

SURFACE CHARGE OF ILLINOIS COAL AND PYRITES FOR DRY ELECTROSTATIC CLEANING

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Introduction

Most of Illinois coal cannot be burned directly because its sulfur content is too high to meet present air pollution requirements. The Institute of Gas Technology Data Book on coal conversion (21) lists the pyrite, sulfate and organic sulfur content of various Illinois coals. Generally more than 50% of the sulfur contained in Illinois coal is in the form of iron pyrites. The organic sulfur content of some Illinois coals, such as Illinois No. 2 coal, is sufficiently low, that the removal of iron pyrites will produce compliance coal that can be burned in pulverized form.

Coal beneficiation techniques were recently reviewed by Tsai (11) and Liu (20). Physical beneficiation methods can be classified into wet and dry processes. Wet processes such as froth flotation have gained commercial status. However, dry methods of pyrite removal such as electrostatic or magnetic methods are potentially more energy efficient since they avoid the need of drying the coal before combustion and also do not use expensive surfactants.

Electrostatic methods used in the past involved expensive rotor type machines and were designed based on only limited fundamental measurements (Inculet, et al., (7), Moore, (13). Gidaspow, et al. (4) have recently shown that an electrofluidized bed can continuously remove iron pyrites from coal. The design and scale up of such a system is based on the fact that the electrophoretic mobility of pyrites is much greater than coal, since the surface charge of pyrites is ten times that of coal. The surface charge of pyrites and coal is used in a mathematical model of electrofluidization (Shih, et al.(17) ; Shih, (16)) to predict the extent of segregation in an electrofluidized bed. The objective of the present study is to obtain charge measurements of coal and pyrites which should be useful in the design of electrostatic separators.

Apparatus and Procedure

For measuring the charge of the particles a closed loop pneumatic system, shown in Figure 1, was constructed. The lift line, 7.62 cm in diameter and 6 meters high, was made of plexiglas. The particles whose charge we wish to measure, were loaded in the top hopper. Air was blown through the bottom of the lift line by a compressor via a honeycomb distributor. The solids were lifted by the air through the transport line and were subsequently returned to this line by means of a 2.54 cm. downcomer by gravity. Earlier a screwfeeder (Gidaspow, et al., (4)) was used, but the screwfeeder has a tendency to break up the particles and thereby creating excessive amounts of dust. Another problem with the screwfeeder was that its motor heats up very quickly, and subsequently jams, when large throughputs were used or when the air flow rates were low. The solids flow rate could be adjusted by controlling valve 1, while the gas flow rate could be controlled by adjusting valve 2. A cyclone with a dust bag was installed at the top to remove any dust, which could otherwise create a fire hazard. Flow rates through the system could be measured by opening a sampling valve 4. The charge of the particles was measured by using a ball probe, the details of which are shown in Figure 2. Other methods for charge measurement are available (Boschung and Glor, (1); Gajewski and Szaynor, (3); Kittaka et al., (8) and Saunders et al., (15)), but the ball probe is simple, reliable and makes in-situ on line measurements possible. The probe which is similar to that used by Soo et al. (8), is inserted into the flow stream of the

particles. The probe picks up a current which is proportional to the charge of the particles. The electrometer is a high impedance instrument which can measure currents up to 10^{-13} amperes. The lead to the ball probe was enclosed in a ceramic tube in order to avoid leakage of current. To reduce background current, the ceramic tube was again enclosed in a copper tube such that the lead to the probe, the ceramic tube and the copper tube formed concentric cylinders. The copper tube acts like a Faraday cage and reduces any disturbances due to build up charges on the walls of the conveyor. The tip of the ball probe was always kept at the axis of the lift line unless otherwise indicated. When measurements of current were taken in the pneumatic conveyor, air was first blown, and the current setting of the electrometer was set to zero. Particles were then blown along with the air, and the reading of the current by the electrometer was taken as the absolute current due to the impact of the particles on the ball probe. The probe and all other electrical connections were stored in alcohol when they were not in use, and just before use, they were cleaned with alcohol, acetone and finally, with distilled water.

The relation between current and the average charge of the particles is

$$i = qn \quad 1)$$

where i is the current measured by the electrometer, q is the average charge of the particle, and n is the number of particles striking the probe per second. From the above relation it is clear that the number of particles striking the probe per second is still unknown. To measure the quantity n , the output of the electrometer was connected to a Hewlett Packard oscilloscope, and an IBM personal computer with an A/D interface. The Keithley electrometer has a built in amplifier so that its output is amplified to a maximum of three volts. Anytime a particle impacts on the probe, a spike was observed on the oscilloscope. The number of peaks per second gave the frequency of particles impacting the probe. This number was obtained in two different ways using the IBM PC. In the first method, a power spectrum of the output of the electrometer was computed by using a Fast Fourier Transform algorithm (FFT), and the frequency of the maximum of the power spectrum gave the value of n . In the second method, whenever the voltage level of the output of the electrometer crossed a certain threshold value, a Schmidt trigger in the A/D converter was activated, which in turn incremented a count. The number of times the trigger was activated per second, gave the frequency of particles striking the probe per second. Both these methods produced a value of n which agreed with each other quite closely. The use of the Schmidt trigger was preferred, since it was less time consuming, and occupied less memory storage space in the computer. The use of the FFT procedure was also complicated by the fact that parasitic frequencies also produced maxima in the power spectrum, which could sometimes be confused with the frequencies of the particles.

The porosity or the volume fraction of particles flowing in the pneumatic conveyor, was measured by an X-ray absorption densitometer. The X-ray densitometer assembly consists of an X-ray source, a detector, and a recording system. A schematic diagram of the system is shown in Figure 3. The X-ray source and the detector were kept on either side of the transport line on a movable table. The table was mounted on a vertical screw shaft, which was driven by a reversible electric motor. The X-ray motor could be moved anywhere up and down by means of the motor. The 200 mCi X-ray source consists of a tiny capsule of Curium-244 isotope having a half life of 17.8 years. The source was well enclosed in a stainless steel container 2.0 centimeters in diameter. The container had a small window in the front for X-ray emissions. The principal emissions of the source were X-rays, of photoenergy between 12 and 23 KeV. A sodium iodide scintillation detector measured the intensity of the X-rays transmitted through the pneumatic line. A schematic diagram of the detector recorder assembly is shown in Figure 4. The output of the scintillation detector was connected sequentially to a preamplifier, a delay line amplifier, a single channel analyzer, and a timer counter unit. This assembly could

count the number of photons of X-rays striking the scintillation detector per unit time. As the counting time was fixed at 10 seconds, the reading on the counter could be interpreted on an arbitrary scale, as the intensity of the transmitted X-rays. This arbitrary scale was calibrated to read the voidage or porosity directly. To calibrate this scale to give values of porosity, particles were placed between rectangular containers of known volume, and the X-ray count was recorded. This step was repeated for various different containers to give a calibration curve of known porosity. The details of the calibration are reported by Luo (12) and Gidaspow et al., (4).

The humidity of the carrier gases was measured by inserting a digital General Eastern model 1200 AP dew point hygrometer in the flow stream of the particles. The materials used for measurement of charge were iron pyrites and coal. The pyrites were obtained from Fischer Scientific Company. The coal used was Illinois 6 coal, supplied by the Illinois State Geological Survey. The average size of both types of particles used were 270 μm . The charge of these particles was measured without any further treatment.

The mass flow rate of particles can be computed by using the relation

$$\frac{\dot{m}}{\pi R^2} = \frac{\frac{4}{3}\pi r^3 \rho_p n}{\pi \frac{d^2}{4}} \quad 2)$$

where \dot{m} is the mass flow, r is the radius of the particle, ρ_p is the particle density, d is the diameter of the probe, and R is the radius of the pipe. In the above equation, it is assumed that the local mass flow rate is constant across the diameter of the pipe.

The velocity of the particle can be computed by using the mass balance equation for steady feed rate

$$\frac{\dot{m}}{\pi R^2} = \rho_p \epsilon_s v_s \quad 3)$$

where ϵ_s is the measured volumetric concentration of the solid phase, v_s is the solid velocity to be computed, and R is the radius of the transport line. All measurements reported here were obtained in the fully developed flow region where volumetric concentration did not change with height.

Results and Discussion

Figure 5 shows the charge of pyrite and coal as a function of solid velocity at a constant gas velocity and humidity. The sign of charges shown here and in subsequent figures is negative. Although the charges of both pyrite and coal are negative, there is an order of magnitude difference in their values. This shows that pyrites and coal get charged selectively and that electrostatic separation of particles is feasible. The electric charge of both coal and pyrites increase as a function of solid velocity, as expected for triboelectric charging. In a related electrostatic separation experiment (Gidaspow et al., (4)), pyrites always moved to the positive electrode in greater amounts than coal, indicating that pyrites were more negatively charged than coal.

Figures 6 and 7, show the effect of varying the gas velocities for transport of pyrite and coal. Since the range of gas velocities is small due to the limitations of the present experimental setup, no observable difference in charging due to variations in gas velocity was noticed. The present experimental set up is being redesigned so that the velocities could be varied over much larger ranges.

Figures 8 and 9, show the effect of humidity on the charging of coal and pyrite. When a particle gets charged by triboelectrification, the amount of charge that a particle is capable of retaining is dependent on the ambient atmospheric conditions. Under dry conditions, most of the charge acquired by the particles, is retained. However, when the humidity content of the surrounding atmosphere is high, the charges accumulated on the particle begin to leak back into the atmosphere due to the bombardment of water molecules. The higher the humidity, the greater is the leakage of charge from the particles to the atmosphere. This shows that electrostatic separation of coal would be optimum under dry conditions.

The effect of particle concentration on charge of pyrites is shown in Figure 10. It is observed that as the concentration increases the charge drops. This could be due to the fact that under dilute conditions, more particle-wall interactions are possible than under concentrated conditions, where particle-particle interactions are more common. Under the assumption that all particles are nearly homogeneous, they would also have similar work functions. Therefore particle-particle contacts will have little bearing on the charging of particles. On the other hand, the work functions of the particle and the wall are much different, hence the probability of the particle getting charged on contact with the wall is much larger.

The amount of charge a particle is capable of carrying is dependent on the size of the particle as seen in Figure 11. These data were taken in the pneumatic conveying system shown in Figure 12. This apparatus is similar to that shown in Figure 1, except that it is of rectangular cross-section. Larger particles are capable of carrying much higher charges. However when particle charge is normalized by the particle surface area, the variation of charge as a function of particle size is minimal, as seen in Figure 13. This shows that only those electrons on the surface of the particles take part in the triboelectrification process.

The radial charge profile in the conveyor is shown in Figure 14. The charge at the center of the tube is constant, while it drops off at the wall. There could be two reasons for this observation. The first is that the probe is influenced by the accumulated charge on the wall of the conveyor, which is opposite to that of the particles. The second reason is that the velocity of the particles close to the wall is much lower than at the center of the pipe (Nakamura and Capes, (14); Syamlal (19)), thus the charge is smaller close to the wall, consistent with the variation of the charge with velocity shown in Figure 5.

Conclusions

We have shown that the electric charge of iron pyrites is generally an order of magnitude higher than that of coal. This higher charge is the basis of electrostatic separation of iron pyrites from coal. Humidity of the carrier gases has the most significant effect on the particle charge. The solid velocity, porosity and the particle size also influence the charge of the particles. The nearly linear dependence of the charge of pyrites and coal on particle velocity suggests that the electric charge is acquired by triboelectrification which is analogous although not identical to streaming current found in colloidal suspensions in liquid.

Acknowledgement

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Literature Cited

1. Boscung, P., and Glor, M. "Methods for Investigating the Electrostatic Behavior of Powders," *Journal of Electrostatics* 8, 205 (1980).

2. Fasso L., Chao, S., and Soo, S. L. "Measurement of Electrostatic Charges and Concentration of Particles in the Freeboard Fluidized Beds," *Powder Technology*, 33, pp. 211-221 (1982).
3. Gajewski, J. B., and Szaynor, A. "Charge Measurements of Dust Particles in Motion," *Journal of Electrostatics* 10, 229 (1981).
4. Gidaspow, D., Wasan, D. T., Saxena, S., Shih, Y. T., Gupta, K. P., and Mukherjee, A. "Electrostatic Desulfurization of Coal in Fluidized Beds and Conveyors," Presented at Miami Beach Annual AIChE meeting, Paper No. 58c, preprinted in Microfiche, November (1986).
5. Gidaspow, D., Wasan, D. T., Saxena, S., and Mukherjee, A. "Electrostatic Desulfurization of Coal," Annual report to the Coal Research Board and the Department of Energy and Natural Resources, Springfield, Illinois, December, (1985).
6. Gidaspow, D., Syamlal, M., Seo, Y. and Luo, K. M., "Dilute, Dense-Phase and Maximum Solid Gas Transport," Proceedings of the Advanced Research and Technology Development, Direct Utilization Contractors Meeting, U.S. Department of Energy, pp 180-189, (1985).
7. Inculet, I. I., Berganou, M. A., and Brown, J. D., "in Physical Cleaning of Coal: Present and Developing Methods," ed. Y. A. Liu, Marcel Dekker Inc. New York, (1982).
8. Kittaka, R., Masui, N., and Murata, Y. "A Method for Measuring the Charging Tendency of Powders in Pneumatic Conveyance through Pipes," *Journal of Electrostatics* 6, pp 181-190 (1979).
9. Kittaka, S., and Murata, Y. "A New System for Measuring the Charging Tendency of Solid Particles," *Journal of Electrostatics* 2, pp 111-119 (1976).
10. Kuczynski, R., Przekwas, A., and Kucinski, W. "The Static Electrification of Particles in Gas Solids Pipe Flow," *Journal of Electrostatics* 10, 309 (1981).
11. Liu, Y. A., "Physical Cleaning of Coal" Marcel Dekker, Inc. (1982).
12. Luo, K. M., "Ph.D. Thesis in progress," Illinois Institute of Technology, Chicago, (1986).
13. Moore, A. D., *Electrostatics and its Applications*, John Wiley and sons, (1973).
14. Nakamura, K., and Capes, C. E., "Vertical Pneumatic Conveying: A Theoretical Study of Uniform and Annular Particle Flow Models," *Can. J. Chem. Eng.* 51, pp 39-46 (1973).
15. Saunders, J. H., Chao, B. T., and Soo, S. L. "Performance of a Device for Entrainment Reduction and Smoother Operation of a Fluidized Bed," *Powder Technology* 35, pp 233-239 (1983).
16. Shih, Y. T., "Hydrodynamics of Separation of Particles: Sedimentation and Fluidization," Ph.D. Thesis, Illinois Institute of Technology, Chicago, (1986).
17. Shih, Y. T., Gidaspow, D., and Wasan, D. T., "Sedimentation of Fine Particles in Nonaqueous Media," *Colloids and Surfaces*, accepted for publication (1986).
18. Soo, S. L., Cheng L., and Tung S. K. "Electric Measurements of Flow Rate of Pulverized Coal," *ASME Journal of Engineering for Power*, April (1970).

19. Syamlal, M., "Multiphase Hydrodynamics of Gas-solid Flow," Ph.D. Thesis, Illinois Institute of Technology Chicago (1985).
20. Tsai, S. C., "Fundamentals of Coal Beneficiation and Utilization," Elsevier (1982).
21. Institute of Gas Technology, "Coal Conversion Systems Technical Data Book". Prepared for the U.S. Department of Energy (1982).

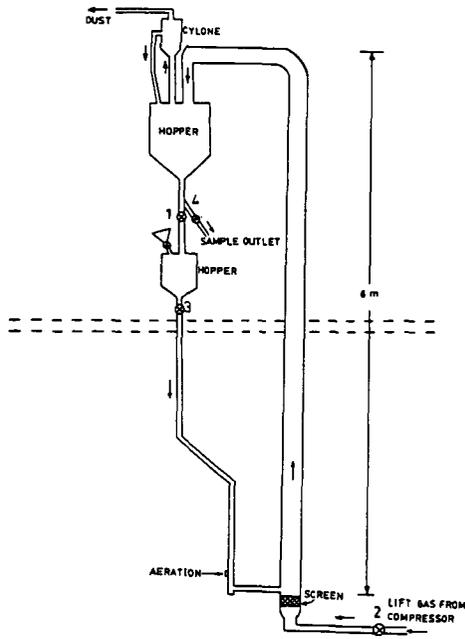


Figure 1. Pneumatic Conveying System.

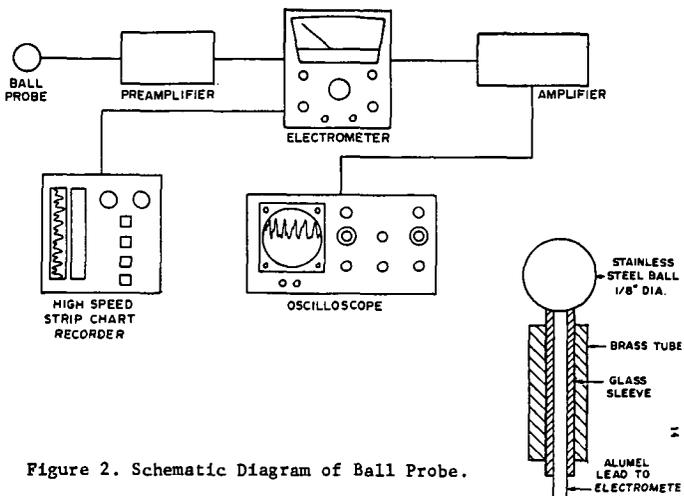


Figure 2. Schematic Diagram of Ball Probe.

1. X-ray Source 2. X-ray Detector
 3. Recorder System 5. Motor

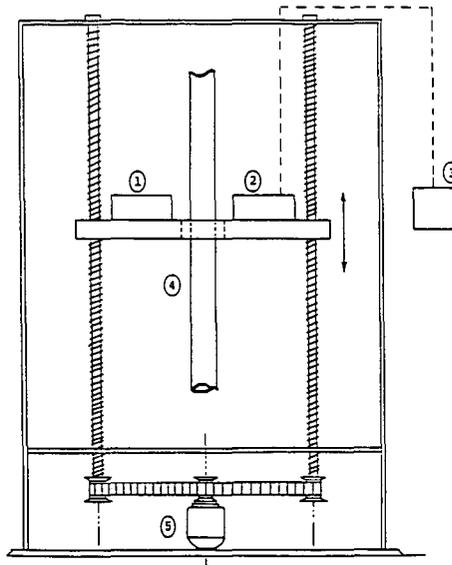


Figure 3. Schematic Diagram of X-ray Densitometer.

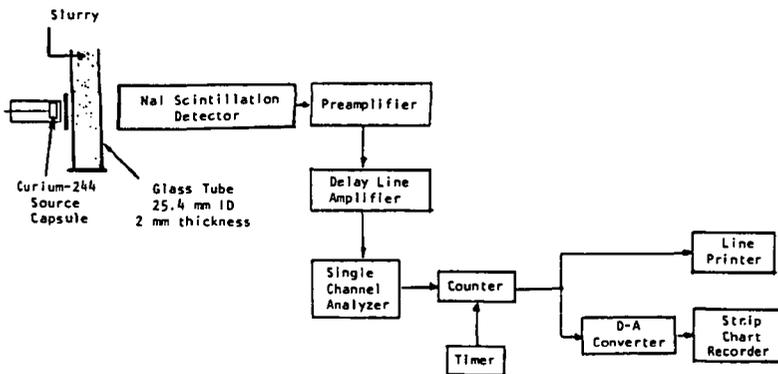


Figure 4. Line Diagram for X-ray Recorder Assembly.

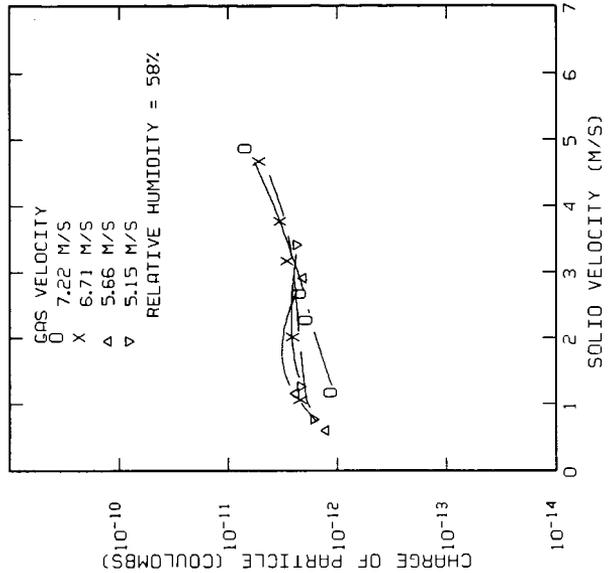


Figure 5. Charge of Pyrite and Illinois No. 6 Coal.

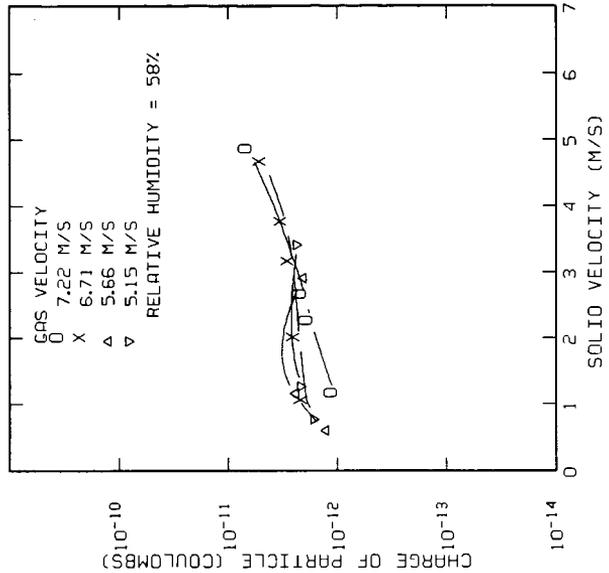


Figure 6. Effect of Gas Velocity on Charge of Pyrites.

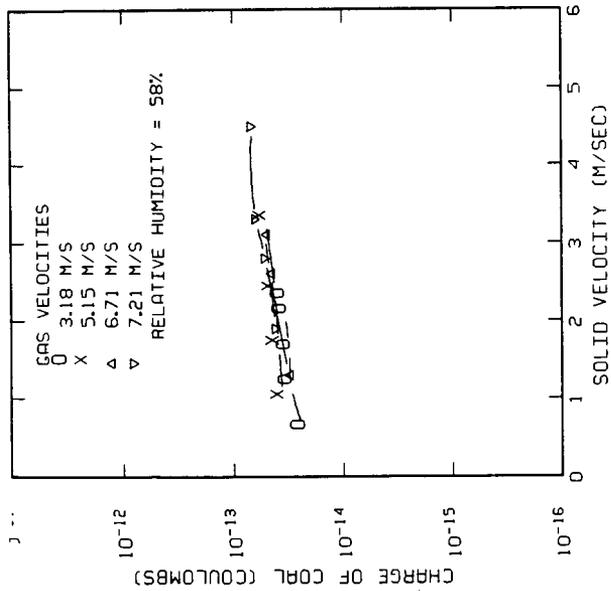


Figure 7. Effect of Gas Velocity on Charge of Coal.

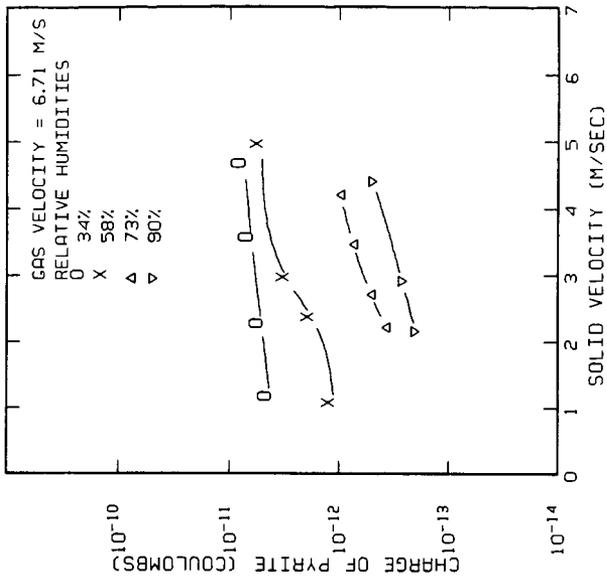


Figure 8. Effect of Humidity on Charge of Pyrites.

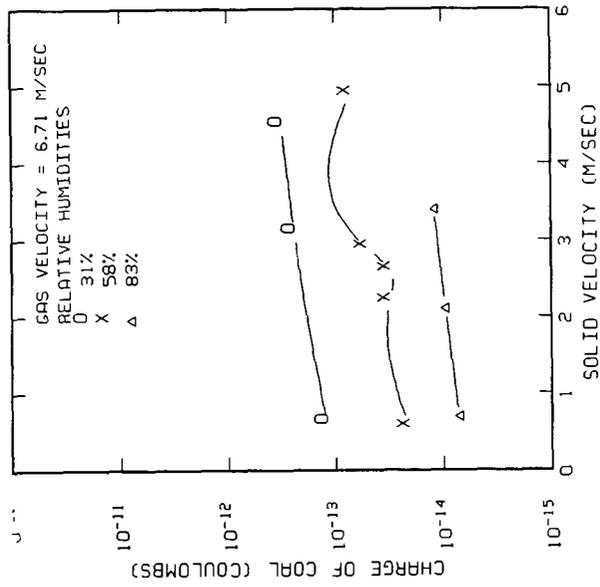


Figure 9. Effect of Humidity on Charge of Illinois No. 6 Coal.

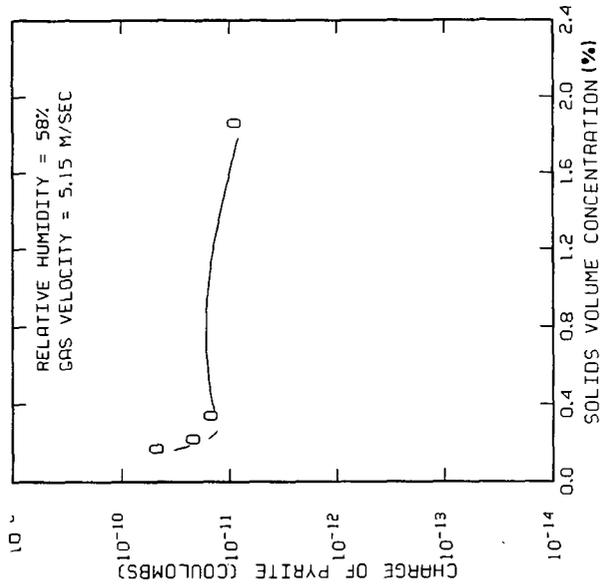


Figure 10. Effect of Particle Concentration on Charge of Pyrite.

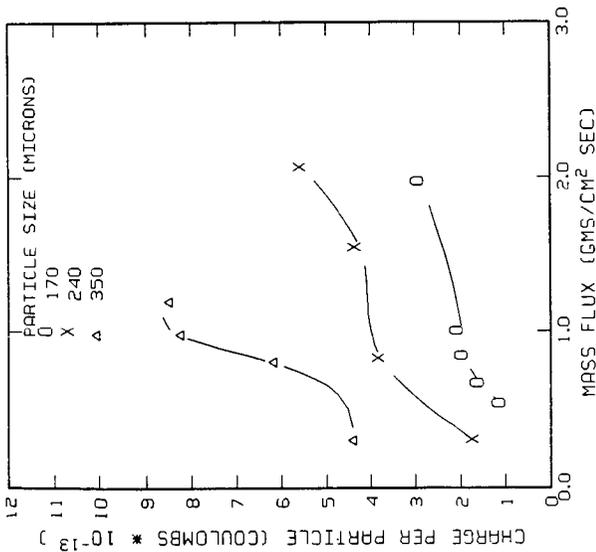


Figure 11. Effect of Particle Size on Charge of Pyrite.

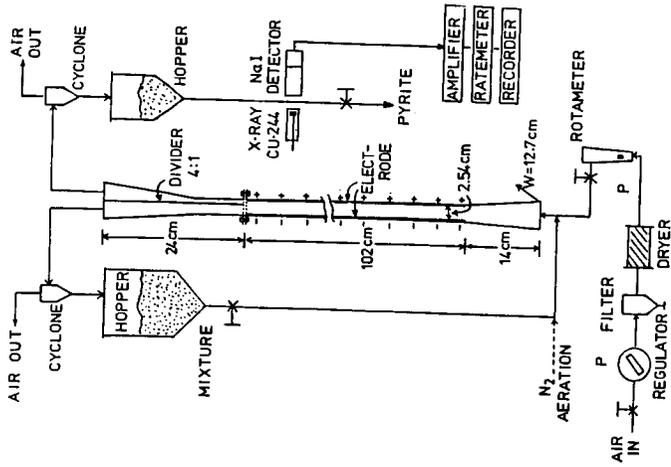


Figure 12. Parallel Plate Pneumatic Conveyor.

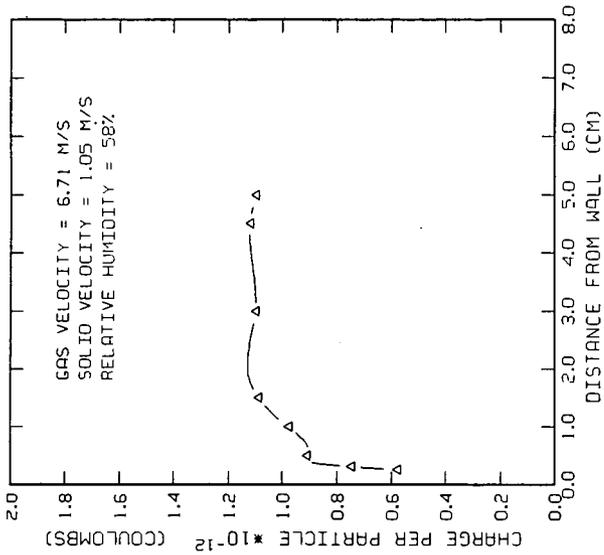


Figure 14. Radial Charge Profile of Pyrite.

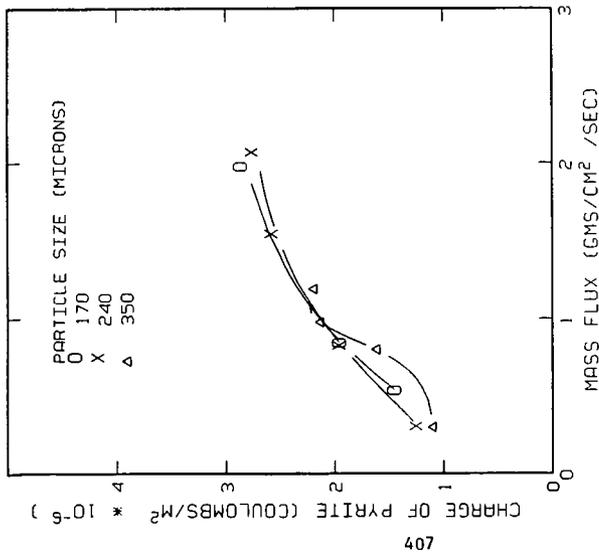


Figure 13. Charge of Pyrite Normalized by Surface Area.