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CONFIGURATIONAL TESTING OF
ELECTRON-BEAM IONIZATION FOR
COAL FLY-ASH PRECIPITATORS

For the Quarter

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Submitted by

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TABLE OF CONTENTS

	Page
ABSTRACT	i
I. INTRODUCTION AND SUMMARY.....	1
II. LABORATORY PRECIPITATOR TEST SYSTEM.....	4
A. Wind Tunnel.....	4
B. Microcomputer Data Handling System.....	4
C. Monitors.....	4
D. Aerosol Generators.....	8
III. EXPERIMENTS.....	9
IV. ANALYSES.....	11
A. Zero Energy Loss Electric Field.....	11
B. Mark I Model for Precharger Transmission....	14
V. PRESENTATIONS AND PUBLICATIONS.....	23
VI. PERSONNEL.....	37

ABSTRACT

Work on machine shop drawings for the electrostatic precipitator test system continued throughout this quarter in consultation with both government-supported and industrial laboratories. The blower fan and the filter were ordered. Specification of the components of the microcomputer data handling system was completed with special attention given to interface compatibility. Familiarity was gained with the cascade impactors in preparation for an in-stack monitor workshop in March and orders were placed for the optical particle counter and gas condition monitors. Experiments were restricted to those required to round out previous work in preparation for the Third Symposium on the Transfer and Utilization of Particulate Control Technology. Two analyses are summarized here: a calculation of zero energy loss electric field and a preliminary calculation of precharger transmission for a simple geometry. One publication was prepared for the Conference on Atomic and Nuclear Methods in Fossil Energy Research held in Mayaguez, Puerto Rico in December and this paper will appear in the proceedings. Visitors during this time were Dr. Paul Feldman of the Research Cottrell Corporation and Dr. W. F. Lawson of the Morgantown Energy Technology Center.

I. INTRODUCTION AND SUMMARY

The purpose of this project is to advance the utilization of energetic electron beams in the control of coal fly ash. As pointed out in the final report for Contract Number DE-AS-21-78ET 11316, utilization of electron beams is of immediate importance to the technology of combustion aerosol control and is of future importance to the possible development of combined removal systems for the control of SO_2 , NO_x and particulate matter.

The requirements for a laboratory test system were discussed in the final report for the previous contract and a design to meet these requirements was presented. During this quarter, the necessary shop drawings were drafted in preparation for bid requests. Functionally, the design of the microcomputer data handling system was fixed by the quantities to be measured and the analyses to be performed. The engineering of a system of commercially available components was essentially completed this quarter. Cascade impactors were already in the laboratory. The optical particle counter and gas condition monitors were ordered and will be delivered at a later date. The design of an aerosol generator for heavy dust loadings continues to be a problem shared by us and by other laboratories. Progress with the laboratory precipitator test system is discussed in more detail in Section II.

Experiments with the parallel plate system were devoted to completing the systematics of previous experiments in preparation for a presentation at the Third Symposium on Transfer and

Utilization of Particulate Control Technology to be held in Orlando, Florida in March. Several other experiments were carried out on the measurement of resistivity of high resistivity dust. Difficulties in these measurements confirmed a need for the construction of a Power Test Code 28 resistivity measurement cell which was initiated during this period. These experiments are briefly reported in Section III.

A variety of calculations were carried out as part of the design considerations for the precipitator test system. Two analyses are summarized in Section IV. The first reports the existence of a minimum electric field such that electrons of a given energy will not suffer a net energy loss in passage through a given gas. The second analysis is a calculation of the particle transmission for a simplified precharger geometry. The results confirmed the need for anode cleaning or guarding. The model predicts superior particle charging even though such important factors as space charge and direct electron charging have been neglected. It serves as a point of departure for future model development which will have the benefit of experimental results.

One presentation was made during this period and it will result in a publication. That was a paper presented at the meeting of the American Nuclear Society in Mayaguez, Puerto Rico. It is reproduced in its entirety in Section V.

During this quarter the project benefited from a visit by Dr. Paul Feldman, Director of Research, Research-Cottrell Corporation. His candid discussions of the electrostatic preci-

pitator development work here and elsewhere were of valuable assistance. A short time later the laboratory was visited by Dr. William F. Lawson, the Technical Project Officer. The visit gave him a first hand opportunity to access the facilities and talent available to the project and to review the progress to date.

The personnel involved in the project are listed in Section VI. Of particular importance to the possible combined treatment of SO_2 , NO_x and particles is the anticipated arrival of Dr. O. Tokunaga who will travel from Japan to Tallahassee early in the next quarter.

II. LABORATORY PRECIPITATOR TEST SYSTEM

A. Wind Tunnel

As mentioned in the final report for contract number DE-AS21-78ET11316, a "race-track" configuration for the test system was adopted (see Fig. II. A. 1). Segments of the system are modular so it can be arranged in different configurations as shown in Fig. II. A. 2. The principle reason for the race track configuration is conservation of energy in the control of humidity. Work on the shop drawings of the system continued throughout this quarter. Final specifications for the blower fan and final filter were fixed and orders were placed.

B. Microprocessor Data Handling System

System engineering and component selection for the data handling equipment continued through the quarter. By the end of that period, specifications were ready for the system shown in Fig. II. B. 1. A problem in setting the specifications for the interface to the Kurz air velocity system remained to be solved at a later date. Design work for the monitoring of the various collector currents and voltages was deferred until additional information was obtained.

C. Monitors

The impactors to be used for time integrated measurements on the test precipitator system were on hand in time for familiarization by one member of the group (WCF) in preparation for attending the In-Stack Impactor Workshop to be held in Gainesville, Florida in March. Orders were placed for the optical particle

F.S.U. ELECTRON BEAM PRECIPITATOR TEST SYSTEM

Fig. II. A. 1

FSU
PRECIPITATOR TEST SYSTEM
CONFIGURATION OPTIONS

Fig. II. A. 2

MICROCOMPUTER DATA ACQUISITION SYSTEM

Fig. II. B. 1

monitor system after one more review of the several alternatives. The Climet system remains the best choice for this laboratory system with regard to performance range, reliability, ease of operation, and cost effectiveness.

D. Aerosol Generators

The aerosol generator for PSL beads was in the laboratory before the beginning of the present contract. The problem of producing a test aerosol from a sample dust over a wide range of loading was discussed in the final report for the previous contract. Further information from users of various systems was gathered and evaluated during this quarter. A fluidized bed with a controlled dust feeder is emerging as the best choice for heavy loading.

III. EXPERIMENTS

Experiments with the parallel plate ionization test system were carried out to complete the data sets already on hand. The results and the analyses were presented in the paper given at the Third Symposium on the Transfer and Utilization of Particulate Control Technology in March 1981. Since this paper summarizes much of the experimental work of the previous contract it was included in the final report. For completeness in chronological presentations, it will be included in the presentation section of the following quarterly report.

Several experiments on the measurement of high resistivities were carried out on various powders including fly ash samples. The ability to independently carry out such measurements is important to the objectives of the project since a primary interest is system performance on high resistivity dusts. The resistivity of powders and dusts is strongly influenced by the conditions under which the materials are shipped and stored. Especially important is the control of humidity since surface conduction is often the dominant conduction mechanism in high resistivity dusts. Even with overnight bakeout to remove water, the experiments did not produce scientifically reliable results. The unavoidable conclusion was that more complete control of sample conditions was essential and a new test system design was undertaken.

Subsidiary to the tasks of the contract is the need to measure resistivity of dusts which have been subjected to various levels of radiation dose. Preliminary and only qualitatively

reproducible experiments show that the resistivity can be markedly reduced. As mentioned above, the correlation of resistivity modification with dose and other parameters requires the establishment of a reliable test procedure in new test cell equipment.

IV. ANALYSES

A number of calculations were performed during the quarter. Two results are reported here because of their novelty and/or implications for subsequent work.

A. Zero Energy Loss Electric Field

One objective of this project is the determination of the optimal combination of electric field and electron beam energy. The point addressed here is that of determining the strength of electric field which is sufficient to compensate for the energy loss of an electron during passage through a gas. The practical implication is that a zero energy loss electric field can be used to extend the range of energetic electrons.

The relevant expression is derived by first writing

$$dE = Fdx \quad (1)$$

where dE is the increment of energy due to a force F acting over distance dx . With no electric field, the energy loss relation, dE/dx , is equal to the force (F) acting on the particle due to dissipative processes,

$$\frac{dE}{dx} = F \quad (2)$$

When an electric field $\mathcal{E}$ is imposed in a direction to accelerate the electron the net force is given by

$$F_{\text{net}} = (\mathcal{E}e - F) \quad (3)$$

where e is the charge on the electron.

The condition which determines the zero energy loss electric field is a null net force

$$F_{\text{net}} = 0. \quad (4)$$

Solving for $\mathcal{E}$, the zero energy loss electric field is given

$$\mathcal{E} = (dE/dx)/e. \quad (5)$$

To put this into a form convenient for the use of available range-energy relations, write for the range R

$$R = \rho \Delta x \quad (6)$$

$$dR = \rho dx$$

where ρ is the density. The zero energy loss electric field becomes

$$\mathcal{E} = (dE/dR) \rho e^{-1} \quad (7)$$

and the energy loss expression dE/dR is available in range-energy tabulations.

The zero energy loss electric field is plotted as a function of the electron energy in Fig. IV. A. 1. Two conclusions are apparent from the figure. First, the minimal value of the zero energy loss electric field is achieved for the electron beam energy of approximately 1 MeV or higher. Second, the value of the electric field is readily achievable in electrostatic precipitator configurations, approximately 2.4 kV/cm. As expected, the required electric field becomes progressively larger as the electron energy is reduced below approximately 1 MeV. This will be important in high field regions since some small fraction of

Fig. IV. A. 1

the secondary electron population will achieve high energies. The importance of the calculation is that configurations can be arranged such that some energetic electrons will not lose energy.

B. Mark I Model for Precharger Transmission

The simplest precharger configuration is a pair of racks each of which is made of parallel rods as shown in Fig. IV. B. 1. This configuration is not expected to provide an optimal precharger geometry, but an investigation of its properties both experimentally and theoretically will provide insight and a basis for subsequent optimization. At the outset it should be noted that this model does not provide for cleaning of the anodes, nor does it take account of impaction loading, space charge effects or contributions to particle charging due to direct electron charging. Furthermore no provision is made to establish a boundary of the ionization zone.

As seen in Fig. IV. B. 1, rods of a given rack (anode or cathode) are spaced by the distance $2d$ and the separation between the anode and cathode is S . The radius of the rod is A .

The establishment of an electric potential difference between anode and cathode requires the support of a linear charge density q_0 on the rods of the rack. For distances greater than $2d$ toward the interior of the ionization volume, it is assumed that the field inhomogeneity due to the rack rods can be neglected. The interior electric field is that which will be produced by two parallel plates carrying surface charge σ_{eff} and separated by distance S . This equivalent geometry for the

interior electric field is shown in Fig. IV. B. 2.

Two properties of the precharger are of interest: the charge deposited on the particle and the probability of transmission of the particle through the precharger. In the later, the function is opposite to that of the usual precipitator i.e., the objective is to not precipitate particles in the precharger since a high resistivity dust deposit on the anodes will impede the operation if left uncorrected. In this model the transmission efficiency ϵ_t is given by

$$\epsilon_t = 1 - \frac{\delta}{d - A} \quad (1)$$

where d and A are defined in Fig. IV. B.1 and δ is identified in Fig. IV. B. 3. In this model, the anode rack is regarded as a "collector" and δ is the distance from a rod along the y axis within which a particle will be trapped by the anode. For simplicity in calculation, it is assumed that the electric field at the surface of the rod $\mathcal{E}_A$ is that for an isolated rod given by

$$\mathcal{E}_A = \frac{q_\ell}{2\pi \epsilon_0 A} \quad (2)$$

where q_ℓ is the linear charge density on the rod. This assumption is conservative with regard to the transmission estimate which follows, but not with regard to the build up of dust on the leading edge of the anode. Given the electric field on the surface of the rod $\mathcal{E}_A$, the linear charge density q_ℓ is given by

$$q_\ell = \mathcal{E}_A 2\pi \epsilon_0 A. \quad (3)$$

Two Rack Precharger

Fig. IV. B. 1

Fig. IV. B. 2

Fig. IV. D. 3

The appropriate charge density in the equivalent parallel plate approximation (see Fig. IV. B. II) is given by

$$\sigma_{\text{eff}} = \frac{\mathcal{E}_A \pi \epsilon_0 A}{d} . \quad (4)$$

The assumption is that most, simplistically all, of the field lines from an anode rod go to the cathode. The average electric field well inside the racks is given by

$$\mathcal{E}_0 = \frac{\sigma_{\text{eff}}}{\epsilon_0} . \quad (5)$$

This is taken as a measure of the charging electric field and is related to $\mathcal{E}_A$ by

$$\mathcal{E}_0 = \mathcal{E}_A \frac{\pi A}{d} . \quad (6)$$

The charge which will be acquired by a particle of radius a is given by

$$q_s = 12 \pi a^2 \epsilon_0 \mathcal{E}_0 \quad (7)$$

which, using the previous results, becomes

$$q_s = 12 \pi a^2 \epsilon_0 \mathcal{E}_A \frac{A\pi}{d} . \quad (8)$$

The thickness of the trapping zone δ (Eq. 1) is related to the migration velocity (ω) and the exposure time (Δt) by the equation

$$\begin{aligned} \delta &= \omega \Delta t \\ &= \omega \frac{2A}{V_g} \end{aligned} \quad (9)$$

where v_g is the gas velocity. Using Stokes Law, where $\mathcal{E}_y$ is the component of the electric field parallel to the y axis, the migration velocity ω is given by

$$\mathcal{E}_y q_s = 6 \pi \eta \omega a . \quad (10)$$

The trapping zone δ becomes

$$\delta = \frac{\mathcal{E}_y q_s A}{3 \pi \eta a v_g} . \quad (11)$$

Assuming that the two adjacent rods dominant the region between the two rods, the y component of the electric field along the rod centers is given by

$$\begin{aligned} \mathcal{E}_y &= \frac{q_l}{\pi \epsilon_0} \frac{y}{y^2 - d^2} \\ &= \frac{q_l}{\pi \epsilon_0} \frac{-d + A + \delta}{(-d + A - d)^2 - d^2} . \end{aligned} \quad (12)$$

For convenience, define parameters α and β by the relations

$$\begin{aligned} d &= \alpha A \\ \delta &= \beta A \end{aligned} \quad (13)$$

With these definitions, the problem of determining the transmission becomes one of evaluating β . Assuming that $\alpha \gg 10$, β becomes, after some algebra

$$\beta = \frac{10^{-10} a \mathcal{E}_A^2}{\eta v_g \alpha} \quad (14)$$

In terms of α and β , the transmission efficiency (see Eq. 1) becomes

$$\begin{aligned}\epsilon_t &= 1 - \frac{\delta}{d-A} = 1 - \frac{\beta A}{\alpha A - A} \\ &= 1 - \frac{\beta}{\alpha - 1}\end{aligned}\quad (15)$$

An example will illustrate the properties of the model. Assume the following parameter set:

$$\begin{aligned}a &= 0.5 \times 10^{-6} \text{ m} = 0.5 \text{ } \mu\text{m} \\ v_g &= 3 \text{ m/s} \\ \alpha &= 10 \\ \mathcal{E}_A &= 2 \times 10^6 \text{ V/m} = 20 \text{ kV/cm} \\ A &= 10^{-3} \text{ m} \\ S &= 0.1 \text{ m}\end{aligned}$$

Using the above relations, the following results are obtained for this set of parameters

$$\begin{aligned}q_s &\approx 0.5 \times 10^{-16} \text{ C} \\ n_e &\approx 310 = \text{no. elementary charges on particle} \\ \beta &\approx 0.4 \\ \epsilon_t &\approx 96\%\end{aligned}\quad (17)$$

The results are calculated for a 1 μm diameter particle. As seen in Eq. 14, the value of β is linearly dependent on the size of the particle. Consequently for a 0.1 micron particle the transmission will become $\sim 99.6\%$.

The estimate of the charge on the particle is that for a

quite strong charging field, ~ 6 kV/cm from Eq. 6. An even larger value will result in a model which includes space charge and direct electron charging effects.

The calculation illustrates the need for correcting the debilitating effect of dust buildup on the anode by using guard electrodes, radiation effects, or mechanical cleaning. Of particular importance is the fact the performance improves as the particles decrease in size.

V PRESENTATIONS AND PUBLICATIONS

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ELECTRON BEAM IONIZATION FOR COAL FLY ASH PRECIPITATORS*

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INTRODUCTION

Sulfur is the element most frequently cited in discussions of emissions from coal combustion or conversion. In pulverized coal combustion, the coal utilization technology for the electric power industry today, the emission SO_2 is directly related to the sulfur content of the coal. Many utilities place a premium on low sulfur coal for the purpose of meeting SO_2 emission standards. But is low sulfur coal a panacea for pulverized coal combustion? In practice, no. In fact, a few utilities have added sulfur oxides to the feed stocks for the purpose of overall compliance with both sulfur and particulate emission standards.

The paradox lies in the role which sulfur plays in the control of particulate emissions. While low sulfur content insures correspondingly low production of SO_2 , sulfur also plays a crucial role in the conductivity of the fly ash produced by pulverized coal combustion. Low sulfur coal produces a fly ash of correspondingly low conductivity or high resistivity. The performance of conventional electrostatic precipitators is successively degraded as resistivity values increase above $\sim 10^{10}$ ohm cm.¹

The origin of the "high resistivity problem" in the electrostatic precipitators and the motivation for electron beam ionization development are evident in the operating principles of corona driven precipitators.² A schematic of the conventional precipitator is shown in Fig. 1 in which the plates are normally at ground and the

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Fig. 1. Typical wire-plate geometry for electrostatic precipitator.

wires are maintained at a negative voltage sufficient to produce corona. As shown in Fig. 2, electrons produced by the corona are typically captured by electronegative oxygen molecules to form O_2^- ions. Particle charging takes place by means of two mechanisms: field charging which is dominant for particles $>0.5 \mu m$ and diffusion charging which is the more probable mechanism for particles $<0.2 \mu m$. The two mechanisms compete in the size range 0.2 to $0.5 \mu m$. Both charging mechanisms strongly depend on the ion current density and, in the case of field charging, explicitly on the local electric field.

The charged particles are driven into the collector plates by the electric field and adhere until a layer is built up which is sufficiently thick for mechanical removal by vibration or "rapping". High resistivity of the fly ash becomes a problem when the potential drop across a layer of adhered fly ash becomes sufficiently large for an electrical breakdown in the fly ash called "back corona". Such discharges reintrain some trapped fly ash but more important introduce positive ions which initiate breakdown between the plate and the corona wires. Such breakdown forces a reduction in the operating voltage of the precipitator, loss of efficiency and possibly the derating of the entire steam plant system.

Three attacks on the "high resistivity" problem are underway

Fig. 2. Schematic details of charge carriers in the vicinity of the corona wire and in the laminar flow zone at the collector plate. The turbulent migration region occupies most of the separation (S) between the wire and plate.

currently: Two-stage operation,^{3,4,5} pulsed excitation^{6,7} and the use of additives which modify the resistivity including SO_3 .¹ The motivation for electron beam ionization lies in the first option, the separation of the control function into two stages of particle charging and subsequent collection in a separate unit.^{8,9} The advantage is that the special problems of particle charging are handled in the precharger without concern for the different problems of collection. In fact it may be advantageous to suppress collection in the precharger. On the other hand, the collector is required to provide nothing more than a migration electric field with little or no ion current to produce back corona. Because of the very high ion current densities, electron beam ionization is a promising technology for particle prechargers.

ELECTRON BEAM IONIZATION

... Energetic electron beams (energies < 3 MeV) are produced by

small commercially available units which are currently used in the number of industrial applications such as paint curing, industrial x-ray work and non-vacuum electron beam welding.⁸ Reliability and performance are essential in these applications. A 3 MeV research accelerator was used to obtain the results reported here.

The equipment schematic for ion current density measurements is shown in Fig. 3. Current density measurements are made in the test volume between plates C and C' and the results of one set of measurements are shown in Fig. 4. The measured values in excess of 100 mA/m² or 500 times larger than typical operating values for corona driven precipitators.⁹

Fig. 3. 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.

The current versus voltage curves of Fig. 4 are curious in two respects: the I-V relationship is more or less ohmic with no evidence for saturation i.e. a current limit due to complete removal of ions, and the measured current values are far in excess of those expected from primary ionizing events alone. While this bonus of current density bodes well for particle charging applications, it is also clear that secondary processes which can lead to breakdown are operating and may require suppression when aerosols are used. An investigation of the conditions for producing ion currents by primary ionization alone was initiated.

Fig. 4. 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.

SATURATION CURRENT MEASUREMENTS

The first saturation current measurements¹⁰ were made with the equipment shown in Fig. 5. The objective of the wedge collimator and honeycomb collimators is to limit the ionization zone in the test volume between plates C and C'. The observation of saturation is evident in the relatively flat segments of the I-V curves in Fig. 6 and 7.

Fig. 5. Schematic diagram of the experimental apparatus. The electron beam passes through either the collimators or baffles with apertures and into the interelectrode region. $L = 10$ cm, foil window to center of plates c, c', $D = 55$ cm.

Fig. 6. The effects of beam energy on ion current saturation, using Wedge A and honeycomb collimators.

Fig. 7. The effects of plate spacing on the ion current vs. electric field relation, using Wedge A and honeycomb collimators.

Saturation was achieved equally well by replacing the collimator wedge and honeycomb wedge by a sufficiently small aperture in a thick plate so that the beam current admitted through the aperture was small. See Fig. 8. The dominant requirement for the observation of saturation is the restriction of the energetic electron flux to a sufficiently small value.

Before comparing the value of the saturation currents with that expected from primary ionization by the energetic electron beam, it is necessary to estimate the recombination rate. This was done by using the relation^{11,12}

$$I = I_S \left(1 - \frac{1}{6} m^2 \frac{IS^3}{V^2} \right) \quad (1)$$

the quantity m in an empirical value which depends on the high mobilities and the recombination coefficient for ions in air at standard temperature and pressure and S is the electrode spacing. An example of the analysis is plotted in Fig. 9. Extrapolation of the curve backwards yields a saturation value of $\sim 25 \mu A$. The measured value of the current on the saturation plateau is $22 \mu A$. Consequently 90% of the primary ionization is collected.

The measured value of the ionizing electron current delivered to the interelectrode volume in Fig. 9 is $I_p = 30 nA$. Consequently

Fig. 8. Ion current vs. plate voltage curves comparing two aperture in baffle configurations.

the amplification factor is

$$I_s/I_b = 833 \quad (2)$$

The path length of the electron beam in the test volume is $\Delta L = 10$ cm. From the range-energy relations for energetic electrons,¹³ the increment in range dR (in mg/cm^2) per a decrement of energy dE :

$$\frac{dR}{dE} = 530 \text{ mg/MeV cm}^2 \text{ @ 2 MeV beam energy.} \quad (3)$$

Fig. 9. Ion current vs. ion current/voltage² curve for Wedge A and honeycomb collimators.

The energy reduction ΔE for the range interval ΔR is given by:

$$\Delta E = \Delta R / 530 \text{ MeV} \quad (4)$$

where:

$$R = \Delta L (\text{air density}) = 12.9 \text{ mg/cm}^2 \quad (5)$$

which yields $\Delta E = 12.9/530 \text{ MeV}$ for a beam energy of 2 MeV.

Taking the specific ionization for air as 32 eV per ion pair, the amplification factor calculated from the energy absorbed is given by:

$$\frac{\Delta E}{32 \text{ eV}} = \frac{I_s}{I_b} = 760 \quad (6)$$

which compares with the measured value of 833.

Similarly, for a beam energy of 1.2 MeV the following values are obtained:

$$(I_s/I_b) \text{ calculated} = 786 \quad (7)$$

and

$$(I_s/I_b) \text{ measured} = 870$$

(8)

The agreement between the calculated and measured values is good.

Additional investigations of the conditions for saturation are under way, but several conclusions are clear from the preliminary results. First, the initial energetic electron flux must be restricted to very small values for the observation of saturation. Second, rather substantial ion current densities are achieved with primary ionization alone. Third, the recombination rate is small enough to be neglected in these experiments. Fourth, secondary ionization processes make significant contributions in the open geometry measurements previously discussed.

Fig. 10. Electron Beam Precipitator Test System.

TEST SYSTEM DESIGN

The schematic for the precipitator test system now under construction is shown in Fig. 10. This system will provide a controlled aerosol with prompt loading monitors before and after the precharger-collector assembly. The precharger geometry to be tried first (Fig. 11) is one in which the function of particle charging and collection are spatially well separated. The electric field established between the anode and the cathode will produce a negative monopolar boundary of the ionization zone in the vicinity of the

anode. Here advantage is taken of the very different mobilities for electrons, ions and charge particles. A requirement is that the stack gas velocity be sufficient to carry forward the bulk of the charged particles while unused ions are collected at the anode. The design result is the production of charged particles with very few "waste" negative ions. The charged particles are then collected in a wire precipitator geometry which is operated at voltages below that for corona emission.

Precharger Module

Fig. 11. Schematic of separated Precharger Test Module

Space charge may be a problem. Also, in the consideration of retrofit applications, it is important to make the electron beam system as compact as possible. The schematic of an immediate precharger is shown in Fig. 12. The ionization zone immediately precedes the entrance to the collector plates. A considerably larger ionization zone is required and in this case the gas velocity is that for typical precipitator operation, 1m/s or less.

One problem which is anticipated is the build up of dust deposits on the anodes or in the case of the immediate precharger on the plates themselves. Guard electrodes which will function in

somewhat the same fashion as the grid in the SRI precharger are shown in Fig. 12. Another possible solution to the problem is radiation induced conductivity which will be taken up first in the section on related problems.

Immediate Precharger Module

Fig. 12. Schematic of Immediate Precharger Test Geometry.

RELATED PROBLEMS

Energetic electrons ionize the atoms of a solid or the atoms of a liquid just as well as they do the atoms of a gas. The temporary ionization of a solid insulator is the basis for modern particle detectors. When subjected to a flux of energetic penetrating electrons, even the resistivity of diamond is drastically reduced. Consequently, one suggestion for solving the anode leading edge problem is to maintain a sufficient flux of energetic electrons that the induced conductivity of the deposited dust is kept at a useful value.

A more provocative question raised by preliminary experiments on radiation induced conductivity is that of persistence. A marked reduction in the resistivity, more than an order of magnitude was

observed for a insulating dust sample under irradiation. What was unexpected was the persistence of this reduction for tens of hours. The persistence is surprising enough. It does raise a question as to whether electron beam treatment of the fly ash while still entrained will have a similar persistent affect on the resistivity. It should be emphasized that any estimates based on conventional solid state relaxation mechanisms are orders of magnitude too short for such an expectation. At the moment the persistence observed for three millimeter thick samples of fly ash and alumina dust remains unexplained.

Another interesting problem is the question of direct electron charging or, in the nomenclature of solid state physics, electron implantation. For a given size of particle there is an upper limit on electron energy such that the electron will be trapped in the particle rather than pass through. Consequently, as the ionizing flux produces a swarm of electrons of increasing number and decreasing energy, a certain fraction of the electrons will have sufficient energy to penetrate a particle but not to escape. There is already some evidence that direct electron charging takes place at elevated temperatures.^{14,15} One advantage of such a mechanism in the case of electron beam ionization is the ability to drive the charge on the particle up to field emission limit or any other limit since electrons are available with sufficient energy to overcome any achievable Coulomb barrier.

An intriguing area for further investigation is the filtration of charged particles.¹⁶ Fabric filters are currently arranged in bag houses for the purpose of removing particulate pollutants from stack gas. The major drawback in the use of bag houses is the fact that the pressure drop increases as the fabric becomes loaded with a dust cake. The increase in pressure drop as fabric loads with dust is substantially reduced when the particles are charged with little or no loss in collection efficiency.^{17,18,19,20} The physics of this filtration improvement is not well understood. Some combination of particle electrification and filtration may constitute a new technology for particulate emission control.

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