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FLUE GAS CONDITIONING FOR IMPROVED PARTICLE COLLECTION IN ELECTROSTATIC PRECIPITATORS

Quarterly Technical Report
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PROGRAM OBJECTIVES

The purpose of this research program is to identify and evaluate a variety of additives capable of increasing particle cohesion which could be used for improving collection efficiency in an ESP. A three-phase screening process will be used to provide the evaluation of many additives in a logical and cost-effective manner. The three step approach involves the following experimental setups:

1. Provide a preliminary screening in the laboratory by measuring the effects of various conditioning agents on reentrainment of flyash particles in an electric field operating at simulated flue gas conditions.
2. Evaluate the successful additives using a 100 acfm bench-scale ESP operating on actual flue gas.
3. Obtain the data required for scaling up the technology by testing the two or three most promising conditioning agents at the pilot scale.

The objectives of this program are addressed in ten tasks defined in the Management Plan. During the three months covered by this report, work was focused in Tasks 3 and 4.

ACTIVITIES COMPLETED DURING CURRENT REPORTING PERIOD

TASK 3. INITIAL SCREENING OF ADDITIVES

All additives were tested during July to determine the dilution ratios necessary for atomization with the lab scale additive injection system. The ultrasonic atomizer is not capable of atomizing most of the pure additives because of their high viscosity. These additives were diluted in water and atomized at room temperature and 180°F. The dilution ratio was chosen which required the least amount of carrier water for atomization.

Pre-screening tests were performed on the combined flue gas simulation-additive injection system to verify outlet humidity and SO_3 concentrations. Initial experiments indicated that the ash obtained from Consol was not responding to SO_3 conditioning. This is a very critical aspect of the laboratory experiments as the resistivity must be decreased to a level below mid-10^9 ohm-cm for particle reentrainment to become a limiting factor in

ESP performance. If this level cannot be achieved, then it will not be possible to detect any improvement when the additives are used to condition the ash.

To understand how resistivity relates to particle reentrainment, it is necessary to understand how the different forces in the dust layer interact. In the dust layer on the collector plate, a surface charge density, σ, is created on the surface due to a discontinuity between the electric field, E_g, at the surface of the layer due to the corona wire voltage, and the electric field, E_l, created by the ionic charges on the collected particles. This charge density can be calculated by:

$$\sigma = \epsilon_0(E_g - \epsilon_l \rho_l J_p) \qquad C/m \qquad (1)$$

where ϵ_0 is the dielectric constant of free space and ϵ_l is the relative dielectric constant of the layer, ρ_l is the layer resistivity in ohm-m, and J_p is the current density. Equation (1) shows the surface charge density can be either positive or negative depending upon the electrical and layer conditions.

An electric force per unit area f_x acts on the surface charge

$$f_x = \sigma(E_g + E_l)/2 \qquad (N/m^2) \qquad (2)$$

The force f_x tends to pull the particles off the surface of the layer back into the gas if σ is positive. If σ is negative, the force tends to hold the layer against the plate.

Figure 1 is a plot of the electrostatic force on the dust layer as a function of resistivity and the electric field strength at the plate. The calculations were made for a constant current density of 60 nA/cm^2 which is typical for a full-scale ESP. This family of curves demonstrates the general trends of the relationships defined by Equations 1 and 2.

When the resistivity is greater than 10^{10} ohm-cm, the electrostatic force rapidly increases toward the plate (i.e. increased clamping force) as the resistivity decreases. At these resistivity levels, the force is independent of the electric field at the plate and only a function of the product of the current density and particle resistivity. For high resistivity applications (i.e. > 10^{11} ohm-cm) the holding force is so great that "power off" rapping is often required to remove the dust from the plates.

At particle resistivity levels below 6 x 10^9 ohm-cm, the electrostatic forces reverse and tend to pull the particles off the plates.

As can be seen from Figure 1, for very low-resistivity levels, the repulsion force becomes relatively independent of resistivity, and correspondingly current density, and only proportional to the square of the electric field strength. Therefore, reentrainment in ESPs will primarily be associated with flue gases where sufficient SO_3 is available to reduce the resistivity below 10^{10} ohm-cm.

The initial problems with conditioning the ash were due to the inability of the pure vanadium pentoxide to catalyze the SO_2 to SO_3. Once a commercial catalyst was purchased and installed in the system, the generation of SO_3 was confirmed via gas measurements.

The SO_3 was then mixed with the other flue gas constituents and injected into the resistivity device. A sample of ash was placed on the lower disc and the resistivity of the sample was measured. Initially the resistivity of the ash was in the range of 10^{11} to 10^{12} ohm-cm but after 10-12 hours of exposure to the simulated flue gas, the resistivity was reduced to 10^{10} ohm-cm. This long time delay has been reported for other laboratory evaluations of the effect of SO_3 on flyash resistivity (Bickelhaupt, 1978)*. It was assumed that this long conditioning time was due to the slow diffusion of gas through the 2 mm thick dust layer.

This long period for conditioning the ash would not be acceptable for the laboratory experiments with additives. However, when SO_3 is injected into actual flue gas where it mixes and interacts with flyash, there is only a one second residence time for the reduction in resistivity to occurs. Therefore, the experimental system was designed to inject both flyash and SO_3 into a mixing chamber to provide at least a second of residence time for the gas to condition the particle. It was expected that this would provide a reasonable simulation of an actual conditioning environment. However, when the ash resistivity was measured with 5 to 10 ppm of SO_3 injected into the flue gas stream, no reduction in resistivity was detected and the resistivity remained in 10^{11}-10^{12} ohm-cm range.

* Bickelhaupt, R.E. "Measure of Fly Ash Resistivity Using Simulated Flue Gas Environments," NTIS, PB-278 758, Southern Research Institute, Birmingham, Alabama, March 1978.

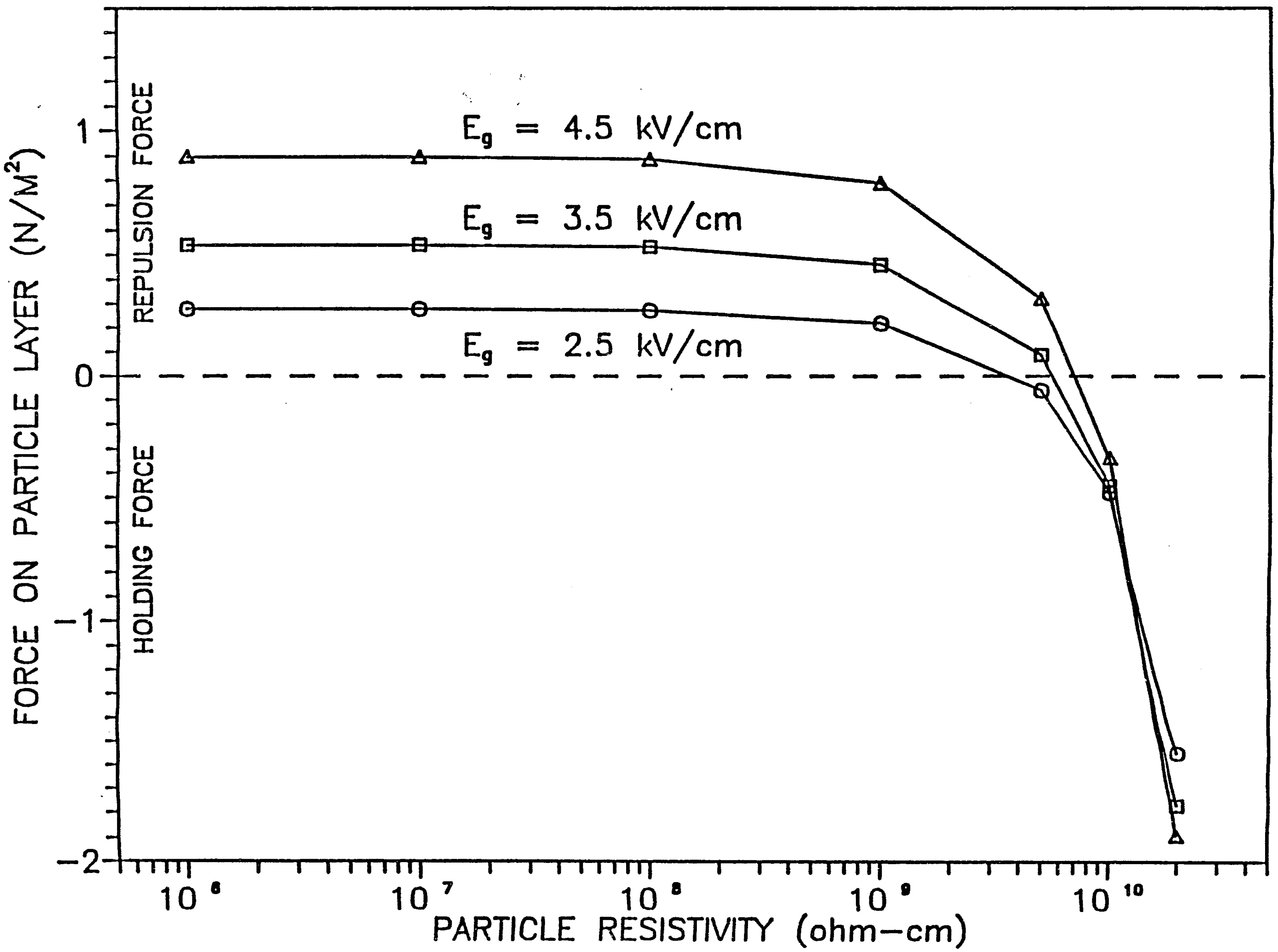

Figure 1. Electrostatic Force Acting on a Dust Layer at a Current Density of 60 $nAcm^2$ as a Function of Particle Resistivity and Electric Field at the Plate

Because of the time and expense of using the controlled condensation system to measure gas phase SO_3 concentration, a Land Dew point Meter was leased to measure changes in the dew point. The conditioning effect of SO_3 is due to an increase in the dew point from a water dew point, approximately 125 °F for flue gas, to an elevated acid dew point, 250-300 °F. Therefore, the presence of SO_3 in the flue gas exiting the resistivity chamber could be detected by the elevated dew point. However, the analyzer detected only the dew point due to water which indicates that the SO_3 had been scrubbed from the system.

Thermocouples were added to the flow system which identified the presence of several cold spots in the tubing. If the conditioned gas comes in contact with a cold wall, portions of the SO_3 will condense and not be available for conditioning the flyash downstream. In addition, some in-leakage was occurring through windows in the precipitator which diluted the relative SO_3 concentration.

The flow system was redesigned to solve the leakage problem and new heaters were installed to prevent cold spots. Additional temperature monitors were installed to continuously monitor the system. However, when the system was started up after the modifications, only minor reduction in resistivity could be detected when a relatively high concentration of 30 ppm SO_3 was injected. In addition, the unheated windows, which had a measured temperature of approximately 200 °F, did not experience any fogging which indicated that the dew point was not elevated by the injection of SO_3.

Since the thermocouples confirmed that cold spots had been eliminated, it was concluded that the ash was scrubbing the SO_3 from the flue gas. It is important to note that it is the gas phase SO_3 that leads to a lowering of resistivity and not SO_3 that has reacted on the surface of the flyash. Without the elevation of the dew point, there is no increase in the surface conduction on the flyash. Therefore, if the SO_3 does react with the flyash, there will be no elevation of the dew point and no decrease in resistivity.

Experiments were then run in which the injection rate for SO_3 was increased and the flyash injection rate was decreased. The purpose of these tests was to identify the condition that resulted in saturating the flyash with SO_3 such that gas phase SO_3 remained. It was discovered that indications of the presence of gas phase SO_3 could be detected when the flyash injection rate was reduced, such that the resulting inlet loading decreased from 2 to 1 gr/acf, and with an SO_3 injection rate of 80 ppm. At this condition, the measured resistivity dropped to 10^8 ohm-cm and the windows on the precipitator began to fog.

Therefore, it appears that it is necessary to inject much higher levels of SO_3 in order to result in sufficient material to remain in the gas phase. This level is much higher than that found in actual flue gas. However, when SO_3 is measured in flue gas, the particles are in equilibrium with the gas and have already had a chance to react with the various flue gas constituents. It is unknown how much SO_3 was originally generated in the boiler and was removed through reaction with the surface of the flyash. Therefore, it is not unreasonable to assume that additional SO_3 must be injected into the simulated flue gas to equilibrate with the particles.

Additional tests were conducted to determine if the SO_3 injection rate could be increased to provide conditioning of higher concentrations of flyash particles. It was discovered that with the limitations of the flow controllers, 1 gr/acf was the highest concentration of particles that could be conditioned with the system. Therefore, tests will be conducted at lower particle concentrations than originally planned.

Because of the interaction between the flyash and the injected SO_3, plans for measuring reentrainment with and without the additives will have to be modified. The original plan called for turning off the dust feeder during the reentrainment measurements. However, because of the interaction between the flyash and the SO_3, removing the particles will result in a change in flue gas conditions. Therefore, a new test procedure will have to be devised to determine the impact of the additives.

By injecting high concentrations of SO_3 (80 to 100 ppm) it was possible to reduce the particle resistivity from 10^{11} to 10^7 ohm-cm. However, it was very difficult to consistently obtain intermediate levels of resistivity. This was because of the steep relationships between gas phase SO_3 and resistivity. It only takes a few ppm of SO_3 to provide an order of magnitude change in resistivity. This is demonstrated by the curves in Figure 2. The water dew point for a gas stream with a moisture content of 10%, which is typical of coal fired boilers, is approximately 120°F. However, in a flue gas with only 2 ppm of SO_3, sulfuric acid will begin to condense at 270°F. The effect of the rapid rise in acid dew point is reflected by the corresponding rapid decrease in resistivity. With no gas phase SO_3 present, the resistivity is in the high 10^{11} ohm-cm range. However with only 10 ppm of SO_3, the resistivity drops three orders of magnitude. Therefore, intermediate levels of resistivity can only be obtained by controlling the SO_3 concentration within 1 or 2 ppm.

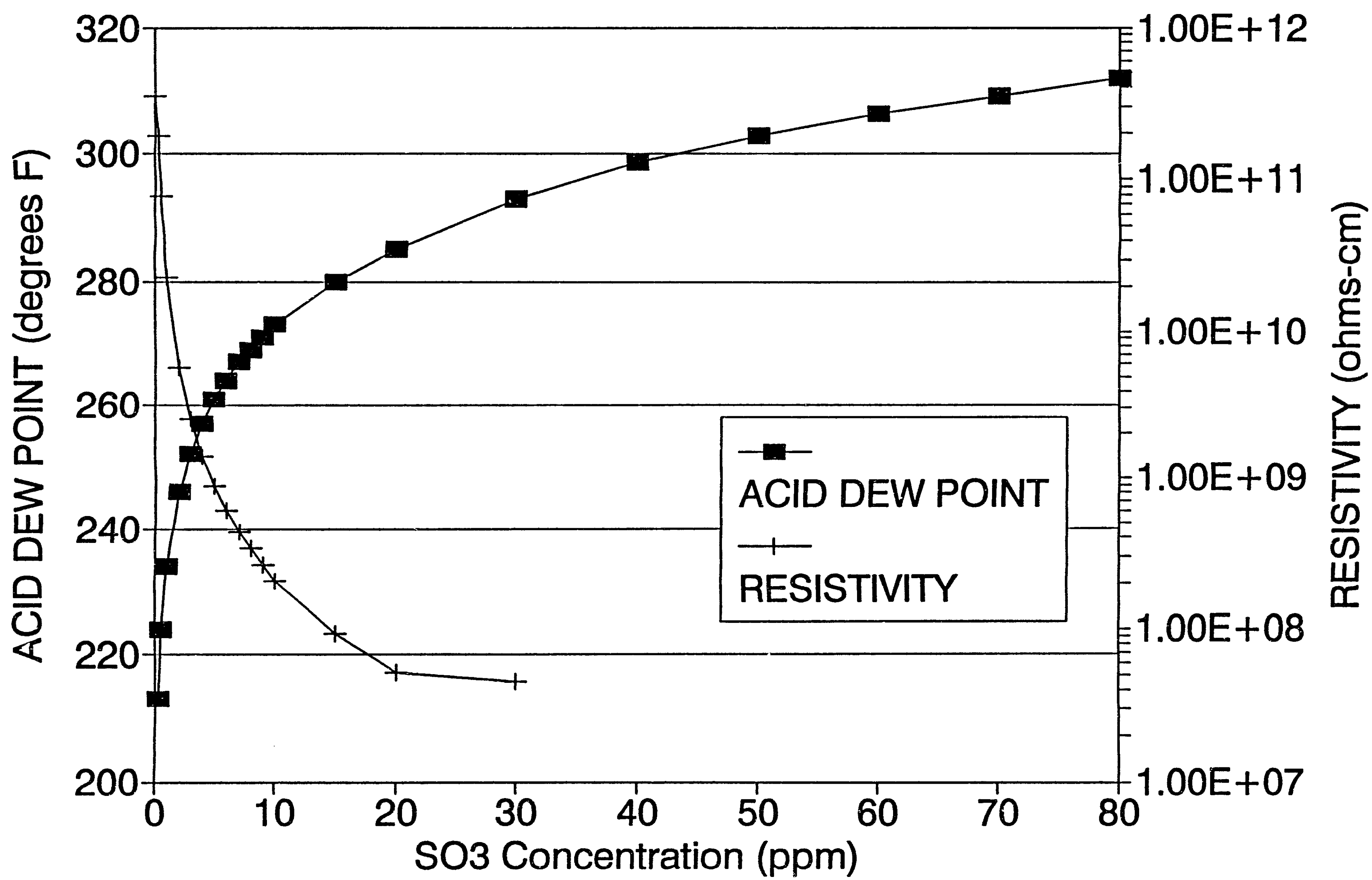

Figure 2. Acid Dew Point Vs Concentration @ 10% Moisture by Volume

Although the gas injection rate could be adjusted to accurately control SO_3 within 1 ppm, the variation in the resulting concentration of gas phase SO_3 was greater that +/- 10 to 20 ppm. Part of this variation was due to fluctuations in the screw feeder. At 1 gr/acf, the screw feeder must be operated in the lower ten percent of its capacity. At this rotation rate, the material inconsistently filled the flights of the screw. In addition, the calibration curve for the mass output of the screw feeder, Figure 3, was very steep in the lower region so that a small change in setting produced a relatively large change in feed rate.

To overcome this problem, the screw was modified by adding a 0.035 inch diameter wire in the bottom of the screw flights as shown in Figure 4. This filled space that would have been filled with flyash during operation, so a higher rotation speed was required to produce a given mass flow. Although this reduced the magnitude of the fluctuation, it did not totally eliminate the problem so that it was still difficult to fine tune the SO_3 concentration.

Because of the fluctuation in the flyash feed rate and its impact on the gas phase SO_3 concentration, it was necessary to provide real-time feedback on the SO_3 concentration during the tests. Since there is no reliable continuous SO_3 analyzer, it was decided to design an acid dew point analyzer into the resistivity instrument, Figure 5, by mounting a bare thermocouple on the inside of one window to the precipitation chamber. This The window is located at the end of a pipe extending approximate three inches from the heated chamber. Since the window and pipe are unheated, the glass surface is cooler than the chamber. When the dew point temperature of the flue gas is higher than the glass temperature, a mist forms on the window. A heat gun is then used to heat up the glass from the outside. When the temperature of the glass rises above the flue gas dew point, the mist disappears. This temperature is recorded as the acid dew point. The measured acid dew point is then used to determine the SO_3 concentration from a calibration curve. This systems appears to correlate well with the expected end result on particle resistivity.

Figure 6 shows a plot of measured SO_3, as determined by the acid dew point technique, versus the amount of SO_3 that was injected. With the injection of up to 30 ppm SO_3, there was no measurable change in flue gas conditions . However, at a feed rate of 80 ppm of SO_3, from 10 to 20 ppm of SO_3 could be detected in the gas stream. While injecting 140 ppm of SO_3, the dew point corresponded to 10 to 30 ppm SO_3. The variation in measured dew point at a constant SO_3 injection rate was possibly due to fluctuations in the flyash feed rate.

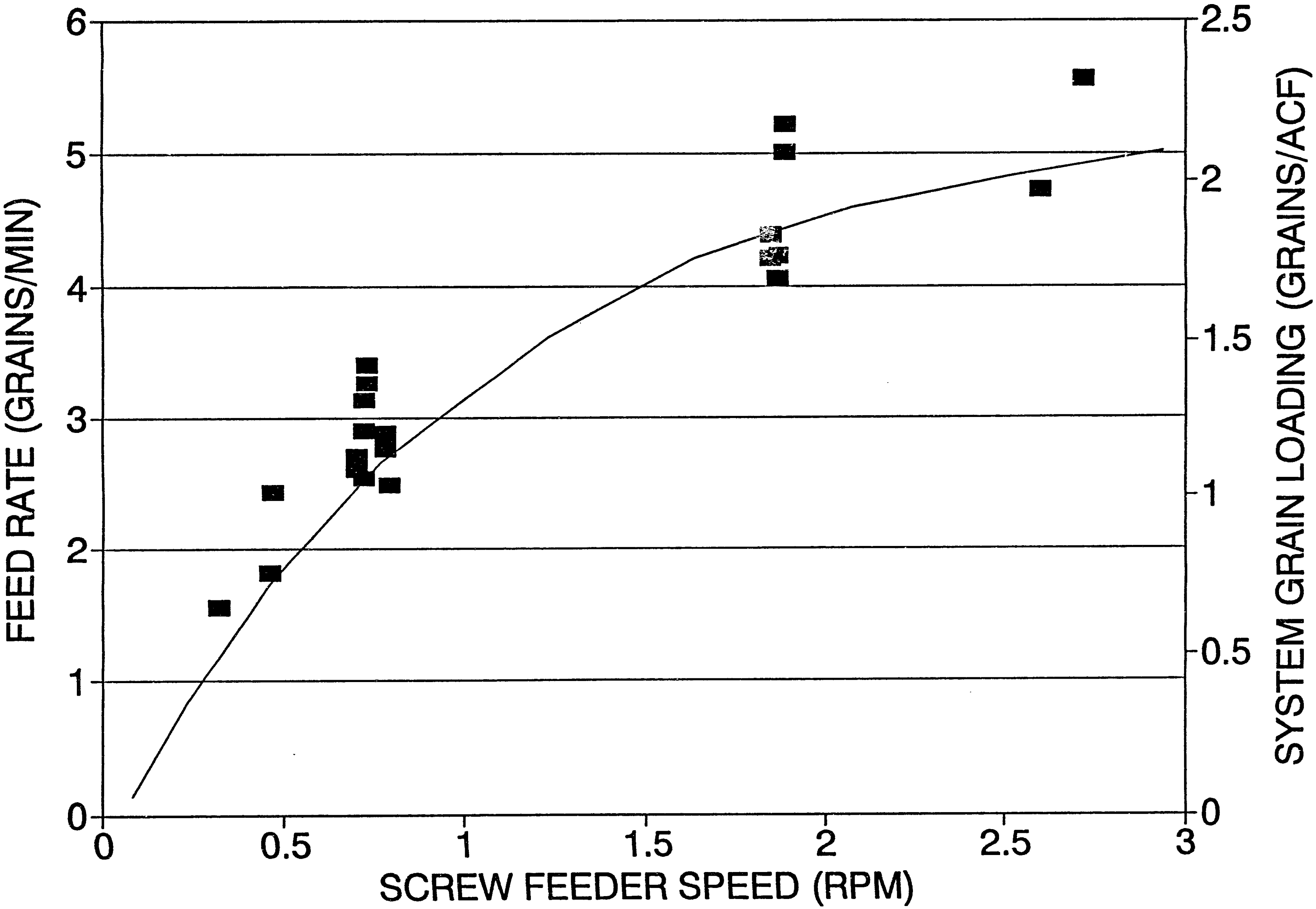

Figure 3. Screw Feeder Calibration

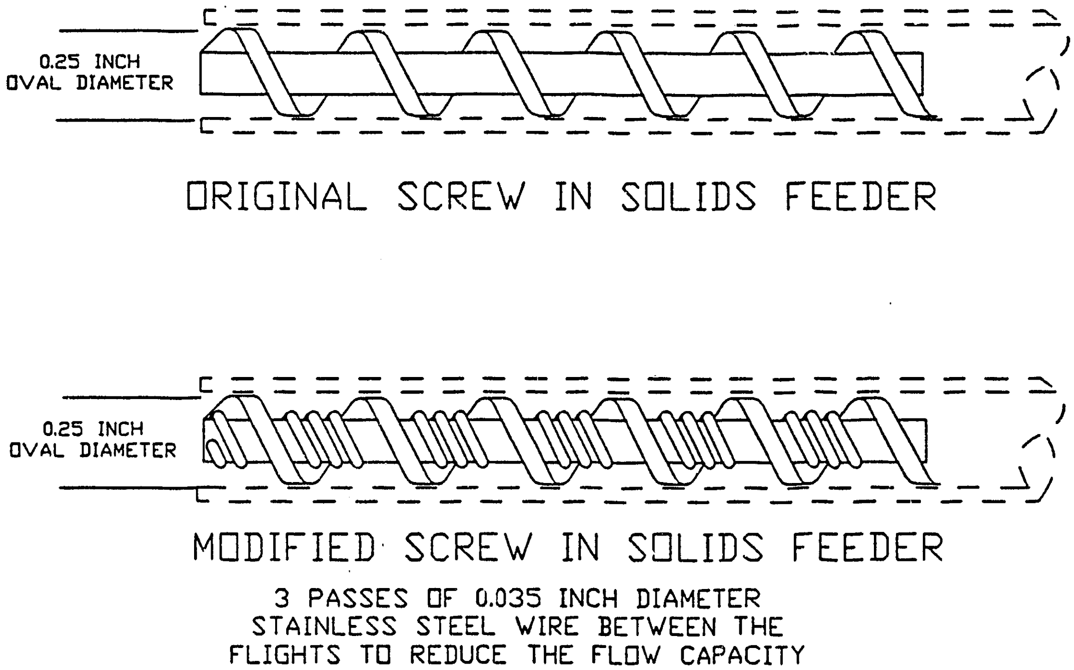

Figure 4. Screw Feeder Modifications to Reduce Flow Capacity

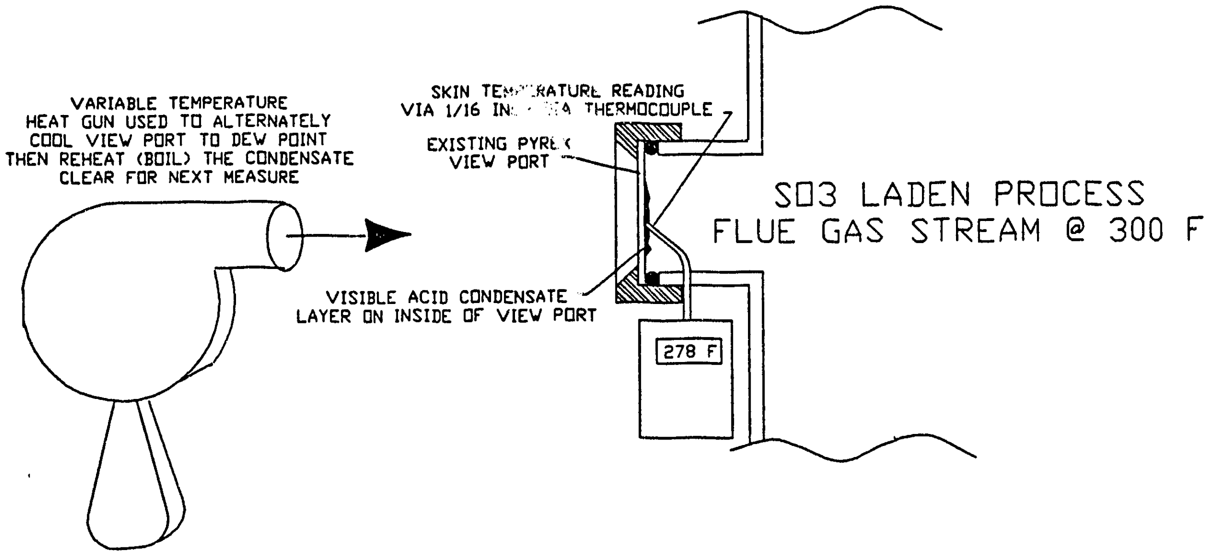

Figure 5. Acid Dew Point Measurement Method

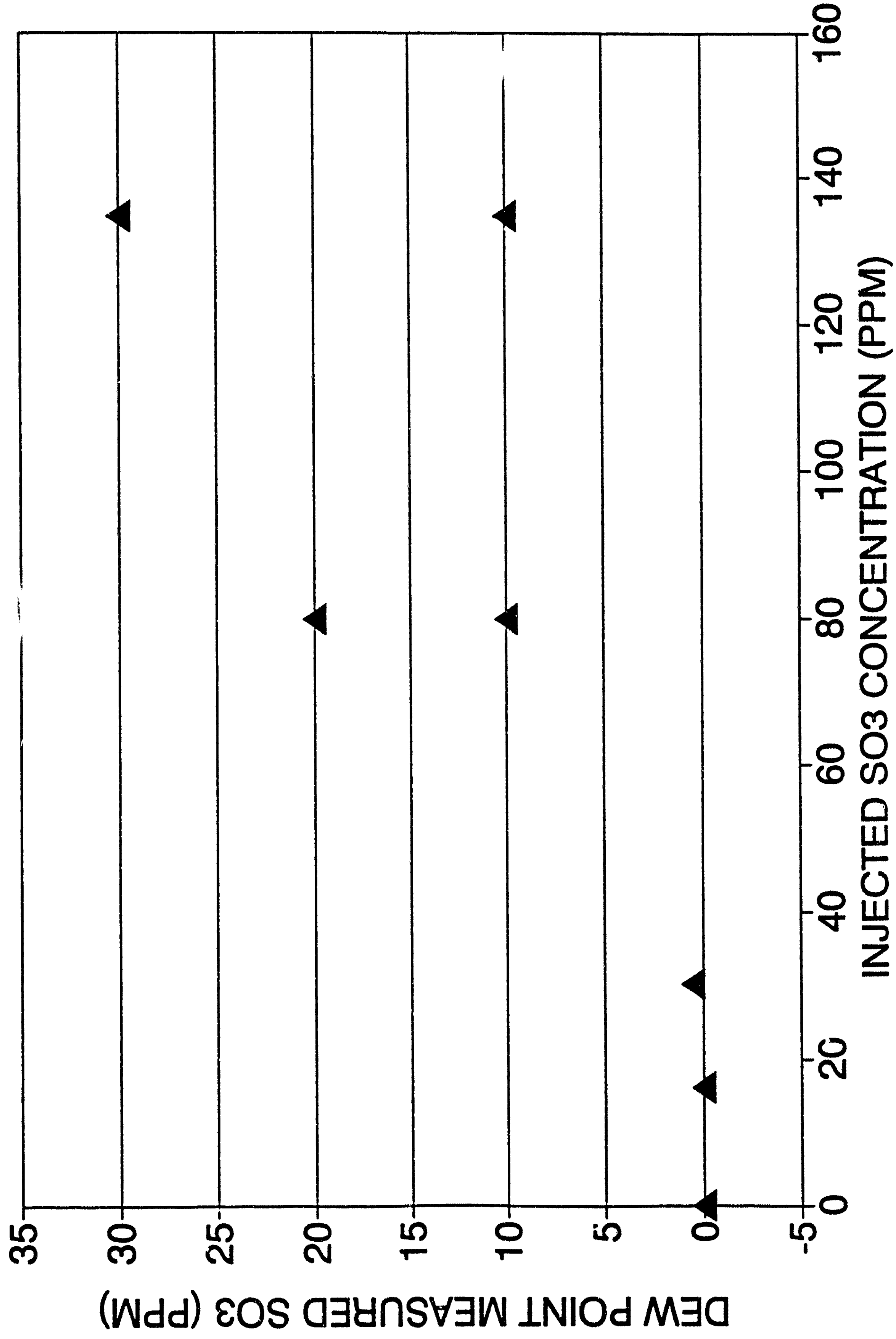

Figure 6. Injected SO_3 Measured @ 300 F, 10% Moisture

A few tests were then conducted to see if collection efficiency in the resistivity instrument precipitator correlated with the resistivity measurements. Tests were conducted at three conditions representing 10^7, 10^9, and 10^{11} ohm-cm and are reported in Figure 7. The precipitation rate was determined by a measured thickness after a fixed sampling period.

The rate for the 10^7 and 10^9 ohm-cm conditions were very low and were relatively equal. This is predicted by the relationships demonstrated in Figure 1. However, the precipitation rate for the 10^{11} ohm-cm case was much higher. This indicates that the lower resistivity leads to increased reentrainment which limits the rate of precipitation. However, at a resistivity that is high enough to have a significant holding force on the collected particles, reentrainment is reduced and the dust builds up much faster. Since precipitation rate appears to be a method of discriminating between two cases with different amount of reentrainment, it could be used as a criteria to judge the effectiveness of the additives.

It is apparent that it is very difficult maintain experimental conditions to produce a consistent resistivity level of 10^9 ohm-cm. Therefore, it is concluded that the laboratory tests should be conducted at high levels of SO_3 such that the resulting resistivity is in the range of 10^7-10^8 ohm-cm.

There are several reasons leading to this conclusion. At SO_3 concentrations of 30 ppm and greater, the curves for both dew point and resistivity are relatively flat so that changes in gas phase SO_3 will have minimal impact on particle characteristics. As shown in Figure 1, the electrostatic forces are relatively flat in this range so that changes in flue gas conditions will that result in a change in resistivity by up to two orders of magnitude will have little effect on the magnitude of reentrainment.

Finally, at the very low resistivity conditions, reentrainment will be the highest. Since the purpose of the laboratory resistivity tests is to determine the relative ability of the various additives to reduce resistivity, the greater the reentrainment, the easier it will be to measure an improvement.

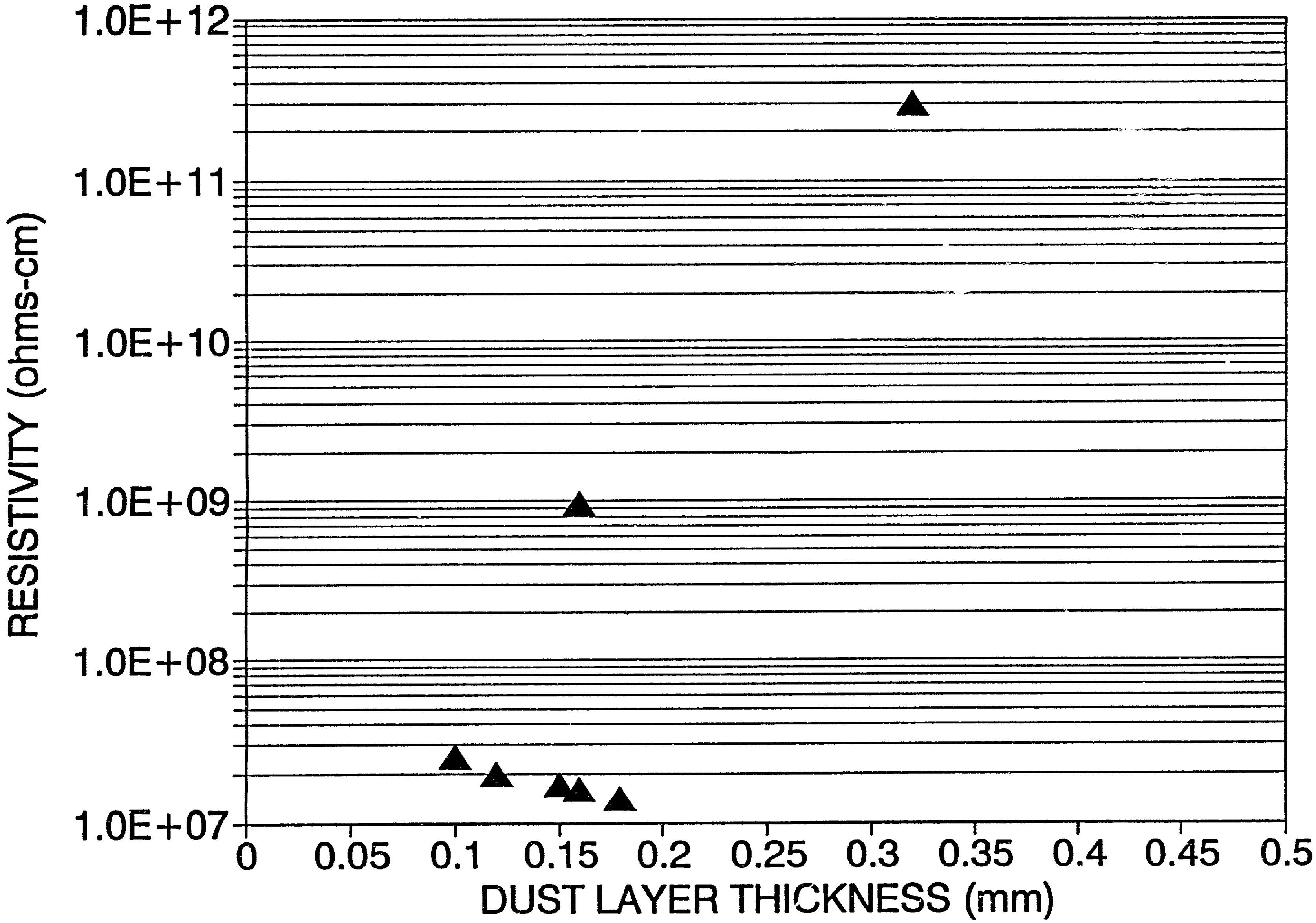

Figure 7. Resistivity Vs Dust Layer Thickness Measure @ 300 F, 10% Moisture

TASK 4.0 BENCH-SCALE TESTING

Subtask 4.1 Comparison of Insitec Instrument with Impactors

Key ADA personnel visited the Consol Test Facility in July to meet with the Consol engineers to discuss details of this task. Sites were identified to locate ports at the inlet and outlet of the ESP for interfacing the Insitec instrument. ADA will provide a support mechanism to suspend the instrument from I beams to allow measurements to be made across windows installed in the horizontal duct at the outlet of the ESP. The suspension system will provide vertical movement of the instrument for calibration and operation.

At the inlet of the ESP, Consol will install beams to mount a horizontal platform to support the instrument. The instrument will slide along the platform to interface with the vertical duct. At both the inlet and outlet, the sampling location will be greater than eight diameters downstream of the nearest upstream perturbance.

Details of the manual sampling requirements were worked out at this meeting. Consol will perform modified Method 5/17 measurements and cascade impactor measurements at the inlet and outlet of the ESP. Series cyclones will also be used by Consol to augment the particle size measurements at the inlet. ADA will operate the Insitec instrument as well as perform complementary cascade impactor measurements at the inlet and outlet.

Drawings were completed and sent to CONSOL to define their responsibility in preparing the ESP inlet and outlet ducting for the Insitec experiments. This involves welding new four inch ports at the inlet and outlet in locations selected by ADA personnel during a site visit in July. At the inlet, horizontal and vertical supports will be installed to provide a means to hang a platform for the Instrument. Preparations have begun to get the sampling equipment (impactors, control boxes, and resistivity instrument) ready for this test program.

Subtask 4.2 Design of Additive Injection System

Candidate injection nozzles were evaluated based on manufacturers performance data. The important parameters are the spray pattern produced by the nozzle and the projected droplet size distribution with the given additive solutions. This is important to minimize wall wetting with the spray and to promote mixing of the additive and flue gas streams.

Subtask 4.3 Setup of Bench-Scale System

The bench-scale ESP is currently being modified for the additive injection tests. Heaters and insulation has been installed to maintain an operating temperature of 300°F. Self-purging windows were installed on the inlet and outlet for Insitec tests, and modifications were made to the inlet and outlet to facilitate installation of the ADA ESP at CONSOL.

END

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