Southern Research Institute

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August 27, 1979

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Dr. J. P. Subramani
Florida Department of Environmental Regulation
2600 Blair Stone Road
Tallahassee, Florida 32301

Dear Dr. Subramani:

Enclosed please find a draft copy of a proposed EPRI-sponsored sampling plan for the Gannon Plant of Tampa Electric Company. It is my understanding that this plan has been described to Mr. W. E. Starnes of your office by Dr. Ralph Altman, who is the EPRI Project Officer for this project.

Southern Research Institute will be prepared to discuss the enclosed plan and the overall goal of the flue gas conditioning project during the meeting scheduled for 10:00 AM on Friday, August 31, at the Florida D.E.R. offices in the Twin Towers Office Building in Tallahassee. The Institute will be represented by Mr. Grady B. Nichols, who is Associate Director of our Engineering and Applied Sciences Department, and myself, and EPRI will be represented by Dr. Altman.

We appreciate your consideration of this project, and please call if you have any questions.

Very truly yours,

Edward B. Dismukes for
John P. Gooch, Head
Control Device Research Division

JPG:mm

Enclosure

cc: Dr. S. K. Nayak

8-30-79

A TEST PLAN FOR THE GAS-CONDITIONED ELECTROSTATIC PRECIPITATOR SYSTEM AT THE GANNON STATION OF TAMPA ELECTRIC COMPANY

Prepared by
SOUTHERN RESEARCH INSTITUTE
for the
ELECTRIC POWER RESEARCH INSTITUTE
Under EPRI Contract
RP724-2

DRAFT

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I. INTRODUCTION

This test plan has been prepared as part of a research project sponsored by the Electric Power Research Institute concerning the use of flue gas conditioning agents to enhance electrostatic precipitator performance. The research program has two overall objectives:

1) Gather sufficiently detailed performance data on flue gas conditioning agents to allow determination of the mechanisms through which the conditioning agents alter the collection process in an electrostatic precipitator.
2) Prepare a definitive guideline document which discusses all of the conditioning agents that are now commonly used in the utility industry. The document is intended to provide a basis for selecting conditioning agents for various circumstances.

Protection of the environment is one of the major concerns of the electric utility industry. Increasingly stringent particulate emission limitations have caused the cost of control devices to rise and have resulted in higher energy cost. Limitations on SO_x emissions have also complicated the particulate control problem. Frequently a utility company will choose to burn coal with a low sulfur content in order to meet SO_x emission limitations, but low sulfur coals generally produce an ash that is difficult to collect in standard electrostatic precipitators.

Only a limited number of approaches are presently available to solve the particulate emissions problem. The most prominent solutions include:

1) Operating the unit at reduced load.

2) Adding collection area to the electrostatic precipitator.

3) Adding a second control device such as a scrubber or bag filter.

4) Chemically conditioning the flue gases to improve the performance of the electrostatic precipitator.

Economic analysis of the available options usually indicates that flue gas conditioning is the most cost effective method to improve particulate collection efficiency in an existing precipitator, and conditioning systems are now in operation in more than 100 plants in this country. However, flue gas conditioning has produced variable, and sometimes disappointing results, and a better understanding of the phenomena involved is of prime importance to the utility industry. Therefore, the Electric Power Research Institute is initiating this project to investigate all of the important aspects of flue gas conditioning and to produce a definitive guideline document for the use of conditioning agents by the utility industry.

A reasonable understanding of the effects of some conditioning agents already exist. Sulfur trioxide and sulfuric acid conditioning systems have been studied in the laboratory as well as in actual field installations. Systems that use sodium compounds as the conditioning agent have also been studied, but additional work on this subject may be required. Another important group of conditioning agents includes ammonia and ammonia related compounds, and a satisfactory understanding of how these chemicals act as conditioning agents does not now exist.

In this research project, ammonia and related compounds will be studied both in the laboratory and full scale flue gas conditioning applications such as the one addressed in this test plan. The emphasis in the research project is to determine the mechanisms through which these compounds alter the collection process, and thereby provide a basis for predicting the effects of the conditioning agents under various circumstances. It is anticipated that the results of the work will improve the capability of the electric utility industry for complying with particulate control standards.

The Gannon Station of Tampa Electric Company was chosen as a test site under this project because the unit has had considerable successful operating experience using a proprietary conditioning agent which contains ammonium sulfate as its principal ingredient. Ammonium sulfate is of particular interest as a conditioning agent because it is relatively inexpensive and easy to handle, and can influence electrostatic precipitator operation through three different mechanisms: resistivity modification, particulate space-charge enhancement of the collecting electric field, and reduction of re-entrainment emissions through changing the cohesiveness of the fly ash.

In order to properly evaluate the mechanisms through which the conditioning agent is influencing the performance of the precipitator, it will be necessary to conduct two comprehensive test series: one of which is performed without the use of a conditioning agent (a baseline test series), and the other of which is performed with the agent in use at the dosage rate which has been successfully employed in the past. The baseline test is required in order to quantify the beneficial effects of the conditioning agent. Both test series should be conducted with the unit operating at a full load condition. The baseline test series may require several days for an equilibrium condition to be reached in the precipitator without the agent in use, and an additional two week period will be required for the actual performance testing of the precipitator without the agent. Therefore, it is necessary to request approval for a three or four week operating period without the use of a conditioning agent. Two weeks of this four week period could be with load conditions as dictated by demand, but the remaining two week period would require full load conditions during the daylight hours when tests are being conducted. During this interval, particulate emissions in excess of those normally experienced with the agent in use are expected.

Tampa Electric Company has reported that the electrostatic precipitator performance continually degrades without the use of the conditioning agent to the point that TR sets must be disconnected due to wire failures and wire deposits which apparently result from excessive sparking. If it is found that the precipitator cannot be operated at low power levels in a steady state condition, the baseline test plan will be changed to emphasize measurements on the particulate and flue gas entering the precipitator by sampling upstream of the injection nozzles or by periodic discontinuation of the agent injection.

The "with agent" test period will require permission to de-energize one transformer rectifier set at a time on the precipitator to obtain secondary voltage current relationships following the completion of each daily test period. These data taking exercises should require no more than one hour per day, and are expected to be the only time periods during the "with agent" test sequence that particulate emissions are increased over those normally experienced. The following sections describe the measurements which will be performed during the test program and the supporting laboratory work which will be performed in association with the field work.

An example overall schedule for either the with or without agent test series and the activities which are scheduled to occur at the two principal sampling locations are detailed in Table 1.

Some modifications of this sampling plan may be required to be consistent with the requirements of the Gannon Plant. Specifically, the baseline test program may be altered as previously mentioned, and secondly, it is desirable to include studies of agent injection before and after the air heater on Unit 6. This will aid in an examination of the causes of air heater pluggage, which sometimes occurs with ammonium sulfate injection upstream of the air preheater. A revised overall sampling plan will be prepared when the requirements have been identified.

TABLE 1. Example Sampling Plan

Sampling Location	Measurements	1	2	3	4	5	6	7	8	9	10	11	12	13
ESP Inlet														
	Impactor	TRAVEL	SET UP EQUIPMENT		X		X	OFF		X				PACK AND TRAVEL
	Mass Train			X		X			X		X	X	X	
	Resistivity			X	X	X	X		X	X	X	X	X	
	Ion Mobility			X	X	X	X							
	Ultrafine Sizing			X	X	X	X							
	SO_x, NH_3, NO_x			X	X	X	X		X					
Stack Location														
	Impactor				X		X			X				
	Mass Train			X		X			X		X	X	X	
	Ultrafine Sizing			X	X	X	X							
	SO_x, NH_3, NO_x									X	X	X	X	

II. FIELD SAMPLING PLAN

As previously indicated, the field sampling plan for the study of conditioning agent mechanisms comprises two comprehensive performance test series: a "baseline" test series and a "with agent" test series. Each test series includes the following items:

1) Measurement of the overall collection efficiency of the precipitator with and without collection electrode rapping.
2) Measurement of the collection efficiency of the precipitator as a function of particle size.
3) Measurement of the <u>in situ</u> electrical resistivity of the fly ash under going collection.
4) Determination of the electrical characteristics of the flue gas with an ion mobility apparatus.
5) Determination of sub-micron particle concentrations at the precipitator inlet and outlet using an ultrafine sizing system.
6) Chemical analysis of the flue gas.
7) Chemical analysis of coal, fly ash, and conditioning agent samples.
8) Collection of pertinent boiler operating parameters.
9) Determination of the voltage current characteristics of the precipitator power supplies.
10) Recording the electrical operating points of the precipitator power supplies during the test period.
11) Recording outlet opacity from the in-stack transmissometer.

III. CONTRACTOR-UTILITY INTERFACES

A. Responsible Personnel

A field sampling crew will be under the supervision of Mr. G. H. (Wim) Marchant, Jr., Head of the Control Device Evaluation Section at Southern Research Institute. Mr. Marchant will be responsible for co-ordinating the test program activities with Tampa Electric Company. Tampa Electric will be provided with a list of Institute personnel who are on site for the test program, the approximate daily schedule for these personnel to be on site, and the approximate number of personnel to be located at each of the major sampling locations.

Overall co-ordination of the project between EPRI and Tampa Electric will be handled by Dr. John Gooch, the project manager at Southern Research Institute, and Dr. Ralph Altman, the project manager for EPRI.

B. Support Requirements for the Test Program

The support required for the test program from Tampa Electric includes electrical power at the sampling locations, maintenance of constant full-load conditions during the test period, designation of a liason personnel, and assistance in obtaining coal and ash samples periodically. A request has also been made to have additional sampling ports and injection ports installed at the precipitator inlet on Unit 6. These requirements have been detailed in a letter to Mr. Jim Hudson. The cleaning of all inlet and stack location sampling ports prior to the test program is also requested. The assistance of an electrician will be needed for a short time period to install voltage divider assemblies in selected TR sets. The power requirements are detailed in Table 2. An area of approximately 40 ft x 12 ft is required for the mobile laboratory listed in Table 2.

An important aspect of this research project is an engineering analysis of the gas-conditioned electrostatic precipitator system. This analysis will include:

1) A system description that will concentrate on the electrostatic precipitator and the gas conditioning system.
2) A capital cost estimate for the ESP system and conditioning system and an equivalent ESP system without gas conditioning.
3) An operating cost estimate for the same items listed above.
4) A study of the maintenance requirements of the precipitator with and without gas conditioning.

Table 3 gives a detailed description of the items which will be requested from plant personnel to enable the engineering analysis to be completed. This portion of the project will be performed by Stearns-Roger, Inc., under sub-contract to Southern Research Institute. The project engineer assigned to this task is Mr. Bob Pearson of Stearns-Roger.

TABLE 2

DETAIL OF POWER REQUIREMENTS
(All 115 Volts)

Location	Number of Circuits	Amperage/ Circuit	Total Amperage Required, Amps
Precipitator Inlet	6	20	120
Stack	7	20	140
Mobile Laboratory	2	30	60

TABLE 3

ENGINEERING ANALYSIS REQUIREMENTS

GANNON STATION - UNIT 6

1. SYSTEM DESCRIPTION

   A. Gannon Station - Unit 6

   B. Precipitator System

   C. Fly Ash System

   D. Gas Conditioning System

   E. Drawings - Flowsheets, General Arrangements, Plan & Elevation, Equipment

   F. Major Construction Specifications and Data on Boiler, Precipitator, Fly Ash Handling, and Gas Conditioning

   G. Data on Electrical Systems, Rapping System, Control System, and Monitoring System

   H. Start-up and Shutdown Procedures

2. CAPITAL COST

   A. Precipitator and Duct System - Equipment and Duct Field Cost

   B. Fly Ash Handling System - Equipment and Duct Field Cost

   C. Gas Conditioning System - Equipment and Duct Field Cost

   D. Indirect Field Cost - Field Supervision, OH, Constructors Fees

   E. Miscellaneous - Insurance, Interest, Land etc. if available

   F. Cost of Precipitator w/o Gas Conditioning

TABLE 3. (Cont'd.)

3. OPERATING AND MAINTENANCE

   A. Personnel - Numbers, Title, Duties

   B. Time Spent and Payrate

   C. Operating Procedure

   D. Maintenance Procedure

   E. Supervisory Costs

   F. Maintenance Supplies

   G. Maintenance Budget

   H. Contract Maintenance

   I. Gas Conditioning Chemical Cost

4. UTILITIES

   A. Electric Power - Motors - HP, Percentage of Time in Operation

      T-R Sets - Power Used, Percentage of Time in Operation

   B. Cost of Power - Produced

      Sold

      Purchased

5. MAINTENANCE

   A. Records Concerned with Precipitators, Fly Ash, and Gas Conditioning

   B. Preventative Maintenance Program

   C. Specific Maintenance Areas

      Wires & Plates

      T-R Sets

      Interlock System

      Instrumentation & Controls

TABLE 3. (Cont'd.)

Ash Handling

Gas Conditioning

6. RELIABILITY

   A. Boiler downtime or reduced load due to problems with precipitator, fly ash, or gas conditioning systems

   B. Individual T-R set downtime

   C. Problems contributing to individual T-R set downtime

7. PERFORMANCE

   The ability of the precipitator to meet design specification when in operation.

   A. Test data from acceptance tests

   B. Before/After Gas Conditioning Data

8. MODIFICATIONS[1] & RECOMMENDATIONS

   A. Problems and implemented solutions

   B. Problems and suggested solutions

   C. Problems without present solutions

[1] These modifications are meant to reduce operating cost, maintenance effort, future repairs, and increase reliability in the Gannon Station or future stations using precipitators with gas conditioning.

IV. SUPPORTING LABORATORY STUDIES

The supporting laboratory work which will be performed in association with the field test at the Gannon Plant includes the following items:

1) A review of thermodynamic data applicable to the conditioning agent (ammonium sulfate) and flue gas constituents which may react with ammonium sulfate at various temperatures.

2) Additional chemical analyses as required.

3) Laboratory resistivity studies.

4) Analysis of the precipitator performance using a theoretical model of the electrostatic precipitation process.

Ash specimens collected from the Gannon Plant precipitator hopper will be proportionately blended and will then be characterized by helium pycnometer density, Bahco particle size distribution, chemical analyses, and a standard resistivity temperature test. In addition to the above characterization tests, the following resistivity determinations will be made in a laboratory:

(a) Using simulated _in situ_ conditions.

(b) Using a standard set of conditions at 145°C and 350°C.

(c) Using the conditions of (b) and two concentration levels of each of the following conditioning agents: sulfur trioxide, sodium carbonate, triethylamine, ammonium sulfate, and the proprietary compound used during the test series.

(d) Same as (c) except conditioning agents employed in pairs as might be suggested by the preceding experiments. Also the ashes obtained during the field test will be tested in the laboratory using simulated in situ conditions and the type and concentration of conditioning agent (in this case, ammonium sulfate) employed in the field test.

Several chemical transference tests will be conducted in an attempt to gain an improved understanding of the increased electrical conduction due to the injection of the conditioning agent.

The laboratory resistivity data will be acquired using equipment and techniques illustrated and described in recent reports.[1,2] In addition to the above laboratory work, the field data may indicate the desirability of performing decomposition studies as a function of temperature and residence time for the conditioning agent employed at the Gannon Plant. A specific plan for these studies will be devised at a later date if they are required.

V. REPORTING

A detailed site specific report will be prepared following the completion of the with and without conditioning agent test series and the analysis of the data. This report will contain both laboratory and field results together with an analysis of the results. As indicated previously, precipitator performance with and without conditioning agent will be analyzed using a theoretical model. The audience to which this report will be directed will be primarily the technical staffs of engineering firms, equipment vendors, regulatory authorities, and utilities. The report will be prepared in draft form and submitted to EPRI and Tampa Electric Company for review prior to release.

VI. TEST METHODS

A. Fractional Efficiency Measurements with Cascade Impactors

It has been established by both theoretical calculations and experimental measurements that the collection efficiency of particulate matter in an electrostatic precipitator is a function of particle diameter. The complete characterization of precipitator performance therefore necessarily includes particle size distribution measurements at the inlet and at the exit of the control device. Inertial impactors are commonly used to perform such measurements because they are sufficiently rugged and compact for *in situ* sampling, and traversing the process stream is a practical operation. *In situ* sampling is preferred since the complete size distribution may be seriously distorted if a probe is used for sample extraction.

The mechanism by which a cascade impactor classifies particulate is illustrated in Figure 1. In each stage of an impactor, the gas stream passes through an orifice and forms a jet which is directed toward an impaction plate. For each stage there is a characteristic particle diameter which has a 50% probability of impaction. This characteristic diameter is referred to as the D50 of the stage. The schematic diagram in Figure 1 shows a single get for illustrative purposes, but commercial impactors may have from one to several hundred jets in a stage. Typical impactors consist of from five to ten stages. Particle collection efficiency of a given impactor jet plate combination is determined by factors such as particle shape and density, viscosity of the gas, and by the design of the impactor stage. The type of collection surface (glass fiber,

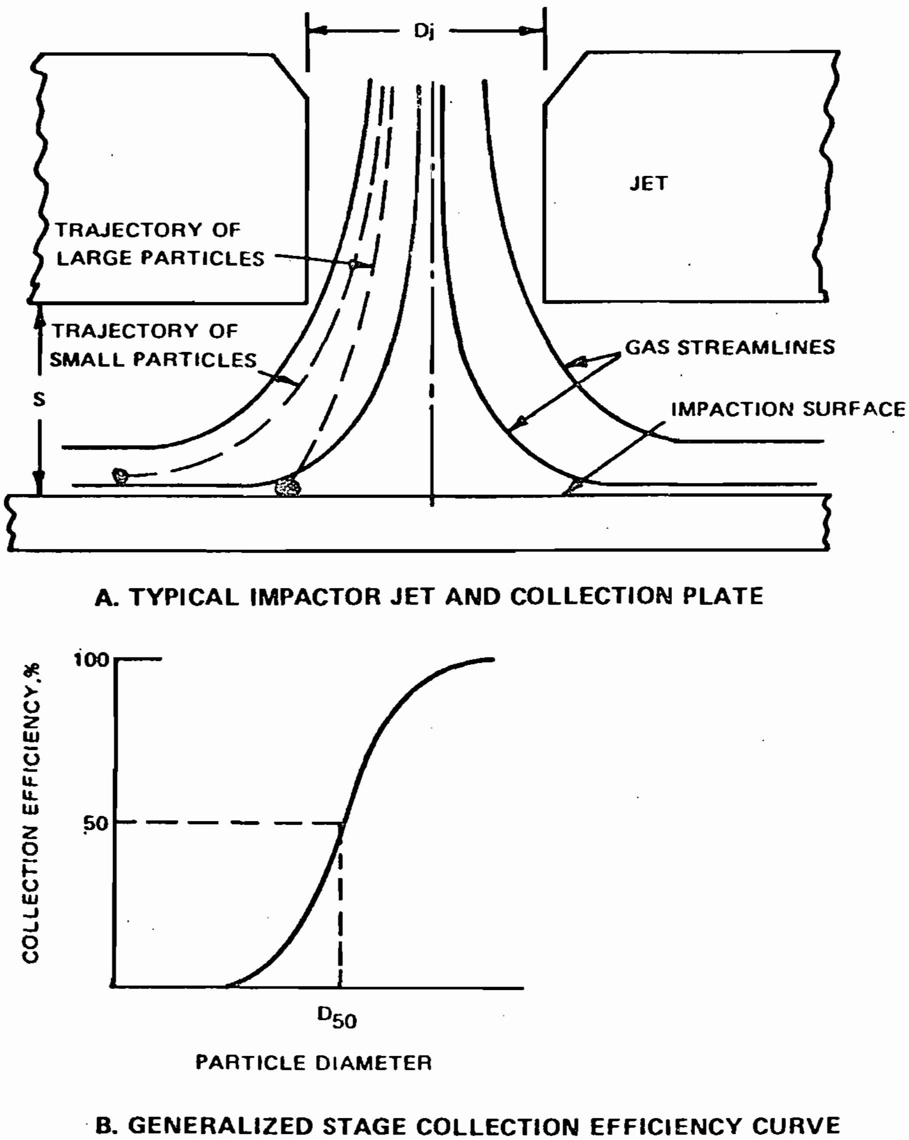

Figure 1. Operation principle and typical performance for a cascade impactor.

grease, metal, etc.) will also influence stage collection characteristics.

Selection of the proper impactor for a given test situation is primarily dependant upon the mass loading of the gas stream and its effect on sampling time. There are three major criteria to be met in the selection process:

1) The sampling period must be of sufficient duration to provide a reasonable averaging of transient conditions in the stack.
2) The loading of a given impactor stage must be sufficiently low to prevent reentrainment.
3) The sampling rate through the impactor must be sufficiently low to prevent scouring of impacted particles by high gas velocities.

For these reasons an impactor with a comparatively low sample rate must be used in a gas stream with a high mass loading. Conversely, in a low mass loading situation such as a control device outlet, a high sampling rate device must be used if a significant amount of mass is to be gathered in a reasonable amount of time. A cascade impactor can normally yield useful information over a range of sample rates differing by a factor of two or three. Since high efficiency control devices will cause the outlet mass loading to differ from the inlet by factors of 10 to 100, both high and low flow rate impactors are usually required for control device characterization. The test plan for the electrostatic precipitator installed at the Corette Station is based on the use of modified Brink impactors for the inlet and University of Washington impactors for the outlet. Typical flow rates for these instruments are 0.025 acfm and 0.5 acfm, respectively.

The impactor stages are generally too heavy for the tare capacity for field usable precision balances. For this reason, the particles are captured on substrates which are low in mass, such as metal foils or glass fibers. For glassy material such as coal fly ash, metal foils must be covered with grease to reduce reentrainment due to particle bounce. Since most greases tend to evaporate at flue gas temperatures, care must be taken to insure that the grease chosen for coating the substrate does not cause anomalous size distribution data as a result of volatilization. Grease substrate coating procedures have been developed and successfully employed at temperatures of 150°C. "Blank" runs will be conducted, which consist of an impactor preceded by a filter sampling flue gas at the same conditions as the "real" runs, to monitor the performance of the substrate coatings which are employed in the field study.

Following sampling and determination of stage weights, data reduction procedures as outlined below will be followed:

1) Stage weights are corrected for "blank" weight gains.
2) Cut points for the individual stages for each impactor are calculated based on calibration studies conducted in the laboratory using polystyrene latex beads for sizes smaller than 2.0 μm diameter and ammonium fluorescein

particles for particle diameters from 2 to 8 μm diameter.

3) Impactor runs are arranged in groups in an appropriate manner for the test program

4) The data are then used as input to a computer program which calculates the size distribution and the efficiency of the precipitator as a function of particle size.[3]

Size disbribution data from the test program will be given on both a differential and a cumulative basis for the inlet and outlet sampling locations, and efficiency of the precipitator as a function of particle diameter will be calculated and plotted with 50% confidence intervals for both the with and without conditioning agent test series.

These measurements are expected to provide the following information with respect to conditioning agent mechanisms:

1) Comparison of the with and without conditioning agent data sets at the precipitator inlet should indicate whether the conditioning agent caused a significant change in the particle size distribution for sizes larger than approximately 0.5 micrometers in diameter.

2) Comparisons of the outlet size distribution, as determined with the impactors, for the with and without agent test series, with each other and with the theoretical projection for each test condition, should enable a determination of the influence of the conditioning agent on primary particle collection in the precipitator

and on emissions caused by non-ideal conditions such as reentrainment from electrode rapping.

B. Measurement of Ultrafine Particle Concentration

There are two physical properties of ultrafine particles (diameter less than 0.5 micrometers) which are size dependent and which can be predicted with sufficient accuracy under controlled conditions to be used to measure particle size. These are the particle diffusivity and electrical mobility. Although ultrafine particle size distribution measurements are still in the developmental stage, instruments are available which can be used for this purpose, and some field measurements have been made. A practical limitation on the lower size limit for this type of measurement is the loss of particles due to diffusion in the sampling lines of the instrumentation. These loses are excessive for particle sizes less than about 0.01 micrometers where the samples are extracted from a duct and diluted to concentrations within the capability of the sensing devices.

Diffusional Sizing

Diffusion batteries may consist of a number of long narrow parallel channels, a cluster of small bore tubes, or a series of screens. The parallel plate geometry is convenient because of the ease of fabrication and the availability of suitable materials, and also because sedimentation can be ignored if the slots are vertical, while additional information can be gained through settling, if the slots are horizontal.

Breslin, (1971)[4] and Sinclair, (1972)[5] report success with more compact tube-type and screen-type arrangements in laboratory studies and a commercial version of Sinclair's Geometry is available.[5] Although the screen type diffussion battery must be calibrated empirically, it offers convenience in cleaning, operation, and compact size. This battery is 21 cm long, approximately 4 cm in diameter, and weighs approximately 0.9 kg.

Variations in the length and number of channels (tubes or screens) and in the aerosol flow rate are used as a means of measuring the number of particles in a selected size range. As the aerosol moves in streamline flow through the channel, the particles diffuse to the walls at a predictable rate, depending on the particle size and diffusion battery geometry. It is assumed that every particle which reaches the battery wall will adhere; therefore, only a fraction of the influent particles will appear in the effluent from the battery. It is only necessary to measure the total number concentration of particles with a condensation nuclei counter at the inlet and outlet to the diffusion battery under a number of conditions in order to calculate the particle size distribution.

Diffusional measurements are less dependent upon the aerosol parameters than the other techniques discussed and perhaps are on a firmer basis from a theoretical standpoint. The disadvantages of the diffusional technique are the bulk of the parallel plate diffusion batteries, although some advanced technology may alleviate this problem, the long time required to measure a size distribution, and the problems with sample conditioning when condensable vapors are present.

Electrical Particle Counters

The most complete set of experiments performed in order to determine the relationship between particle size and charge were reported by Hewitt, (1957).[6] These experiments confirmed theoretical predictions that there exists a unique charging rate for each particle size if the charging region is homogenous with respect to space charge density and electric field.

In the course of his work, Hewitt developed a mobility analyzer, shown in Figure 2. Charged particles enter through the narrow annular passage "A", and experience a radial force toward the central cylinder due to the applied field. By moving the sampling groove "B", axially, or by varying the magnitude of the applied field, the mobility of the charged particles can be measured. In Hewitt's experimental work, the particle size was known, and the mobility would determine the charge. If however, the particle charge were known, the mobility would determine the particle size. This concept has been used by Liu, Whitby, and Piu[7] at the University of Minnesota to develop a series of electrical aerosol analyzers. A ruggedized field test unit based on the earlier University of Minnesota designs is now commercially available.[8] A schematic of this system is shown in Figure 3.

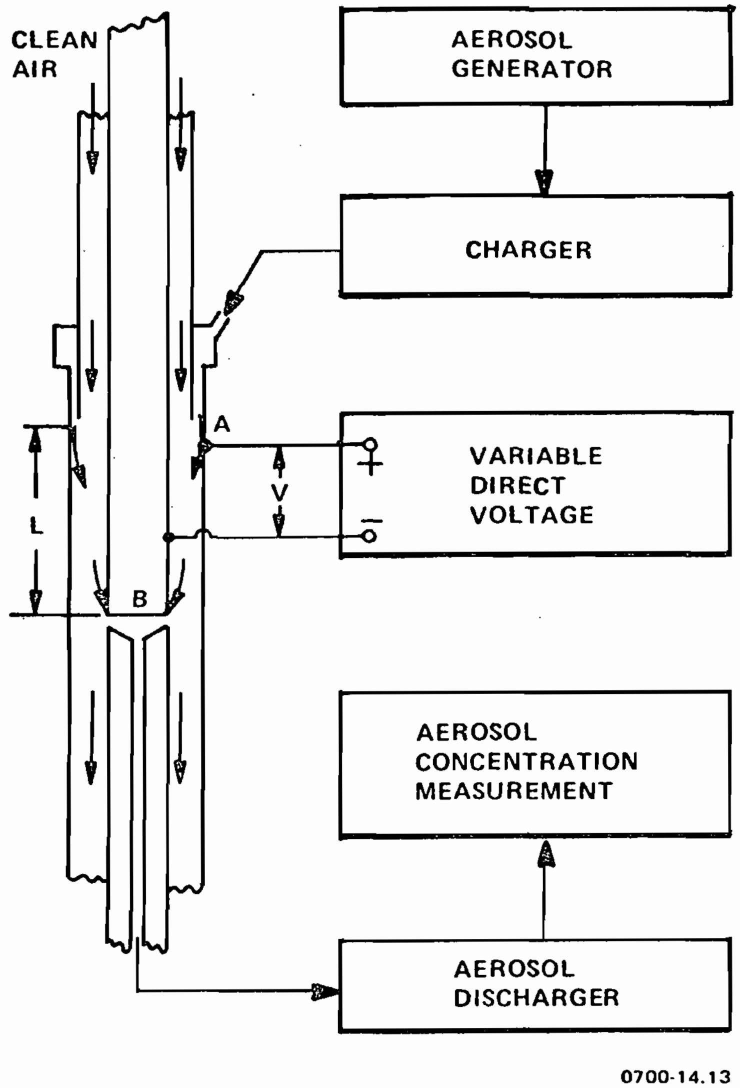

Figure 2. Coaxial cylinder mobility analyzer. Charged aerosol enters at A. Sampling groove is at B in inner cylinder, which is adjusted axially. After Hewitt (1957).

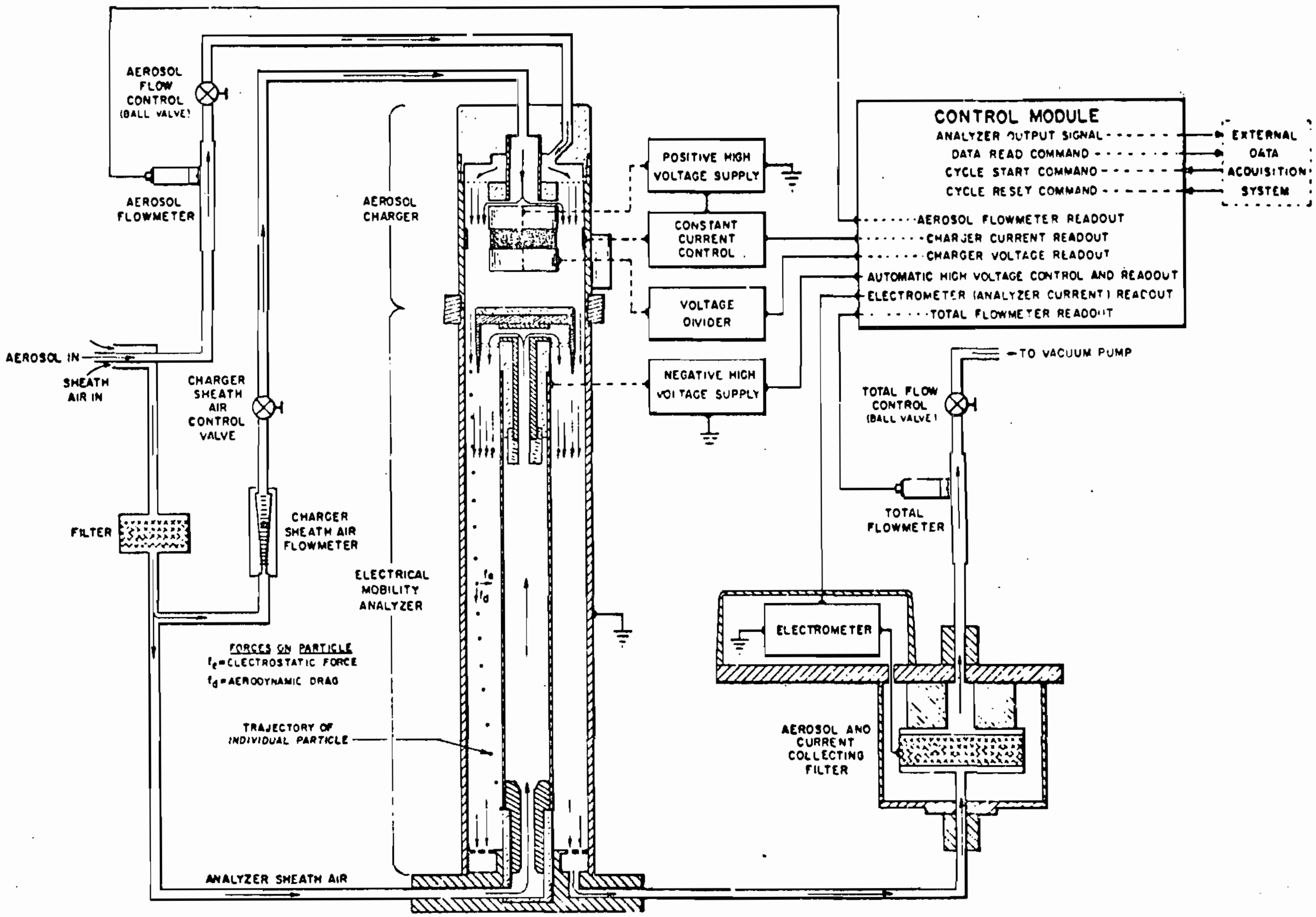

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Figure 3. Flow schematic and electronic block diagram of the Electrical Aerosol Analyzer. After Liu, Whitby, and Pui (1973).

The EAA has the distinct advantage of very rapid data acquisition compared to diffusion batteries and condensation nuclei counters (2 minutes as opposed to 2 hours for a single size distribution analysis). The TSI model 3030 electrical aerosol analyzer is used by Southern Research Institute for ultrafine measurements.

Southern Research Institute has developed under EPA contract an ultrafine particle sample extraction dilution system (SEDS). This system, which is shown in Figure 4, utilizes a heated probe and a sampling line to extract a sample from the flue, a cyclone to remove large particles which might plug the orifice, and a sample orifice, all of which are maintained at flue gas temperature. This method usually prevents condensation of sulfuric acid fumes by not cooling the sample until it is diluted. The sample then goes into a zone where turbulent mixing occurs with cool dry clean dilution air which is metered by a second orifice. From the ratios of sample flow to dilution air flow the final concentration of the diluted mixture can be determined. The sample is now cool and dilute enough to be sampled with the electrical aerosol analyzer. Because of the cyclone and line losses of large particles, the upper size limit of this system is limited to 2.0 μm.

The measurements with the ultrafine sizing system will address the following possible effects of the use of the conditioning agent:

1) The addition of an ultrafine fume which would change the electrical operating characteristics of the precipitator by increasing the electric field caused by particulate space charge.

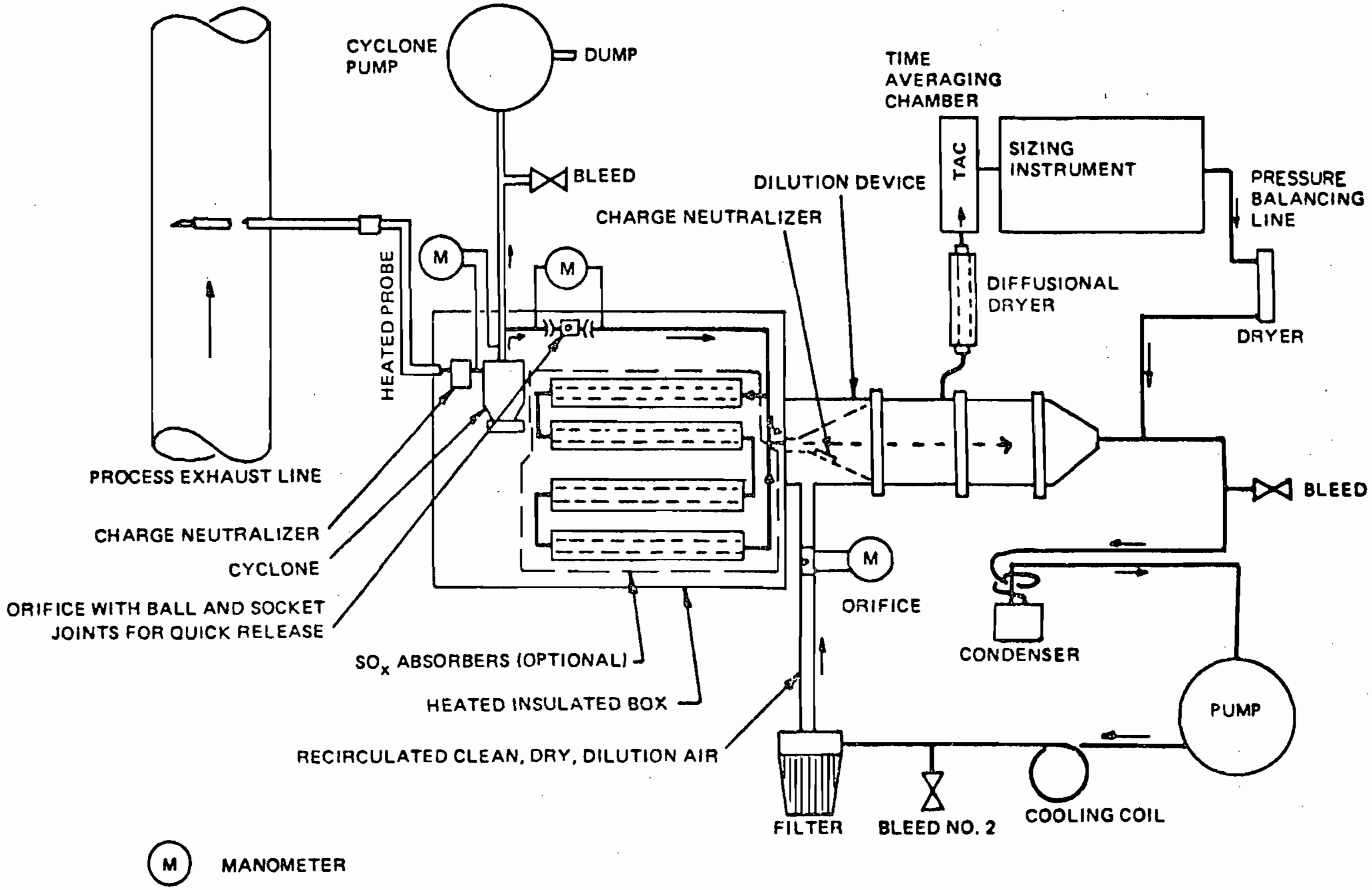


Figure 4. SRI Ultrafine Particle Sample Extraction-Dilution System (SEDS).

2) An increase in the ultrafine particle collection efficiency.

3) An increase in ultrafine particle emissions which may cause opacity or health related problems.

C. Mass Concentration Measurements

Since the objective of employing a conditioning agent is to reduce particulate emissions, the evaluation of a conditioning agent's effectiveness must include a determination of precipitator collection efficiency and the measurement of total mass emissions. Mass measurements will be conducted at the inlet and outlet sampling locations as outlined in EPA method 17.[9] The main difference between this method and the EPA method 5 is the location of the particulate filter in the stack. With this arrangement a thimble-shaped filter is used to sample high mass concentrations and a conventional disk-shaped filter is used for low mass concentrations. The advantage of this system is that the particles are traped before they enter the probe and a probe wash is not required. A condenser and gas cooler are still required between the probe and the gas metering system. The pitot tube, pump and other parts of the system are similar to the EPA method 5 sampling train. The thimble-filter system has often been used in engineering tests to evaluate the performance of a control device.

In general, the method 17 system is easier to use than the EPA method 5 sampling train. The main advantages are the elimination of the probe wash routine and greater flexibility in the placement and mounting of the larger and bulkier components of the system, especially the impinger box, that is available when the rigid probe, filter, impinger box connection is eliminated. If a ceramic thimble is used, the technique is sometimes referred to as the "ASME" method (American Society Mechanical Engineers).

We plan to use glass fiber thimbles at the inlet sampling locations and glass fiber, disk-shaped filters at the outlet sampling locations. Temperature and velocity profiles will be obtained at the inlet and outlet sampling planes. These will be useful in evaluating the electrical operating parameters, (as influenced by temperature), and the particulate collection characteristics of the precipitator.

It is possible for ammonium sulfate conditioning agents to influence particulate emissions by changing the cohesiveness of the ash particles which are collected on the grounded collection electrodes in the precipitator. Such an increase in cohesiveness has the potential of reducing particulate emissions resulting from rapping the collection electrodes. Therefore, a modified sampling procedure has been developed for use at the outlet sampling location in determining the relative contribution of electrode rapping to total particulate emissions. This sampling procedure consists of traversing the outlet sampling ports with mass trains during alternating periods with rappers energized and subsequently de-energized. Two sampling trains are used at the outlet location, one of which is dedicated to sampling only during periods with rappers energized, and the other which is dedicated to sampling only during periods when the rappers are de-energized. Ports are alternated to compensate for differences caused by spacial concentration gradients. This work is scheduled to take place on schedule days 10, 11, and 12 indicated in Table 1.

D. In Situ Resistivity Measurements

It is well known that the electrical resistivity of particulate matter present in the flue gas stream is one of the primary factors which determine the operating characteristics of an electrostatic precipitator. Modification of the particulate resistivity is one of the primary effects that introduction of the conditioning agent can produce. Although laboratory resistivity measurements will be made upon several fly ash and conditioning agent combinations, the conditioning agent's effect on resistivity will also be measured in the natural flue gas environment.

We plan to use Southern Research Institute's point-to-plane resistivity probe illustrated in Fig. 5. This device consists of a stationary point for the generation of a negative corona, a grounded plate or plane for collection of particulate matter, and a movable disk for contacting the sample and measuring the thickness. Two different measures of resistivity can be obtained with each sample using this probe. The first method is termed the "V-I" method. In this method, a voltage current curve is attained before the electrostatic deposition of the dust while the collecting disk is clean. A second voltage current curve is obtained after the dust layer has been collected. After the layer has been collected and the "clean" and "dirty" voltage-current curves are obtained, the second method of making a measurement may be used. In the second method, a disk the same size as the collecting disk is lowered on the collected sample.

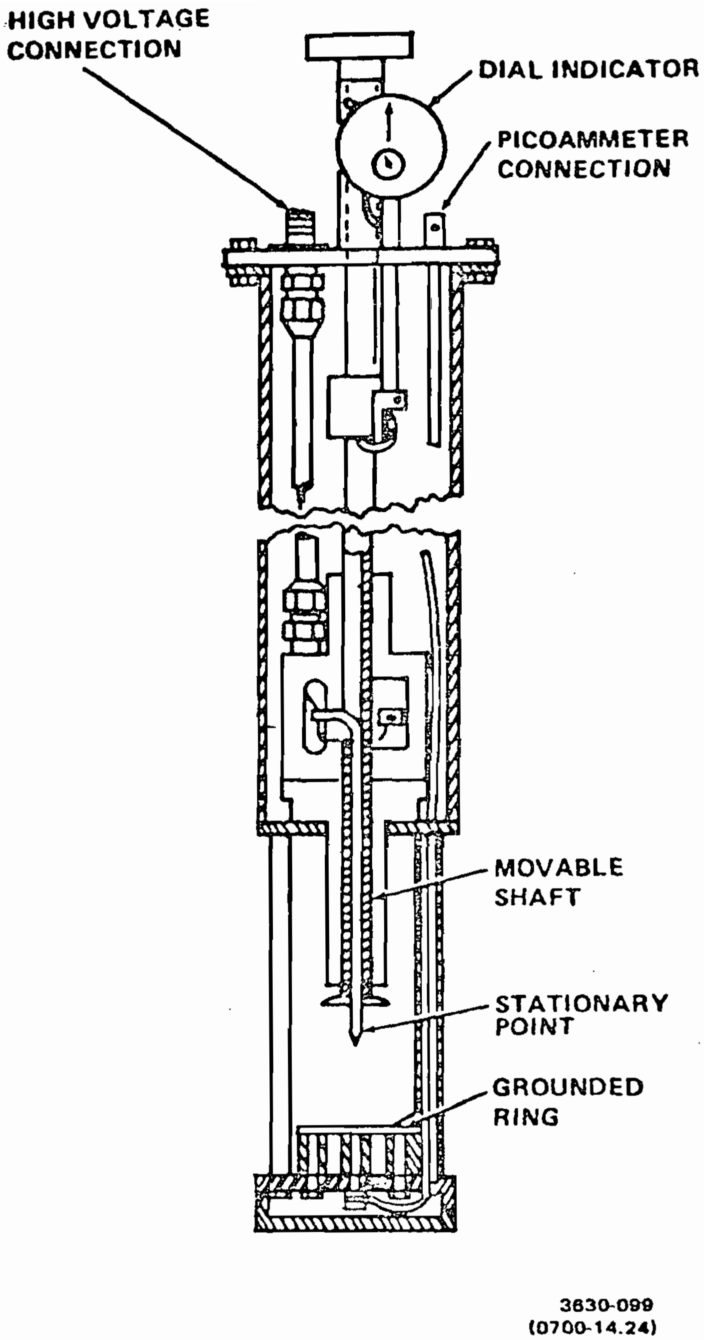


Figure 5.   Point-to-plane resistivity probe.

Increasing voltages are then applied to the dust layer and the current obtained recorded until the dust layer breaks down electrically and spark over occurs. The geometry of the dust sample, together with the applied voltage and current, provide sufficient information for the determination of the dust resistivity.

In the "V-I" method, the voltage drop across the dust layer is determined by the shift in the voltage vs. current characteristics along the voltage axis as shown in Fig. 6. The situation shown is for resistivity values ranging from 10^9 to 10^{11} ohm·cm.

If the parallel disk method is used, dust resistance is determined from the voltage measured just prior to spark over. In both methods, the resistivity is calculated as the ratio of the electric field to the current density. The practice of measuring the resistivity with increasing voltage is used because the dust layer behaves as a non-linear resistor. As the applied voltage is increased, the current increases greater than that attributable to the increase in voltage. Therefore, as described in the ASME Power Test Code Number 28 Procedure, the value just prior to spark over is reported as resistivity.

There is considerable justification for using the value of resistivity prior to electrical breakdown as the resistivity, since it is an electrical breakdown of the dust which causes problems within the precipitator. Electrical breakdown in the dust layer in the operating precipitator either initiates

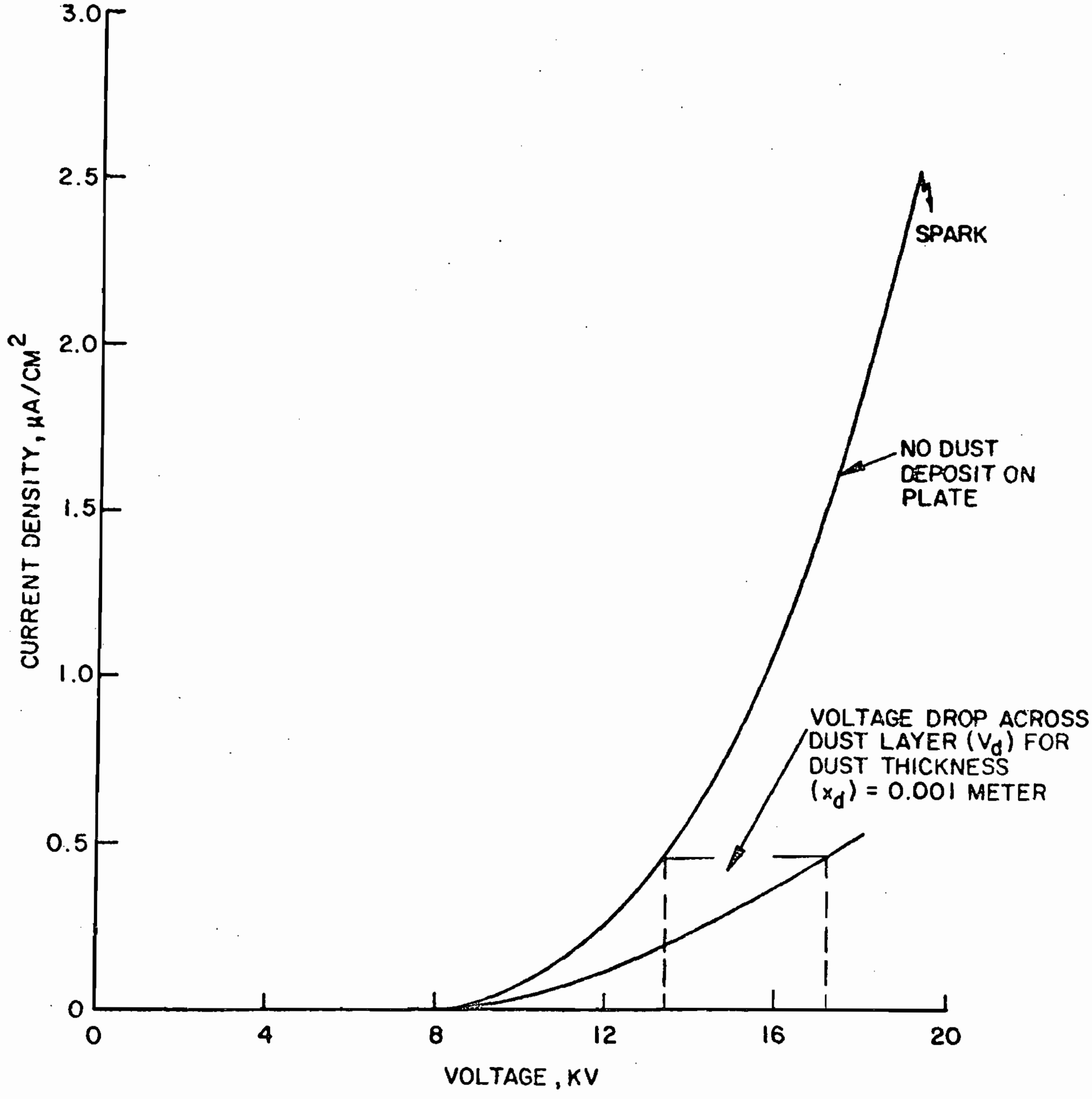


Figure 6. Typical voltage-current relationships for point-to-plane resistivity probe.

electrical spark over or reverse ionization (back corona) when the resistivity is the factor limiting precipitator behavior.

E. Voltage-Current Measurements on Precipitator Power Supplies

To determine the effect of the introduction of the conditioning agent on the precipitator's electrical operating conditions, those conditions must be carefully documented with and without the agent in use. The factors which are considered important are the secondary voltage-current relationships and the shape of the voltage wave form. With this information, the electrical characteristics of the precipitator can be established, and the improvement due to the conditioning agent can be determined.

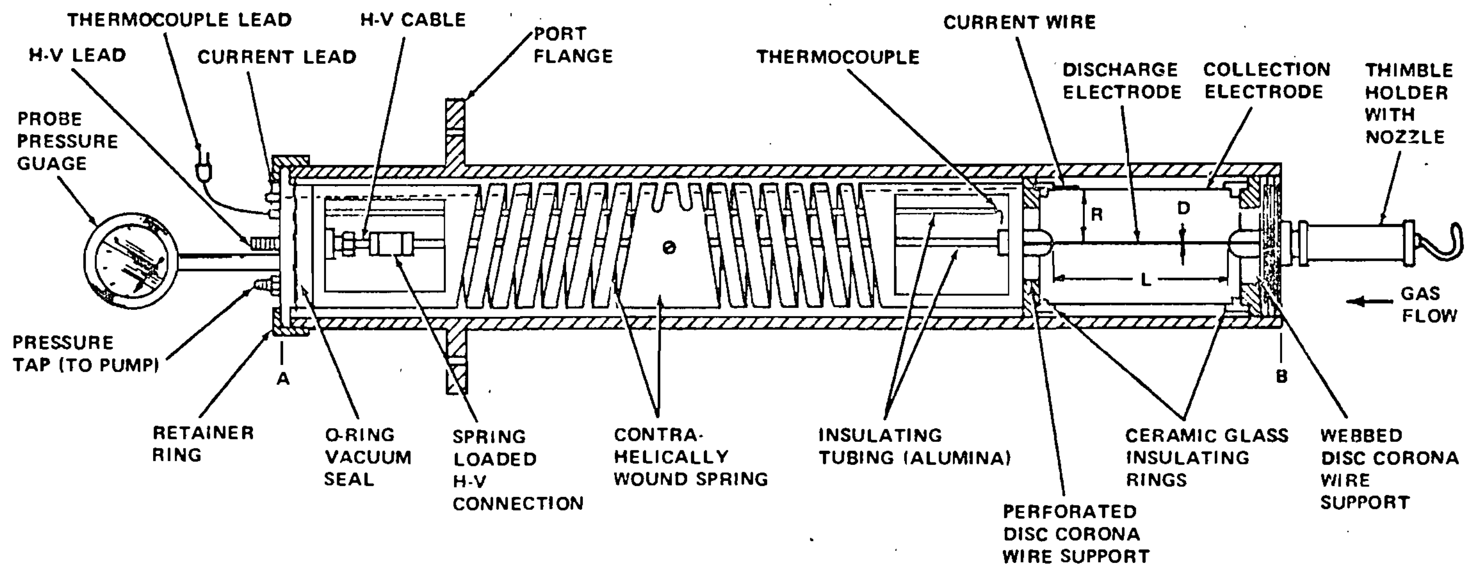
In order to obtain accurate measurements of the secondary voltage, calibrated voltage dividers will be installed in selected transformer rectifier sets. Hourly readings will be taken of the secondary voltage, current, and spark rate during all testing to monitor the electrical operation. Voltage-current curves will be obtained for the selected TR sets at the completion of each test, and the voltage wave forms will be photographed at corona start, normal operating point, and maximum potential. A change in resistivity or particulate space charge should be evident through these measurements.

F. Measurement of Effective Ion Mobility

The effective mobility of ions which are created in a corona discharge is an important parameter associated with the electrostatic precipitation process. This parameter influences the voltage-current characteristics of the corona discharge, the electric field distribution in the gaseous inter-electrode region, and the particle charging process. Thus, the effective ion mobility can have a significant effect on particle collection efficiencies in an electrostatic precipitator. In general, the effective ion mobility depends on the temperature, pressure, and composition of the gas and the electric field strength.

The technique for determining the effective ion mobility is based on fitting the theoretical voltage-current characteristics of a wire cylinder corona discharge to the experimental voltage-current characteristic. This technique has been used previously by Spencer[10] and Tassicker[11] in laboratory applications. The theoretical voltage-current relationship will be fitted to the experimental data by means of Marquardt's[12] non-linear least squares algorithm. In this procedure, the effective ion mobility, and a quantity consisting of the product of the electric field strength at the outer radius of the region of ionization and the outer radius of the region of ionization, are used as adjustable parameters. In previous laboratory and field work, this method of fitting the experimental data and of determining the adjustable parameters was found to work quite well.

An instrument referred to as an ion mobility probe has been designed and developed for making measurements of wire cylinder voltage-current characteristics in a flue gas environment. Fig. 7 shows a schematic diagram for the ion mobility probe. The probe, which is made of stainless steel, was designed to be inserted through a standard 4-inch diameter test port into a flue gas environment at temperatures up to 400°C. A wire cylinder discharge system with its supportive and protective devices and connections for measuring voltage, current, and temperature are contained inside this probe. The ends of the discharge system fit into grooved ceramic glass insulating rings, and this isolates the cylinder from ground. An inner support tube machined as a contrahelically wound spring provides the force necessary to maintain electrode alignment and allows thermal expansion and contraction through the necessary temperature excursions. The high voltage current and thermocouple wires are enclosed in alumina tubing. The high voltage wire is spring loaded at both the corona wire and high voltage lead connections. The end of the probe, which is inserted into the flue gas, has provision for mounting either an Alundum thimble holder or glass fiber filter holder in order to remove the particles from the gas before it enters the discharge system. The end of the probe, which remains outside the flue, has feed-throughs for the high voltage cylinder, electrode current, and thermocouple wires. This end also has openings for a suction pump and pressure gauge.



R - COLLECTION ELECTRODE CYLINDER RADIUS = 4.32 cm

L_1 - EFFECTIVE DISCHAGE ELECTRODE LENGTH = 22.86 cm

D - DISCHARGE ELECTRODE DIAMETER = 88.9 mm

L_2 - TOTAL PROBE LENGTH = A TO B 1.22 m

Figure 7. Ion Mobility Probe.

Analysis of the data obtained at Gannon with this device should indicate whether trace gaseous constituents contributed by the conditioning agent are influencing the voltage-current characteristics of the gas in the absence of particulate.

G. Outlet Opacity

Another possible effect of a conditioning agent which is of prime interest to the electric utilities and regulatory authorities is the reduction of outlet opacity. It has been reported that the use of the proprietary conditioning agent containing ammonium sulfate significantly lowers the opacity of the plume at the Gannon Plant. The opacity of the plume exiting the precipitator must be measured with and without the agent present to quantify this effect. The presently installed in-stack transmissometer will be used to monitor opacity during all test periods. The relationship between outlet opacity, total mass concentration, and size distribution with and without the use of conditioning agent will be examined.

H. Monitoring of Boiler Operation

Since the operation of the boiler influences the operation of the precipitator, data pertinent to precipitator operation will be logged from the control room displays. Examples of parameters of interest include plant load, air flow and fuel flow rates, number of burners in operation, oxygen content of flue gas, and air preheater inlet and outlet temperatures.

I. Chemical Analyses

Chemical analyses of conditioning agents, coal, and fly ash, will be performed in the laboratory to support various phases of the program. An especially important analytical task will be to identify the components of proprietary conditioning agents. Analyses will be made of samples secured before the test program has begun and during the time that a field test is in progress. These analyses will be performed in an effort to ensure that the test program is being conducted with the agent in use for which the test plan was developed.

Coal and fly ash samples will be collected periodically during each field test. Coal will be analyzed by ASTM methods and fly ash will be analyzed for the individual oxide components mostly by atomic absorption spectrometry. Fly ash will also be analyzed for the residues of conditioning agents of interest in this case, ammonia and SO_3.

If suitable arrangements can be made, fly ash samples will also be subjected to chemical analysis using surface spectroscopic techniques. It is hoped that these techniques will aid in determining the form in which the ammonium sulfate is collected with the fly ash.

The gases closely related to the conditioning processes to be studied include: water vapor, sulfur trioxide or sulfuric acid, and ammonia. Water vapor will be determined by drawing a measured volume of flue gas through a pre-weighed Drierite cartridge and weighing the quantity of water retained on the drying agent. Oxygen and CO_2 will be determined with commercial Fyrite type apparatus.

A method which will be used for determining SO_2 and SO_3 is illustrated in Fig. 8 and is similar to one described by Lisle and Sensenbaugh.[13] The sampling probe includes two concentric tubes with lengths of 1.2 meters; the inner tube or sampling line is made of pyrex with an internal diameter of about 7 mm and the outlet tube used for support and insulation is made of stainless steel with an external diameter of about 25 mm. The annulus between the two tubes contains an electrical heating tape around a wall of the pyrex tube and an insulating asbestos tape around a heating tape. The end of the pyrex tube that is inserted in the flue is packed with quartz wool to prevent particles of fly ash and H_2SO_4-H_2O condensate from entering the collection system; the other end of the pyrex tube is fitted with a ball and socket joint for connection to the condenser. The condenser consists of a helical condensation tube made with pyrex tubing with an internal diameter of about 7 mm and an overall length of about 1 meter; a spray trap consisting of a fritted glass filter (sealed to the helix near the exit); a heated bath of ethylene glycol and water around the helix and filter; and a steel pipe fitted with an external heating tape for containing and heating the water-glycol mixture. The SO_2 scrubber is a bubbler filled with a 3% solution of H_2O_2 in water. The flow rate indicator is a charcoal test meter (product of American Meter Co.) with an inlet filter of Drierite, or as an alternative, a vapor trap emersed in ice water. The charcoal test meter registers the integral of flow rate with time and thus shows the total volume of dry flue gases

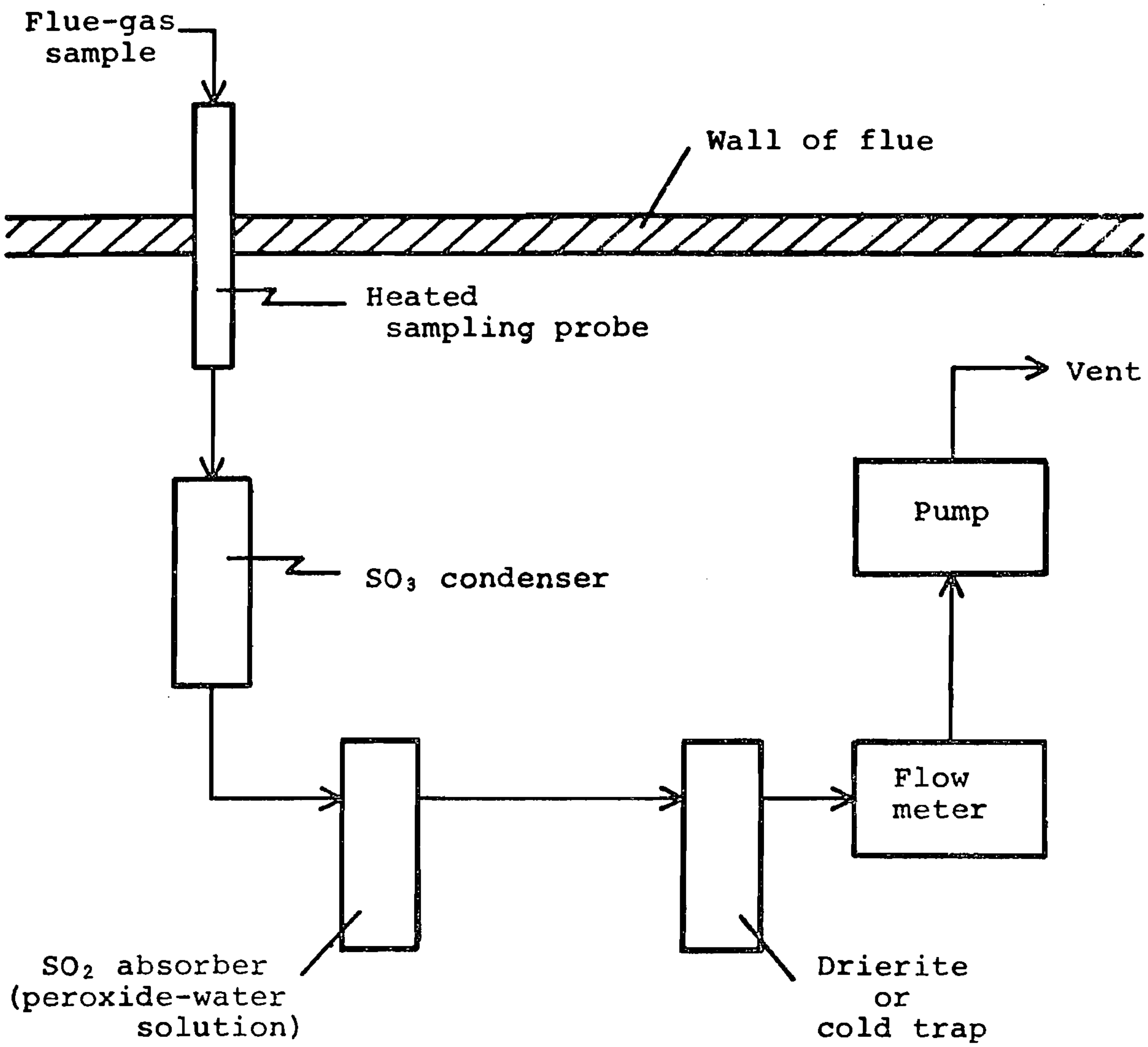


Figure 8. Schematic Diagram of Apparatus for Collection of SO_3 by the Condensation Method

sampled except for the relatively small volume of SO_3 and SO_2 collected upstream. A small vacuum pump is used for sampling flue gases at an approximate rate of 2 liters per minute for a period of about twenty minutes.

A titration method will be used for determination of SO_3 and SO_2 collected as H_2SO_4. The method is based on titration of H_2SO_4 with $Ba(ClO_4)_2$ with a 4 to 1 mixture of isopropanol and water as a solvent and the organic dye thorin as the indicator of the end point. This titration method is sufficiently sensitive for use in determining SO_3 and flue gases at concentrations down to 1 ppm with reasonable sample volumes ($\sim$40 liters). It is also sufficiently sensitive in determining the characteristically much higher concentrations of SO_2.

Ammonia will be collected from a known volume of flue gas in bubblers filled with dilute sulfuric acid. The ammonia will then be determined by the use of an Orion ammonia-sensitive electrode or by use of a phenol-hypochlorite colorimetric procedure. An effort will be made to obtain a material balance for the ammonium sulfate conditioning agent by:

1) Sampling flue gas at the precipitator inlet and outlet for ammonia and SO_3.
2) Analyzing the particulate collected from a traverse at the inlet sampling plane, the precipitator hoppers, and a traverse at the outlet sampling plane for ammonia and sulfate.
3) Calculating the equivalent mass flow rate of ammonium sulfate at the injection point, the inlet sampling plane, precipitator discharge hoppers, and the outlet sampling plane.

These analyses and calculations should indicate whether significance should be attached to possible reaction between ammonia and NO_x to form nitrogen, or to possible build-up of ammonium compounds at points upstream of the precipitator inlet.

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