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ELECTROSTATIC BENEFICIATION OF COAL

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ABSTRACT

Dry physical beneficiation of coal has many advantages over wet cleaning methods and post combustion flue gas cleanup processes. The dry beneficiation process is economically competitive and environmentally safe and has the potential of making vast amounts of US coal reserves available for energy generation. While the potential of the electrostatic beneficiation has been studied for many years in laboratories and in pilot plants, a successful full scale electrostatic coal cleaning plant has not been commercially realized yet. In this paper we review some of the technical problems that are encountered in this method and suggest possible solutions that may lead toward its full utilization in cleaning coal.

ELECTROSTATIC BENEFICIATION OF COAL

The electrostatic beneficiation process is based on the difference between physical properties of organic coal and those of the inorganic impurities. One process uses the difference in electrical resistivities while a second uses differences in electronic surface structure. In the first process, a rotating metal drum separator is used that carries the particles through a corona charging zone where the particles acquire a charge, the magnitudes of which depend upon the size and dielectric constant of the particles. Once the charged particles leave the charging zone and are carried along the surface of the rotating electrically grounded drum, the particles loose their charge at a rate depending upon their electrical resistivity. Conducting particles loose their charge rapidly and are thrown from the drum surface by gravity, often aided by an induction field. The insulating particles retain their charge, and are held to the drum surface until they are brushed off. In this manner, highly resistive coal particles are separated from the inorganic mineral particles.

In the second method, particles are charged triboelectrically against the grounded surface of a metal, most frequently copper. Because of the differences between the electronic surface structures organic coal particles acquire a positive charge while inorganic impurities, such as pyrites and clay particles acquire a negative charge. The coal particles are then separated from the impurities by passing the particles through a separator, consisting of two parallel plate electrodes across which an electric field is applied. Positively charged coal particles move toward the negative electrodes and deposit on the electrode surface while the mineral particles, such as pyrites and silicates move toward and deposit on the positive electrodes. The design of the electrodes and the magnitude of the applied electric field are often optimized for maximum separation. The deposited particles are then removed from the electrode surfaces and collected. The process can be performed continuously.

In both corona and tribocharging processes the separation is effective only when mineral particles have been liberated from the organic coal matrix during the grinding process and have electrical resistivity or tribocharging properties that are significantly different from those of the organic coal particles. Once these two fundamental constraints are met, the electrostatic beneficiation process is simple in operation, results in less overall environmental pollution than wet cleaning or post combustion flue gas cleaning, and is energy efficient.

PREVIOUS STUDIES: FAILURES AND SUCCESSES

Work on electrostatic separation of ash from coal was reported[1] as early as 1914 by Withington and in two U.S. patents for electrostatic separation techniques granted to F.W.C. Schniewend in 1915. The first pilot plant and larger scale implementations of electrostatic cleaning were done around 1940 in Germany. The German coal could be reduced from 14-17% ash to 1.5%. Most early work was done on intermediate size material (10 - 100 mesh). Many systems required pre-separation of the ground coal by size, mainly to eliminate the 'dust' which adversely affected separation. During this period, ultrafine coal was financially insignificant. Now pulverization of coal for power plants produces powdered coal that is about 70% below 200 mesh. In addition, granule size for pyrites has been found to be less than five micrometers.[2] Therefore, without fine grinding, the pyrites may remain locked within the coal matrix and cannot be separated by physical cleaning methods.

Singewald, in a 1976 US patent, described a triboelectric separator with a feed size of 800 μm and at a feed rate of 5 tons per hour. A recovery rate of 88% was obtained in the form of concentrate containing 94.7% pure coal from a feed having only 57% purity.[3] Advanced Energy Dynamics (AED) developed electrostatic separators for both fine and ultrafine coal. Using pilot scale studies with rotating-drum separators, they designed a continuous belt system for separating pyrites from coal. However, the test results showed that the belt system worked on one type of coal while it was ineffective against another type of coal. The electrostatic drum-type separator was only marginally successful at best.

In 1983, Masuda, et al.,[4] reported a triboelectric cyclone charger and a separator system that was effective in separating coal from mineral matter, however, they observed that the material to be chosen for the cyclone wall will depend upon the type of coal used. In a 1984 patent, Ciccu reported a tribocharger where the particles are charged by impaction using a rotating disk placed inside a cylinder. The particles are fed at the center of the rotating disk and are therefore thrown off by centrifugal forces and impact against the cylindrical wall surrounding the rotating disk. Ciccu, et al.[5] examined this tribocharging process against different materials, particularly stainless steel and copper, and also at different temperatures. They also noted that various coal macerals have different tribocharging properties. He and his colleagues have been operating a pilot plant in Italy since 1990. In 1980, Inculet, et al.[6] reported their studies on the triboelectrification of ultrafinely ground and finely ground Canadian coal for separation using a closed loop system where particles can be recirculated for a more efficient separation.

The Pittsburgh Energy Technology Center (PETC) of the Department of Energy (DOE) has been investigating triboelectric coal beneficiation since 1985.[7] They have developed a static copper pipe charger in which particles are carried on a jet stream of nitrogen at a high velocity through a helix shaped copper tube. The high velocity of particles inside the charging section charges the particles triboelectrically and keeps the oppositely charged particles separate from each other before they enter into the separator. Test results using a parallel plate separator showed good separation for Pittsburgh #8, Illinois #6, and Upper Freeport coal samples. Gidaspow et al.,[8] have reported a fluidized bed particle separator in which both particle charge and the particle density are taken into account in the separation process. Their work shows excellent removal of pyrites from coal.

TECHNICAL PROBLEMS IN ELECTROSTATIC SEPARATION PROCESS

Particle Size Distribution

Definitions of "locked", "attached", and "liberated" pyritic impurities are sometimes made to correspond to particles consisting of <30%, 30-70%, and >70% pyrite, respectively. For grind levels of -28, -100, and -400 mesh, the percent of the total pyrites falling into the liberated category was found by Irdi, et al.,[2] to be 37-61, 64-84, and 76-90, respectively, depending on the origin of the coal. Therefore, adequate liberation of the pyrites from the organic coal requires that the run-of-mine (ROM) coal be ground to about -325 mesh. However, ultrafine grinding of coal is expensive and storage of such ultrafine coal creates an explosion hazard since the increased particle surface area promotes rapid oxidation.

In the corona separating process using rotating drums, the fine particles adhere to the surface of the drum and the van der Waals forces of attraction dominate over the electrostatic forces. Therefore, the fine ash and pyritic particles do not fall off from the drum surface once they loose their charge and cannot be separated efficiently using the rotating drum method.

In the tribocharging process, where the charging is performed by impaction of the particles against the wall of the charger, the ultrafine particles do not come in close contact with the metal surface because of their low inertial mass unless a very high velocity is used. However, with high velocity gas flow through the static charger, larger particles will cause rapid erosion of the charging unit so that the copper charger must be frequently replaced. In order to have effective removal of the pyritic particles from the organic coal matrix, the electrostatic separators must employ techniques where particle charging is efficient and oppositely charged particles do not agglomerate. Dust containment and safety features against possible explosion hazards must be included.

Tribocharging through a milling process similar to charging of toner particles in electrophotography, is efficient. However, since coal and mineral particles are charged with opposite polarities, there may be a significant problem due to the agglomeration of the particles of opposite polarities. The tribocharger developed at the PETC has a high velocity air passing through the charger and therefore both the impaction on the surface and the associated turbulence keeps the oppositely charged particles apart from each other.

TRIBOCHARGING OF THE PARTICLES

The basic mechanisms involved in the tribocharging of the coal and mineral particles may include: 1) electron transfer, 2) ion transfer, and 3) material transfer, but the actual process is not well understood. It is therefore necessary to characterize the surface properties of micronized coal powders by scanning electron microscopy, x-ray diffraction analysis, and x-ray photoelectron spectroscopy in order to correlate the tribocharging properties with the electrostatic surface structure and work functions which depend on 1) the type of coal, 2) surface contamination, 3) presence of dust layer, and 4) moisture content. Perhaps the most important parameter affecting the charging process is the oxide layer that covers the coal surface. Therefore the process of optimization will require an understanding of the surface activation of coal either by physisorption or chemisorption mechanisms. Experimental determination of charge-to-mass ratio distribution as a function of particle size for different types of coal maceral and mineral particles are needed.

An automated control of the electrostatic beneficiation process with in-situ measurements of the electrodynamic properties of the coal and mineral particles inside the separator is needed in order to optimize the separation and collection processes. Further, an efficient means for dislodging the coal and mineral particles deposited on the electrodes needs to be developed. An alternative design would be such that the particles do not make contact with the electrode, yet the particles can be collected efficiently in a continuous process.

For developing a self-cleaning electrode, we are designing an electrodynamic screen where the electrodes will consist of a pair of insulating parallel plates with embedded parallel wires. The wires of each plate will be connected to a DC high voltage (+ 25 kV for positive electrodes and - 25 kV for negative electrodes) with a superimposed AC field (3.5 kV p-p) of variable frequency between alternate wires in the same plate. The DC field will provide the electrical migration velocity of the charged particles toward the electrodes whereas the superimposed AC field, which extends only a few millimeters beyond the surface of the plate will provide a confinement force preventing particles from contacting the parallel plates.

EXPERIMENTS AND RESULTS

The surface energy structure of ROM coal particles are being determined with respect to coal surface chemistry, specific surface area, particle size and shape, and the status of new surface formation (with respect to the time from when the particles are freshly ground). Using an E-SPART analyzer, the electrostatic charge and particle size distribution of the coal particles have been measured after tribocharging against a copper surface. Table I shows that the particles were bipolarly charged. A bipolar charge distribution is expected for a mixture of orgnaic coal and inorganic mineral particles. The particle size distribution is shown in Figure 1. This size distribution represents particle size for both coal and mineral particles. We are also developing a real-time digital image processor to analyze the particle size, charge-to-mass ratio, and the trajectories of the particles inside the separator. Application of the E-SPART analyzer and the image processor will be presented in detail. In addition, we will present a new configuration of the separator with electrodynamic screen to be used in the laboratory scale separator unit.

CONCLUSION

A comprehensive analysis of electrostatic charging processes related to coal and mineral particles, an understanding of the particle motion under the influence of aerodynamic and electrostatic forces inside a separator, and development of self-cleaning electrodes are needed in order to achieve commercial application of electrostatic beneficiation in coal cleaning.

TABLE I

PITT 8

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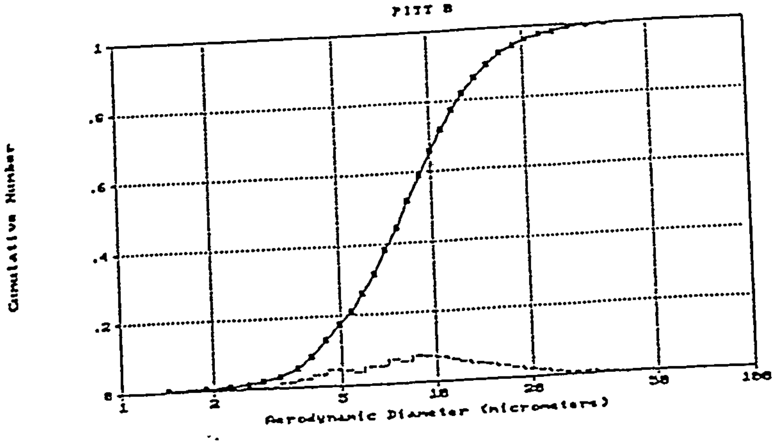
Field Voltage: 50.00 volts   Particle Density: 1.00 g/cm^3

No.	Dia.(um)	------ Negative ------ Count	femto-C	uC/g	------ Positive ------ Count	femto-C	uC/g	Total uC/g
1	1.43	11	-2.39	-141.15	3	0.17	36.45	-103.09
2	1.89	12	-7.74	-182.95	2	3.83	542.39	-79.33
3	2.25	7	-0.93	-22.41	4	3.51	147.67	39.44
4	2.56	11	-9.51	-98.74	2	1.76	100.70	-68.06
5	2.83	12	-4.91	-34.39	3	0.21	5.90	-26.33
6	3.19	35	-15.83	-26.58	11	14.88	79.47	-1.22
7	3.63	58	-24.06	-16.51	13	1.18	3.63	-12.82
8	4.03	97	-51.87	-15.59	9	12.89	41.77	-10.72
9	4.48	142	-52.95	-7.95	16	42.54	56.66	-1.40
10	4.97	123	-98.30	-12.41	17	16.53	15.10	-9.07
11	5.43	109	-45.77	-5.00	15	13.69	10.86	-3.08
12	5.94	148	-74.79	-4.61	19	38.00	18.26	-2.01
13	6.49	151	-43.94	-2.04	21	8.46	2.82	-1.44
14	7.08	212	-110.92	-2.82	16	5.80	1.95	-2.49
15	7.72	184	-103.40	-2.33	21	7.73	1.53	-1.94
16	8.42	222	-181.79	-2.62	28	45.88	5.25	-1.74
17	9.19	218	-171.89	-1.94	22	39.78	4.44	-1.35
18	10.00	209	-133.84	-1.22	22	6.70	0.58	-1.05
19	10.86	178	-223.73	-1.87	21	48.50	3.45	-1.31
20	11.80	158	-179.90	-1.32	24	30.49	1.48	-0.96
21	12.85	143	-159.29	-1.00	18	28.60	1.43	-0.73
22	14.08	124	-129.85	-0.72	19	19.33	0.70	-0.53
23	15.43	108	-140.85	-0.68	14	7.20	0.27	-0.57
24	16.96	91	-129.03	-0.55	10	38.75	1.52	-0.35
25	18.73	54	-102.20	-0.55	13	9.25	0.21	-0.40
26	20.54	51	-214.14	-0.93	5	3.74	0.16	-0.83
27	22.66	32	-67.23	-0.34	8	5.90	0.12	-0.25
28	25.13	23	-50.38	-0.26	3	4.58	0.18	-0.21
29	28.32	22	-57.57	-0.22	5	49.45	0.83	-0.03
30	32.64	13	-24.68	-0.10	1	0.85	0.05	-0.09
31	36.84	11	-25.96	-0.09	2	1.92	0.04	-0.07

	Negative	Positive	Total
Count	2969	387	3356
Mass (nano-gram)	3043.39	452.43	3495.83
Charge (femto-C)	-2639.63	512.10	-2127.53
Charge/Mass (uC/g)	-0.87	1.13	-0.61

Max particle charge (neg) = -61.41 femto-C
Max particle charge (pos) = 42.07 femto-C
Count Median Diameter = 8.256 micrometers
Mass Median Diameter = 17.807 micrometers

FIGURE 1



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Sample Time: 2571 sec

Count Median Aerodynamic Diameter = 8.256
Mass Median Aerodynamic Diameter = 17.807
Count Weighted Geometric Std. Deviation = 1.679
Mass Weighted Geometric Std. Deviation = 1.607
(Based on data in diameter range 1.00 to 100.00)

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