana County, PA with a top size of 400 mesh. Series 1 investigated all four variables at two levels. Results from this test indicated that plate loading (weight and thickness of attached material) had no effect on separator performance, only on the unit's batch capacity. Material would simply fall off the charged plates if too large a sample was fed through the system. Series 2 investi-

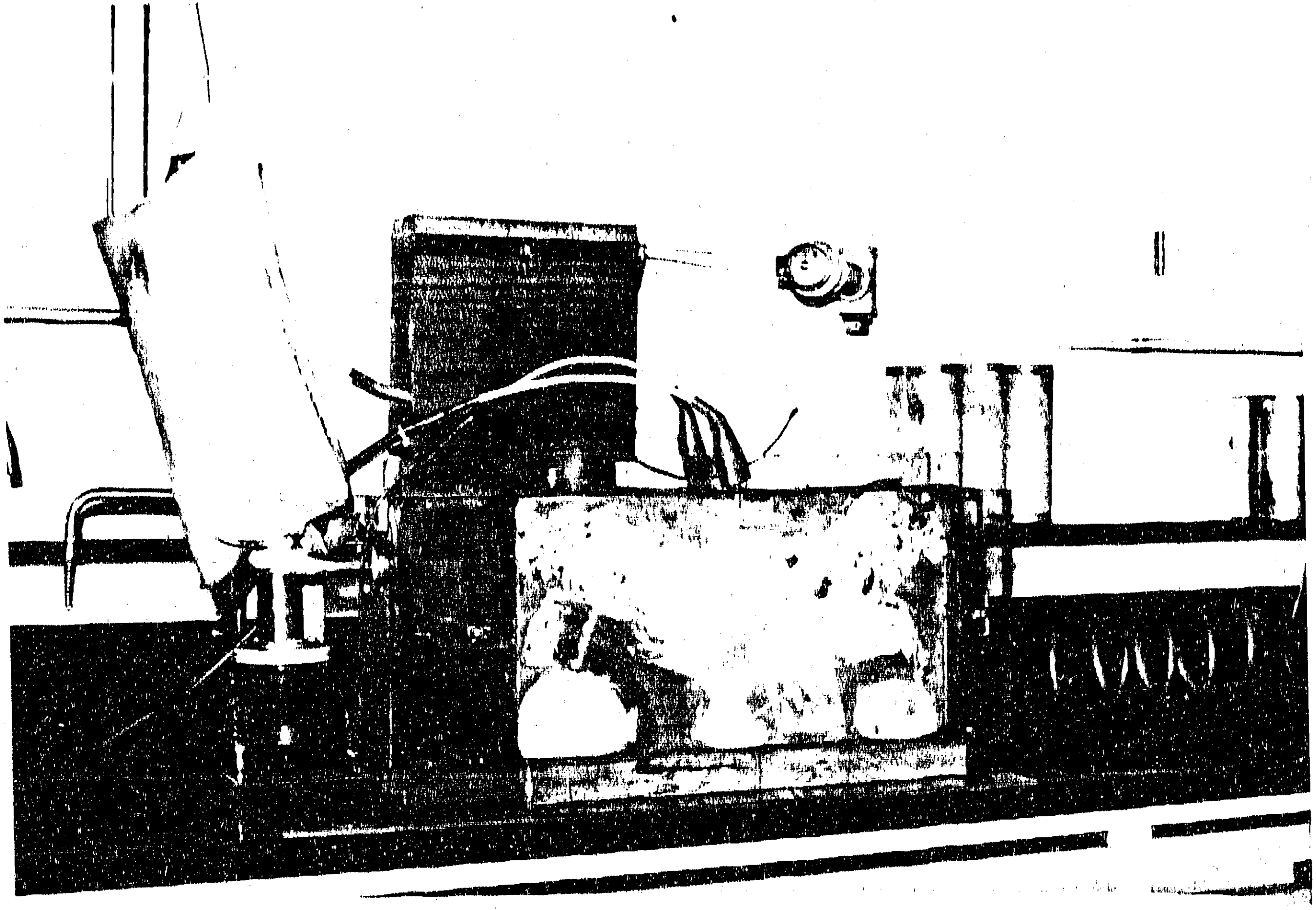


FIGURE 10. SECOND-GENERATION TRIBOELECTROSTATIC SEPARATOR.

gated only the first three variables at two levels. Table 6, therefore, shows only the tabulated data for the highest batch capacities (100 g) for both series of tests.

Analysis of the matrix data in Table 6 indicated that the following parameters would produce the cleanest coal and greatest yield: a solids concentration of 0.03 grams/liter, a velocity of 120 feet/sec, and a separator voltage of 50,000 volts. Utilizing these matrix-determined parameters, a series of experiments was carried out to check repeatability of the results. Shown in Table 7 are data from five independent runs done on consecutive days by two different workers. These results clearly indicate the capabilities of the TriboElectrostatic Separation process under a set of optimum parameters. Clean-coal product is recovered with reductions of 80% in ash and of 50% in sulfur. Second-stage cleaning of these products produced a clean-coal product with 2.1% ash and 0.6% sulfur at a recovery rate of 38.8% of the original feed coal (see Table 8).

Table 6. SECOND-GENERATION TRIBOELECTROSTATIC SEPARATOR STATISTICAL MATRIX RESULTS (UPPER FREEPORT COAL)

	Aerosol Solids		Negative Plate (Clean Coal)			Positive Plate (Refuse)		
Velocity (ft/s)	Loading (g/L)	Voltage (kV)	Wt. (%)	Ash (%)	Sulfur (%)	Wt. (%)	Ash (%)	Sulfur (%)
60	0.06	10	52.8	6.0	0.70	39.6	46.2	2.10
60	0.06	25	55.4	5.2	0.79	36.5	48.5	2.20
60	0.06	50	55.7	5.4	0.70	42.2	48.5	2.40
60	0.06	70	58.2	5.8	0.78	37.4	48.2	2.10
60	0.12	25	51.8	7.2	0.80	40.7	46.4	2.40
60	0.12	50	53.8	5.4	0.70	41.9	46.1	2.30
60	0.24	10	47.0	7.8	0.79	41.5	43.4	2.20
60	0.24	70	53.4	6.2	0.73	41.5	47.3	2.50
120	0.03	25	57.4	5.0	0.90	34.8	50.6	1.90
120	0.03	50	56.8	4.5	0.72	38.0	51.0	2.30
120	0.06	25	53.3	5.7	0.82	37.4	50.6	2.20
120	0.06	50	56.0	6.3	0.73	39.0	49.3	2.40
180	0.02	10	49.7	5.2	0.75	35.5	48.4	2.10
180	0.02	70	58.9	5.5	0.84	36.0	50.8	2.20
180	0.08	10	46.1	5.4	0.68	36.4	46.2	2.10
180	0.08	70	52.0	5.5	0.71	37.8	49.4	2.30

Table 7. SECOND-GENERATION TRIBOELECTROSTATIC REPEATABILITY EXPERIMENTS UTILIZING MATRIX-DETERMINED "BEST" OPERATING PARAMETERS (UPPER FREEPORT COAL)

	Feed		Negative Plate (Clean Coal)			Ground Plate (Refuse)		
Run #	Ash %	S %	Wt.%	Ash %	S %	Wt.%	Ash %	S %
1	24.1	1.5	57.8	4.7	0.79	36.8	51.6	2.20
2	24.1	1.5	56.2	4.7	0.74	38.4	49.9	2.10
3	24.1	1.5	56.9	4.8	0.75	37.9	50.5	2.20
4	24.1	1.5	57.2	4.7	0.80	37.2	50.8	2.00
5	24.1	1.5	57.2	4.7	0.78	37.5	51.0	2.10

Table 8. TWO-STAGE TRIBOELECTROSTATIC RESULTS UTILIZING MATRIX-DETERMINED "BEST" OPERATING PARAMETERS (UPPER FREEPORT COAL)

First-Stage Product	Run #	Feed		Negative Plate (Clean Coal)			Positive Plate (Refuse)		
		Ash %	S %	Wt.%	Ash %	S %	Wt.%	Ash %	S %
Negative Plate	1	4.7	0.77	68.4	2.0	0.60	22.0	13.4	1.20
	2	4.7	0.77	68.4	2.2	0.65	22.0	15.1	1.27
Positive Plate	1	50.6	2.10	38.2	29.2	2.00	50.2	66.5	1.80
	2	50.6	2.10	38.7	29.3	2.10	50.6	66.7	1.70

To evaluate the efficiency of the TriboElectrostatic process, a centrifugal float sink analysis was completed on the same 37-micron top size Upper Freeport coal used for the TriboElectrostatic two-stage cleaning experiment (see Table 9). This float-sink analysis at 1.3 specific gravity produced a clean coal with 1.4% ash and 0.58% sulfur at a yield of 46.9%. These results indicated that the electrostatic process is producing a clean-coal product very near the best yield/ash ratios obtained by washability analysis.

Table 9. CENTRIFUGAL FLOAT-SINK ANALYSIS DATA

Product	Ash %	S %	Wt. %
Float 1.30	1.44	0.58	46.9
1.30 x 1.40	6.50	0.62	10.4
1.40 x 1.60	16.30	0.66	10.7
Sink 1.60	64.00	3.16	32.0

CONCLUSIONS

This initial laboratory study, conducted through 1986, investigated the potential for the dry beneficiation of ultrafine (<37 microns) coal using triboelectric charging coupled with electrostatic separation. The study investigated a number of experimental variables including particle size, suspension velocity and concentration, and strength of electrostatic field. The results of this work indicate that the tribophysics of the coal system are such that it is possible to charge both the mineral matter (including pyrite) and the organic component of the coal simultaneously, and furthermore the charges acquired by these two constituents are opposite in sign. The fact that both pyrite and other minerals acquire a charge which is opposite to the organic coal matrix indicates that TriboElectrostatic Separation has the potential to simultaneously remove both ash-forming minerals and pyritic sulfur from the combustible matter in the coal. Also, this work demonstrated that the charging efficienc in this totally pneumatic system is sufficient to permit greater than 95% recovery of the feed as clean coal and refuse in the batch testing unit. These two observations, high mineral/organic selectivity and efficient charging, indicate that the fundamental physics of the dry TriboElectrostatic beneficiation of coal are workable. This information suggests that it is worthwhile to pursue further work to determine potential ways to develop this separation into a process for ultrafine coal beneficiation.

FUTURE WORK

In the future, research will be directed towards development of the TriboElectrostatic Separation process. Specific objectives are the following:

1. Continue testing of the second-generation separator with other coals.
2. Test finer top sizes in stages down to 5 or 10 microns.
3. Investigate materials other than copper as triboelectric chargers.
4. Continue multistage cleaning experiments to include third-stage cleaning.
5. Construct a continuous cleaning system integrating the grinding, charging, and separating processes.

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