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PULSED ELECTRON BEAM PRECHARGER

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Aerosol Physics Group
Department of Physics
The Florida State University
Tallahassee, FL 32306-3016

Principal Investigator

Dr. W. Neil Shelton
Professor of Physics
(904) 644-6552

Report Editor

Wright C. Finney
Associate in Research
(904) 644-1598

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I. INTRODUCTION AND CURRENT STATUS OF THE PROJECT

Quarter Eight of the Pulsed Electron Precharging project was principally devoted to the operation of the E-beam precharger in the pulsed anode mode.

We shall first briefly review the motivation for carrying out this project and the experimental approach used. The combustion of low sulfur coal for the purpose of generating electric energy in power plants results in the production of a flue gas containing very high resistivity fly ash. This fly ash is not easily collected by conventional electrostatic precipitators due to the large electric potential difference which develops across the layer of fly ash on the collector plate. If this layer of collected material is allowed to reach a thickness as great as is normally desirable before "rapping" the plates, then the collected fly ash is subject to re-entrainment into the flue gas stream due to back-corona. The back-corona corona problem is described more fully in the next section of this report. This re-entrainment problem can be eliminated through reduction of the voltage applied across the high voltage wires and the grounded plates of the electrostatic precipitator. This is not a good solution to the problem since the charging capability and collection efficiency of the precipitator system are both greatly reduced at the low voltages required to avoid the back-corona problem.

Another approach to solving the problems inherent in collecting high resistivity fly ash in an electrostatic precipitator is to decouple the charging and collecting functions. At FSU an electron beam precharger is employed directly before (upstream in the flue gas pathway) the precipitator. This precharger can be optimized for the charging function while the downstream collector can be optimized for collection of the high-resistivity fly ash. The characteristics of the Mk. III electron beam precharger have been investigated in a prior phase of this research. In that previous work electrons from an ionization zone created by the electron beam were drawn across the flue gas stream by the application of a constant high potential. The maximum voltage was limited by the onset of sparking or production or production of opposite sign ions in the precharger.

Numerous studies have shown that the precharger approach was an excellent solution to the back-corona problem. The results of this research suggested that even better results should be obtainable provided that the precharger anode potential could be raised above the sparking potential limit. Since it has long been known that short duration potentials exceeding the onset of sparking can be applied to gases without the initiation of spark production, the present research with pulsed anode potentials of short duration (200 ns) was undertaken. The present research using pulsed anode potentials has been highly successful, and we believe that this success is due to the formation of streamers in the gas stream during the high-potential pulse.

Although the present research has not been concerned with removal of sulfur dioxide from the flue gas stream, it is likely that the streamers created in the pulsed electron beam precharging process would convert this pollutant to sulfides in a condensible vapor form. These condensible products would tend to collect on the fly ash particles and be removed concurrently with the fly ash in the collecting section. The deposited sulfides would reduce the resistivity of the fly ash layer on the collector plates thereby further reducing the back-corona problem. The sulfur dioxide removal efficiency of the pulsed electron beam precharger has not be investigated in the present research, but should certainly be addressed in future research. We are very excited about the possibilities inherent in such future research.

II. PULSED ANODE ELECTRON BEAM PRECHARGER EXPERIMENTS

The present phase of the Electron Beam Precharger Project is devoted to determining whether any advantage accrues to pulsing the positive anode potential of the precharger. The motivation for undertaking an experimental study of anode pulsing is discussed above in Section I.

In proposing this study it was anticipated that the voltage could be increased above the dc sparking potential for a short time (200 ns or so), but that in order to gain an advantage over dc operation of the anode it would be necessary to provide many pulses per second. For this reason, we originally proposed running the pulsed precharger at several frequencies provided we had time and resources to do this at the end of the project. It turned out not to be necessary to operate the pulsed anode at a frequency higher than that obtainable from the AC utility line (60 Hz) due to the fact that pulsed anode operation of the precharger has been much more effective than was anticipated in the proposal. A duty cycle of the anode pulses (fraction of the time the anode was 'on') of only 0.0012% was found to be adequate (200 ns pulse width, 60 Hz frequency). It was found that pulsing of the anode was ineffective in the absence of a small dc bias, however. These matters are discussed further in Section VI.

Before the anode pulsing experiments were undertaken, several improvements were made to the precharging module and associated equipment. These improvements have been discussed in previous Technical Progress Reports. Some experiments with the anode operated at a dc potential were carried out during this contract period in connection with these improvements, and these results have also been presented in previous reports.

One serious problem was immediately encountered when measurements with pulsed power were attempted. The rotating spark gap pulsed power supply was found to produce a great deal of radio frequency electromagnetic emissions which interfered with the data acquisition and analysis system electonics. A great deal of effort was made over a considerable period of time to shield the pulsed power supply and provide an optimum network of earth grounds between the various electronic devices of the data accumulation system. It was possible to operate the apparatus which performed the charge-vs.-radius measurements after the shielding and grounding modifications were made. However, the Climet optical particle counter could not be operated even after all the grounding and shielding precautions had been taken.

An alternative method was implemented whereby a nozzle was inserted into the ductwork at the exit of the collector, and an aerosol sample was drawn into an absolute filter holder containing a a paper filter. A series of filters was weighed before, during, and after a run to determine the aerosol transmission through the precharger-collector system. This new method of determining the aerosol concentration was checked by comparing the results obtained in this way with results obtained under the same experimental conditions using the Climet optical particle counter. Good agreement was obtained. Please also refer to previous Technical Progress Reports Numbers 1 through 7 for details of the modifications made to the experimental apparatus in order to carry out the pulsed electron beam precharging experiments described here.

The experimental results obtained using pulsed power are discussed in the following sections. First, the pulsed power measurements of the collection efficiency and improvement factor are described in Section III, and a description of the corresponding charge-vs.-radius experiments follows in Section IV. A sample calculation of the collection efficiency and improvement factor is given in Section V, and the conclusions are presented in Section VI.

III. COLLECTION EFFICIENCY MEASUREMENTS USING PULSED ANODE

We present and discuss here comparisons of pulsed precharger anode runs (with and without a dc bias) with runs for which the anode was maintained at a constant potential. These experimental results are presented in Table I. The constants at the top of the table are the experimental parameters common to all of the experiments in Table I.

First, consider the results with the precharger turned off and the electrostatic precipitator (collector) operated at 4 kV/cm. This electric field strength is appropriate for collecting high resistivity fly ash without producing back corona. In this case the only charging of the particles before passing into the collector is due to incidental frictional charging in the fluidized bed and gas stream. Collection efficiencies of approximately 90% were obtained. The efficiencies vary somewhat between the four different runs which were carried out on different days, with the values varying from 86.1% to 93.2%. These differences are attributed to the fact that 1) there is always some uncontrolled variation in the frictional charging (see Section IV) in the gas stream prior to its entry into the collector, and 2) turbulent mixing of the aerosol in the ductwork. The frictional charging is uncontrolled insofar as we do not fully understand the details of its origin.

Looking next at the pulsed anode results with no dc bias applied (runs B-30, B-60 amd B-100) which carry the label "pp" in the precharger voltage column to indicate pulsed power, one can see that the collection efficiencies are much less than those in which the precharger is not energized at all. This trend holds for both Hydral and fly ash test aerosol. The collection efficiencies are only about 50% to 60% in the pulsed-only situation. Aerosol particles are being charged in the E-beam precharger in this situation (see Section IV), but it is believed that about equal numbers are being given positive and negative charges. Obviously, positively charged

Table I. Results from experimental runs measuring the collection efficiency and precharger efficiency improvement factor. The improvement factor is listed in the last column and is designated by the symbol α. The first row for each run in the table gives the collection efficiency obtained when the precharger was not energized. The constants listed immediately below apply to all the experiments except that the electron beam current and voltage were zero for the first row of each run. The data listed are representative of those obtained in the DC, pulsed, and pulsed-with-DC-bias modes of operation of the precharger.

Constants:

Gas Velcity	3.2 ft/s
Collector Electric Field	4.0 kV/cm
Collector Ion Current	30 μA
Electron Beam Voltage	90 keV
Electron Beam Current	2.0 μA

Run Number	Comparison (Test Dust)	Precharger Voltage (kV)	Precharger E-Field (kV/cm)	Precharger Ion Current (μA)	Collection Efficiency (%)	α-Value (Collector + Precharger)
A-430	dc-only	--	--	--	86.1	--
	(Hydral)	55 dc	3.9	40	98.3	8.2
		66 dc	4.7	41	98.7	10.4
B-30	Pulse Voltage	--	--	--	89.8	--
	(Hydral)	60 pp	4.3	3 rms	48.8	< 1
		70 pp	5.0	4 rms	57.8	< 1
		70 pp,20 dc	6.4	21 rms	96.2	2.7
B-60	dc vs. Pulsed	--	--	--	93.2	--
	(Hydral)	66 dc	4.7	30	99.3	9.7
		66 pp	4.7	4 rms	53.5	< 1
		66 pp, 10 dc	5.5	6 rms	96.2	1.8
		66 pp, 20 dc	6.2	8 rms	99.5	14.0
B-100	dc vs. Pulsed	--	--	--	88.2	--
	(Fly Ash)	66 dc	4.7	20	97.8	5.5
		66 pp	4.7	4	61.4	< 1
		66 pp, 10 dc	5.5	6	97.4	4.5
		66 pp, 20 dc	6.3	8	99.4	21.1

aerosol particles are highly unlikely to be collected in the negatively-biased electrostatic precipitator, and therefore the collection efficiency falls drastically.

Looking now at the results for operation of the precharger anode at a dc potential, which are indicated with the label "dc" in the precharger voltage column, it can be seen that the results are comparable with the results given in the final report of the previous project (DOE Contract Number DE-AC22-86PC91021) entitled Flue Gas Cleanup Technology Using Energetic Electrons. The precharger, collector, and wind tunnel system used for the present dc E-beam precharging experiments is nearly identical to the apparatus in those earlier experiments, except for slight modifications to the electrode configuration, and the fact that the Climet particle counter which was used in those experiments is not used here due to the presence of RF interference during anode pulsing. The time-averaged filter weighing technique used here to determine the collection efficiency is subject to greater random error than the Climet particle counter real-time technique, and this accounts for the slight discrepancy between the present results and the results reported earlier. The run-to-run reproducibility of measurements reported here is not quite as good here as it was in the earlier experiments for the same reason (see, e.g.the collection efficiency for the 66 kV dc condition during runs A-430 and B-60 in Table I, each of which were made on different days).

Consider next the pulsed-anode precharger runs made with a positive dc bias applied simultaneously to the anode. These measurements were made using a small dc bias of only 10 kV to 20 kV along with positive anode pulses of 66 to 70 kV. Runs B-60 and B-100 for Hydral dust and fly ash show that the collection efficiencies obtained using 66 kV pulses and 20 kV dc bias are better than those obtained using 66 kV dc alone. This is an impressive result in view of the fact that full voltage is applied to the anode only 0.0012% of the time in the pulsed mode. Power consumption in the precharger is thereby reduced by approximately a factor of three in the pulsed mode as compared to the dc mode. The next Technical Progess Report (TPR-9) will be devoted to a discussion of possible microscopic (i.e. atomic and molecular) processes which could explain these experimental results for the case of pulsed anode with a dc bias. It is clear that charging is so rapid in this situation that the standard theoretical model previously used to interpret dc precharging data is inadequate.

IV. CHARGE-VS-RADIUS EXPERIMENTS USING PULSED ANODE

Table II lists the charge-vs-radius runs and the corresponding experimental conditions. This table also lists the number of the figure which exhibits the data in graphical form for each run. The samples for the charge-vs-radius measurements were taken in all of the following cases directly from the gas stream exiting the precharger. The collector is also energized in all cases except the first.

Table II. Listing of dc and pulsed charge to-diameter experimental runs.

Run No.	Collector Voltage	Precharger dc Bias (kV)	Precharger Pulse Voltage (kV)	Figure No.
1	0	0	0	1
2	4	66	0	2
3	4	0	60	3
4	4	0	66	4
5	4	0	70	5
6	4	10	66	6
7	4	20	66	7

Figure 1 shows the charge-vs-particle diameter measurements for the case of the precharger not in operation, i.e. both the electron beam and anode potential are turned off. The hydral particles are incidentally frictionally charged in the fluidized bed and wind tunnel. As shown in the previous section, the collection efficiency is about 90% in this case. The Hydral particles are

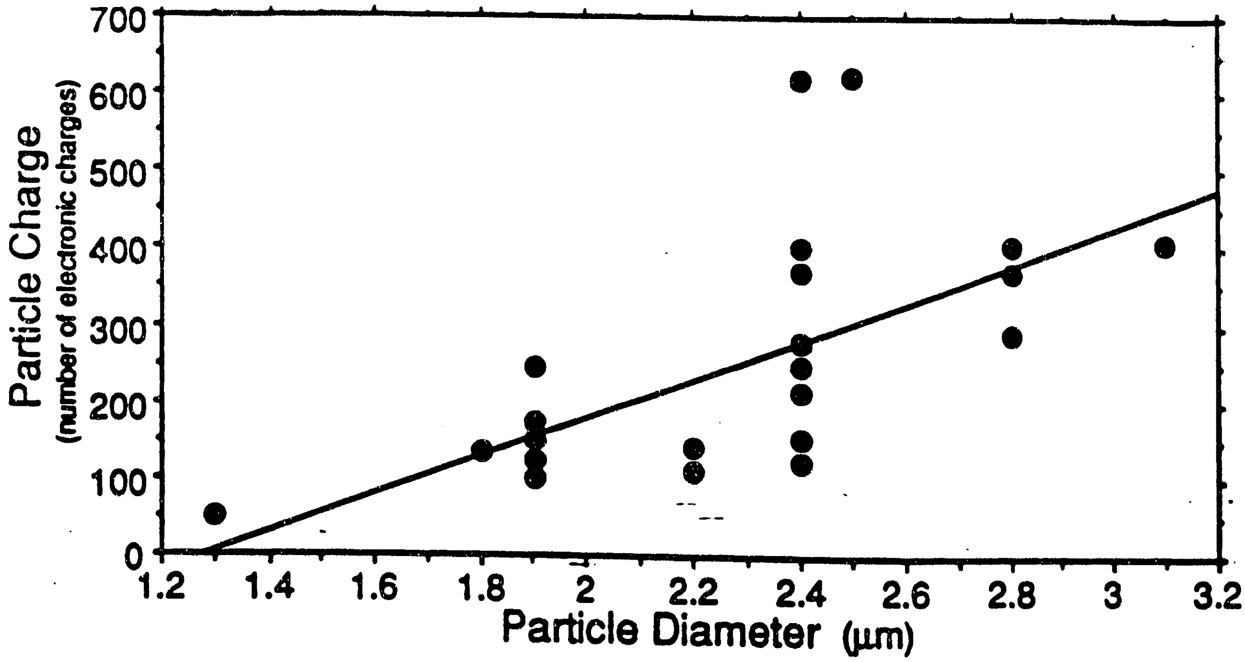

Fig. 1 Charge-vs-diameter measurements for the case of both the precharger electron beam and precharger electric field turned off. The measured charge observed results from frictional charging in the fluidized bed particle feeder and in the gas stream. The closed circles are data points for composite hydral particles. Although the particles are monodisperse with a diameter of approximately 1μ, composite particles are formed in the gas stream due to clumping. The straight line is a best fit for the data, and serves mainly as a guide to the eye. In this figure and the those that follow, the scatter in the data points is not due to experimental error, but is due to the statistical nature of the charging process. Averaging the charge of the particles found at each diameter eliminates much of the scatter, but the present form is preferred because it exhibits the maximum amount of information.

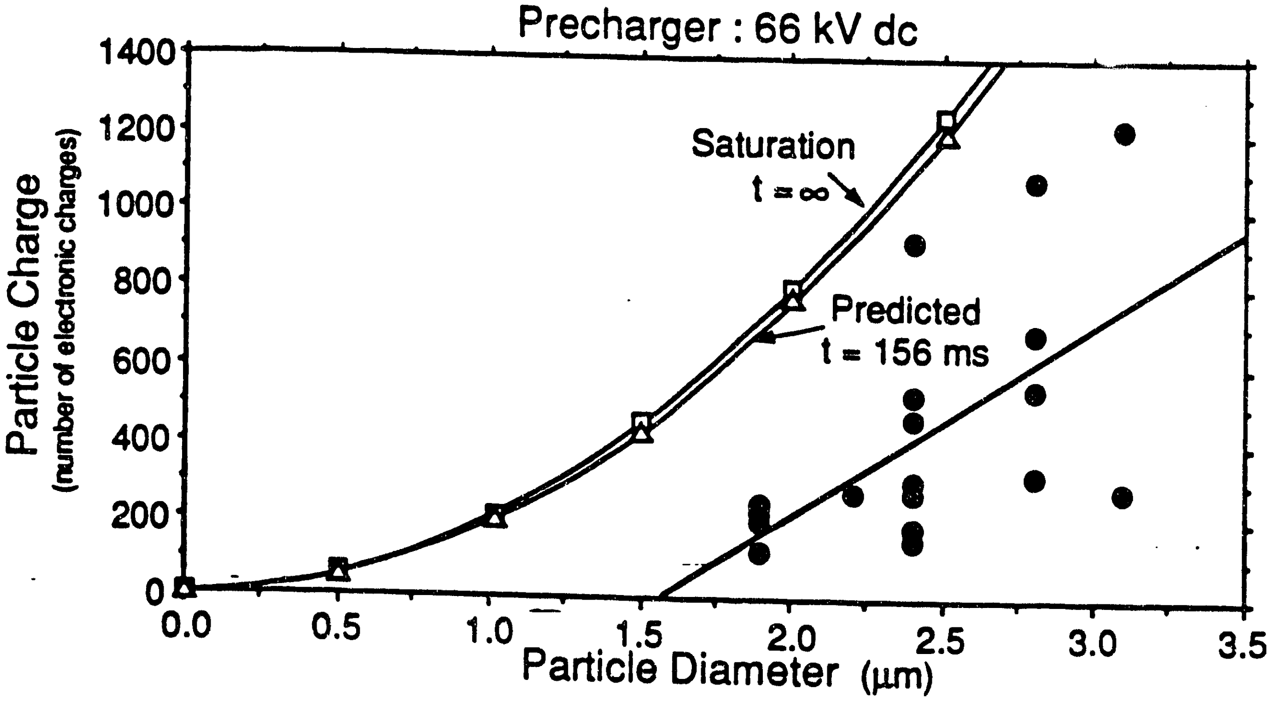

Fig. 2. Charge-vs-diameter measurements for the case of the precharger operating with a potential of 66 kV dc applied between the anode and cathode. The solid points are the experimental points for individual composite Hydral particles. See the caption of Figure 1 for an explanation of the scatter. The time required for an element of the gas stream to be transported through the precharger is 156 ms. The reason the experimental values fall below the theoretical curve is probably due to the fact that the theoretical model fails to take into account the reduction of electric field in the charging region due to space charge. The straight line fitted to the data is intended only as a guide to the eye.

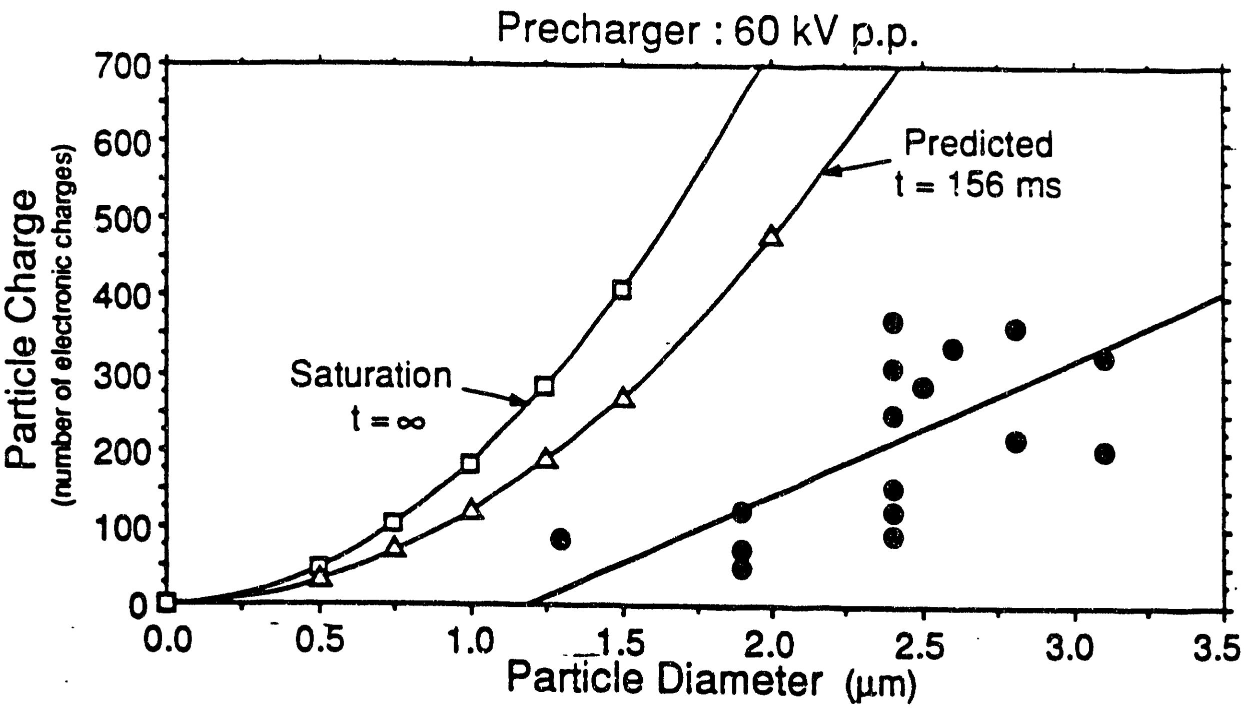

Fig. 3 Charge-vs-diameter measurements for the case of the precharger operating with 60 kV positive pulses applied between the anode and cathode. The temporal length of each pulse is approximately 200 ns. The closed circles are the experimental points. See the caption of Figure 1 for an explanation of the scatter. The straight line fitted to the data is intended only as a guide to the eye. The theoretical curves shown do not apply to the pulsed case but are rather for dc charging; they are shown merely for reference.. A theory of the pulsed case has not yet been formulated.

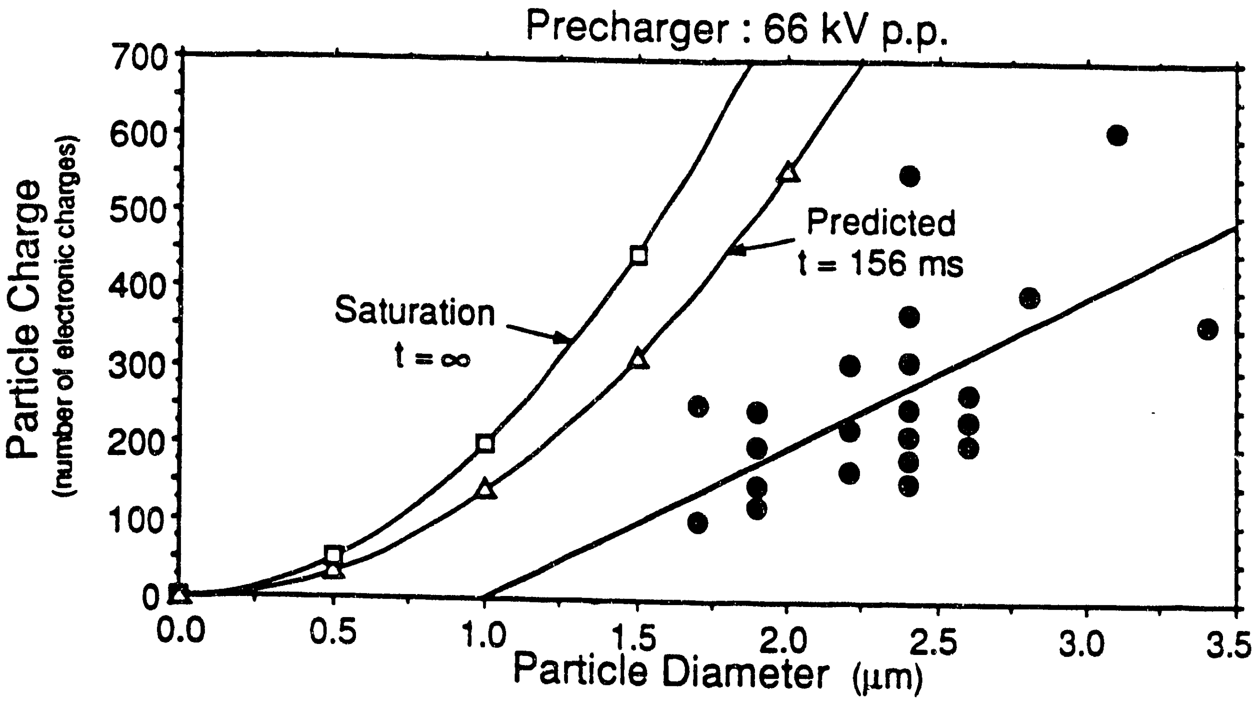

Fig. 4 Same as Figure 3 except that 66 kV anode pulses are employed.

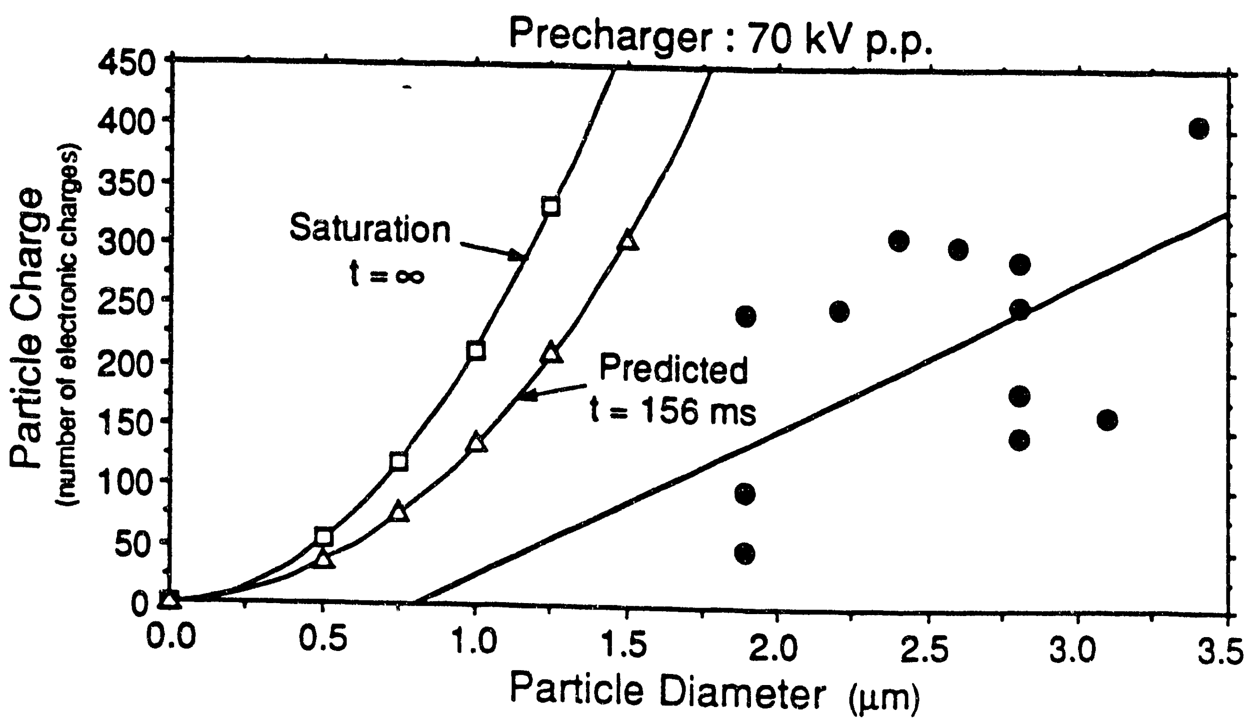

Fig. 5. Same as Figure 3 except that 70 kV anode pulses are employed.

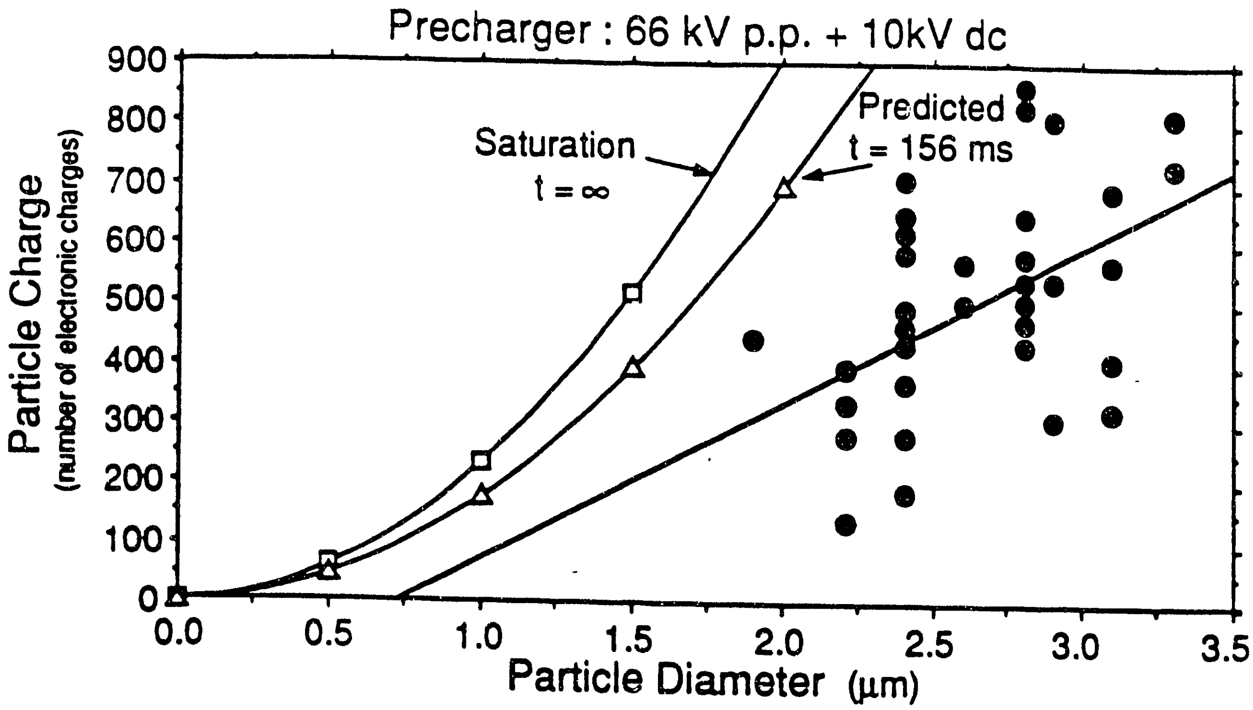

Fig. 6 Charge-vs-diameter measurements for the case of the precharger operating with 66 kV positive pulses and 10 kV positive dc bias applied between the precharger anode and cathode. The duration of each pulse was approximately 200 ns, and the repetition rate was 60-Hz. The closed circles are the experimental points. See the caption of Figure 1 for an explanation of the scatter. The straight line fitted to the data is intended only as a guide to the eye. The theoretical curves shown (squares and triangles) do not apply to the pulsed-plus-dc-bias case but are rather for dc charging; they are shown merely for reference. A detailed microscopic theory of the pulsed-plus-dc-bias case at overvoltage has not yet been formulated.

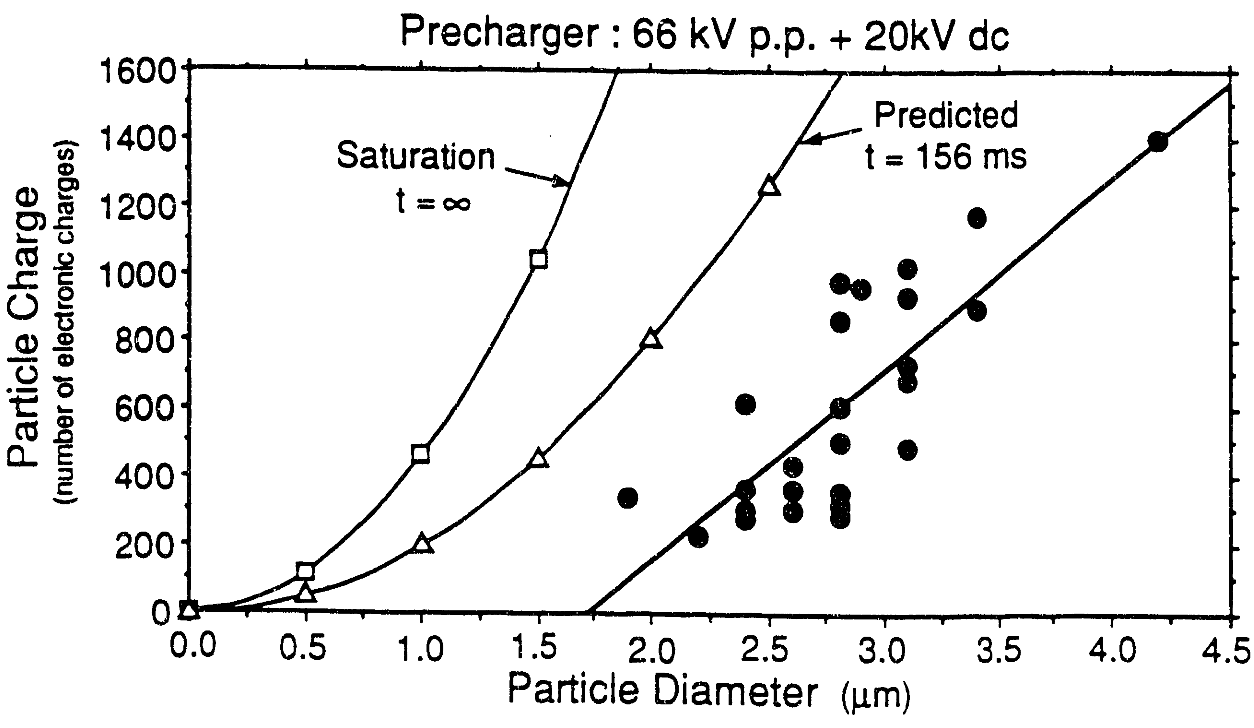

Fig. 7 Same as Figure 6 except that the dc bias is 20 kV.

monodisperse, that is to say all the particles have approximately the same diameter ($1.0 \pm 0.5\mu$).
The fact that particles of various diameters are found in the measurements results from the situation where two or more Hydral particles clump together to form a composite particle of a greater effective diameter. Note that these diameters are "quantized" as a result of clumping, that is to say particles are found only at certain distinct effective diameters.

Figure 2 gives the charge vs. particle diameter measurements for the situation of the precharger operated at 66 kV dc and the collector energized. This is the situation which was found to produce the most efficient dc precharging in the previous contract research, and the present results are consistent with those obtained in that earlier work.

Figures 3, 4, and 5 give the charge vs. particle diameter measurements for purely pulsed operation of the precharger anode with no applied dc bias; the peak voltages of the pulses are 60 kV, 66 kV and 70 kV, respectively. Comparing the 66 kV pulsed run of Figure 4 with the 66 kV dc run of Figure 2 shows that particle charging in the pulsed case is slightly greater that one-half that obtained in the dc case. This may seem strange in light of the collection efficiency data listed in Table I for the collection of Hydral in the two cases. The collection efficiency for the anode operated at 66 kV dc is 99.3% while for a 66 kV pulsed anode it is only 53.5% . The difference in collection efficiency is much greater than that which should be expected from the above comparison of the the charging data. There is a simple explanation, however. The charge-to-radius apparatus does not measure the *sign* of the charge on the aerosol particles. Since the electrostatic collector is operated in a polarity appropriate to the collection of negatively charged particles, it can be immediately seen that purely pulsed operation of the precharger is not producing monopolar charging of the aerosol particles. A collector appropriate to the collection of particles having mixed charge polarities would be one with parallel plates oppositely charged.

Given the proper collector having a small ion current for particle retention, it may be true that pure pulsing of the anode is a useful way to operate the precharger. Only the wire-to-plate geometry has been used in the present electrostatic collector (plates positively charged), and it was found that pure pulsing (with no dc bias) is not a useful mode in which to operate the electron beam precharger in conjunction with a collector of this type.

Figures 6 and 7 give the charge-to-diameter measurements in the case of a pulsed anode with a dc bias. Figure 6 shows the data for the case of 10 kV dc anode bias while Figure 7 gives the data for 20 kV dc anode bias. The pulsed voltage is 66 kV in each case. When allowance is made for the different scales of the plots, it is seen that 66 kV dc operation of the anode (Figure 2) gives approximately the same charging as is obtained with a 20 kV dc bias along with 66 kV pulsing (Figure 7) on the anode. However, much lower power consumption results from using 66 kV pulsed power with a 20 kV dc bias compared to 66 kV dc, for the same approximate collection efficiency. Pulsing the precharger anode gives an economic advantage over normal dc precharging. Reduction of the dc bias to 10 kV gives reduced charging (Figure 6) and thus lower collection efficiency (Table I).

We emphasize again that the best collection efficiency results were obtained with 66 kV pulsed power along with 20 kV dc bias on the anode, and point out that the power consumption is greatly reduced in comparison with the use of pure dc power in the precharger. Operation of the precharger with only 20 kV dc bias eliminates sparking and makes for a more stable operation. These matters will be discussed further in the next Technical Progress Report (TPR-9).

V. COMPUTATION OF THE COLLECTION EFFICIENCY AND IMPROVEMENT FACTOR

Table III gives a sample calculation of collection efficiency and improvement factor for two different dc potentials applied to the precharger anode. The improvement factor measures the reduction of the amount of particulate material emitted into the atmosphere when the precharger is employed on an open-flue system. In the case of pulsed experiments, the particle count would be replaced by the mass of material collected on a filter; the calculation is otherwise the same.

VI. CONCLUSION

Pulsing the anode electrode of an electron beam precharger gives excellent collection efficiency results provided that a small dc bias of approximately 20 kV is maintained on the anode. Power consumption is reduced and a more stable operation is obtained in this mode. Anodic pulsing without a dc bias is not a useful mode in which to operate the precharger while using a collector with the present wire-plate geometry collector.

Table III. Example calculations of the collection efficiency (A), and precharger efficiency improvement factor (B). The improvement factor is designated by the symbol α.

A. Collection Efficiency Calculation

Hydral Dust Only......................Average Count = 2,270,500

Hydral, Collector On...................Average Count = 315,000
(Precharger Off)

Particles, Collector On
Precharger = 55 kV.................Recorded Count = 38,200
Precharger = 66 kV.................Recorded Count = 30,400

Collector-Alone Penetration	=	13.87%
Collector-Alone Efficiency	=	86.13%
Precharger-Collector Penetration		
Precharger = 55 kV	=	1.682 %
Precharger = 66 kV	=	1.339 %
Precharger-Collector Efficiency		
Precharger = 55 kV	=	98.32 %
Precharger = 66 kV	=	98.66 %

B. Precharger Efficiency Improvement Factor (α)

$$\alpha = \frac{\text{Collector Penetration}}{\text{Precharger - Collector Penetration}}$$

For Precharger at 55 kV,

$$\alpha = \frac{13.87\%}{1.682\%} = 8.246$$

For Precharger at 66 kV,

$$\alpha = \frac{13.87\%}{1.339\%} = 10.36$$

Therefore, at 66 kV precharger voltage, the Electron Beam Precharger generates more than a 10-fold increase in overall system collection efficiency.

VII. PERSONNEL

A. Scientific Investigators

1. Dr. W. Neil Shelton — Principal Investigator
2. Mr. Wright C. Finney — Associate in Research

B. Undergraduate Student Assistants

1. Chris Oswald
2. Misho Sarwar
3. John Blair

C. Part Time Secretaries

1. Nancy Lochner
2. Amy Maxey
3. Natalie Duguid

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