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ION CURRENT DENSITIES PRODUCED BY ENERGETIC

ELECTRONS IN ELECTROSTATIC PRECIPITATOR GEOMETRIES*

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ABSTRACT

A new laboratory test system for electron beam ionization in electrostatic precipitator geometries has been constructed to measure ion current densities as a function of voltage differences for clean (bare) plate conditions. The new system incorporates improved electrodes which withstand a driving voltage of ± 55 kV, a factor of 5 increase over the previous test system. A 3 MeV Van de Graaff accelerator produced ionizing electron beams of 1.2 and 2 MeV and currents of 10.5 and 21 μ A in place of corona wire ionization. Current densities of up to 130 mA/m² were measured before breakdown between the plates, and no current saturation was observed. A comparison of I-V curves and sparkover voltages for various beam energies, currents, and collimation are discussed and the need for measurements with good beam geometry is reviewed.

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INTRODUCTION

Experiments using electron beam ionization instead of corona wire ionization in electrostatic precipitators were introduced in an earlier paper (Davis and Finney, 1978)¹. In these earlier experiments, ion current densities were measured which were 65 times larger than those which could be obtained in a duct-type electrostatic precipitator with corona ionization (White, 1963)². Since particulate charging and collection in electrostatic precipitators depend on the ion current density within the interelectrode space, electron beam ionization is being appraised as a replacement for corona wire ionization.

In this paper, a new laboratory scale electrostatic precipitator test system incorporating improved electrodes and higher operating voltages was used to extend the earlier measurements which were limited by the available power supplies. Current versus voltage curves for several electron beam energies, beam currents, and beam profiles were measured, and increased ion current densities were noted in all cases. No saturation of ion current density was observed and the reasons for this will be discussed.

The earlier paper (Davis and Finney, 1978)¹ presented data using a poor geometry beam configuration in which the electron beam was not scanned or trimmed by collimators to form a narrow corridor of ionization but instead formed a plasma in and beyond the ionization zone. In a second set of measurements, a collimator was used to confine the beam and restrict its spreading. The present work incorporates uncollimated and collimated beam profiles and these are discussed in conjunction with good geometry experiments which are planned to further investigate electron beam precipitation.

EXPERIMENTAL APPARATUS

The objective of this work was to study the effects of beam energy, current, and profile on the ion current characteristics of the laboratory precipitator. A schematic diagram of the test system is shown in Figure 1.

The laboratory scale electrostatic precipitator constructed for these experiments was composed of an upper and a lower set of 3 parallel plates separated by a distance of 10 cm. The plates are $\frac{1}{2}$ inch thick aluminum, and the plate margins were rounded and polished to a smooth finish to reduce edge effects on the field distribution of the system. The collecting area was 400 cm² for plates b, b', d, and d' and 200 cm² for plates c and c'. The outside plates served as guard electrodes while the current flow through the inner two plates (c and c') was measured. Two DC power supplies capable of delivering 130 kV (optional polarity) and 28 mA were connected to the electrodes so that the upper set was positive (anode) and the lower set was negative (cathode), both with respect to ground.

The electron beam was delivered between the electrodes by the 3 MeV Van de Graaff electron accelerator at the Florida State University (Davis, 1976)³,

Figure 1. Schematic diagram of the experimental apparatus. The electron beam is delivered between the upper and lower sets of plates. $S = 5$ cm, $L = 10$ cm.

which was operated to produce beam energies of 1 MeV and 2 MeV and initial beam currents of $10.5 \mu\text{A}$ and $21 \mu\text{A}$. The distance from the foil window to the center of plates c, c' was 55 cm. To determine the effect of electron beam collimation on the ion current characteristics of the system, a ± 0.1 radian honeycomb collimator was mounted on the end of the accelerator tube downstream of the foil window.

RESULTS

Current-to-voltage characteristics for two beam energies, two initial beam currents, and with and without the collimator are shown in Figure 2. Only the anode current (c) is plotted against voltage because the anode and cathode currents were equal in magnitude. For all six experimental conditions plotted, the I - V curves approximate straight lines, indicating an ohmic relationship between current and voltage. No tapering off of current at the highest voltage readings occurs, therefore no saturation in ion current density is observed for the experimental conditions reported here.

Figure 2. The effects of beam energy, beam current, and collimation on the ion current characteristics. Plots are for the current read from the anode (plate c). Uncoll. - Uncollimated beam; Coll. - Collimated beam.

Table 1. Sparkover Voltages and Maximum Ion Current Density for Various Beam Conditions

Energy	Sparkover Voltage (kV)			Maximum Ion Current Density (mA/m ²)		
	10.5 μ A		21.0 μ A	10.5 μ A		21.0 μ A
	Uncoll. ^a	Coll. ^b	Uncoll. ^a	Uncoll. ^a	Coll. ^b	Uncoll. ^a
No Beam	55	--	--	0	--	--
1.2 MeV	48	52	40	80	35	89
2.0 MeV	46	52	ca. 40	100	60	130

^aUncollimated
^bCollimated

Large ion current densities were obtained in each case as shown in Table 1. For 1.2 MeV beam energy, 10.5 μ A beam current, and uncollimated beam, an ion current density of 80 mA/m² was obtained, six times the ion current density of 13 mA/m² found in earlier experiments under similar beam conditions (Davis and Finney, 1978)¹. The highest ion current density found was 130 mA/m² for 2.0 MeV energy, 21.0 μ A current, and uncollimated beam.

Several general results are illustrated in Figure 2 for the values of beam energy, beam current, and collimation conditions studied here. As beam energy increased from 1.2 to 2.0 MeV, ion current density increased by ~25% and 75% for uncollimated and collimated beam, respectively. A doubling in beam current from 10.5 to 21 μ A caused an ion current density increase of 33% and 50% for 1.2 and 2.0 MeV energies, respectively. Finally, the uncollimated beam produced ion current densities of 150% and 100% greater than the collimated beam for 1.2 and 2.0 MeV beam energies, respectively.

As seen in Figure 2, the current versus voltage curves for each experiment were extended until sparkover occurred. Sparking usually occurred between the lateral edges of plates c and c'. Further control of edge effects may be important in preventing premature sparkover. A comparison of sparkover values for various experimental conditions is summarized in Table 1. For specific conditions, beam energy had little effect on sparkover voltage (a 2 kV or less difference between 1.2 and 2.0 MeV). Doubling the beam current from 10.5 to 21.0 μ A causes sparkover voltage to decrease by 6-8 kV. A slight (4 kV) increase in sparkover voltage is noted with collimated versus uncollimated beam.

DISCUSSION

Ion Current Characteristics

The relationship between the ion current and the applied voltage is approximately ohmic for voltages up to sparkover value. This suggests that most of the space between plates c and c' is occupied by a virtually grounded plasma generated by the ionizing collision of the electron beam and air molecules. The driving field is limited by the breakdown field strength, which is, in turn, determined by the presence of a copious supply of ions and the effective plasma-to-plate distance. Therefore, saturated extraction of ions is not expected, and, as shown in Figure 2, no current saturation occurs in any of the I-V plates. Higher driving voltages not limited by sparkover or lower ionization production rates are required to reach the saturation point.

The linear relationship between current and voltage in the electron beam test system is in contrast to the quadratic ($I \propto V^2$) (White, 1963)² relationship prevailing in corona wire ionization systems. This difference may represent an advantage of the electron beam precipitator over its corona wire counterpart.

Ion current densities which are much higher than previously obtained have been produced in these experiments. Using electron beam ionization with the electrode system shown in Figure 1, the ion current density is 100 mA/m^2 at 2.0 MeV energy, $10.5 \text{ } \mu\text{A}$ current, uncollimated beam, and $\pm 44 \text{ kV}$ applied voltage. For a similar plate geometry, conventional electrostatic precipitators have a maximum ion current density of about 0.2 mA/m^2 (White, 1963)² which is space charge limited. Therefore, the laboratory electron beam precipitator yields an ion current density that is ~ 500 times greater than a conventional corona precipitator, and to date it is limited only by sparkover, which is in turn determined by beam geometry, plate spacing, and edge effects.

As shown previously, ion current density increased as beam energy and beam current increased which is expected because with greater beam energy or current more ionization takes place and a larger extraction of charge occurs. The uncollimated beam produced larger ion current densities because the collimator reduces the actual beam current delivered to the interelectrode space while providing a better beam geometry with less beam spreading. Even so, the ionization yield was not exhausted prior to sparkover.

In these poor geometry experiments, the spreading of the plasma column generated by the electron beam reduces the effective distance between plates c, c', and the grounded plasma. It has been estimated (Davis and Finney, 1978)¹ that for a beam energy of 1 MeV and a beam current of $10.5 \text{ } \mu\text{A}$ that the penetration of the electric field adjacent to each electrode is 2.5 cm at a current density of 13 mA/m^2 and an electrode voltage $+10 \text{ kV}$ (anode) and -10 kV (cathode). The sparkover between parallel plates at this distance (5.0 cm) is $\sim 137 \text{ kV}$ (Meek and Craggs, 1978)⁴. A higher driving voltage would be required to reach current saturation. The sparkover voltage is further reduced by field distortion caused by the edges of the electrodes. Collimation

Figure 3. Diagram of three different electron beam geometries. A poor geometry beam configuration with a wide ionization zone is shown in part a). The collimated geometry used in the present experiments with a more restricted plasma is shown in part b). Good geometry with a very narrow ionization zone is shown in part c).

of the beam confines the plasma column to a smaller cross-sectional area, thus increasing the plasma-to-electrode distance and the effective inter-electrode gap. Consequently, this results in a slight increase in sparkover voltage as shown in Table 1.

Poor vs. Good Geometry Beam Configurations

To simulate the small radius ionization cylinder of a corona wire, an electron beam should be prevented from spreading and instead retained within a narrow region centered between the electrodes. As pointed out earlier, the spreading of the plasma column is probably the major cause of early sparkover because the effective gap distance from electrode to plasma is reduced. This poor geometry beam configuration is diagrammed in Figure 3a, and shows the limited reach of the electric field and the expanded ionization zone and reduced effective gap.

A honeycomb collimator which passes electrons within $\pm 1/10$ radian of the beam direction was used to trim the edges of the beam and the result was less

scattering, a wider electrode-to-plasma gap, and an increased sparkover voltage (Figure 3b). The beam current is reduced because the surface area of the collimator tubes presents an obstacle and eliminates the fraction of the beam which is not projected straight through the honeycomb.

Although the honeycomb collimator does improve beam geometry, further refinement is projected by reducing the surface area of the collimator in the beam path while further reducing scatter. A good geometry beam configuration, shown in Figure 3c, would restrict the ionization zone to a column with small cross-sectional area, allowing more complete charge extraction and raising sparkover voltage to a level at which ion current density saturation may be found. Collimation of the beam just prior to its entry into the electric field may serve to further define the ionization zone.

CONCLUSIONS

Earlier experiments using electron beam ionization in electrostatic precipitators were extended using a new laboratory scale test system and larger power supplies. An approximately ohmic relationship between ion current and plate voltage suggests the formation of a large grounded plasma region between the electrodes. Large current densities, as high as 500 times that of conventional precipitators, have been observed with no saturation. Variations in ion current densities with beam energy, current, and collimation are due to the intensity of beam ionization in the interelectrode space. Sparkover voltage is probably determined by beam geometry which controls the plasma-to-electrode gap distance and the width of the ionization zone. Measurements with good geometry are required to observe saturation and investigate the interplay between ionization zone restriction and sparkover. Future work (Thanh *et al.*, in preparation)⁵ will include the use of a medium which simulates fly ash and will address the phenomenon of back corona and its effect on sparkover.

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