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IMPROVED ELECTROSTATIC PRECIPITATOR PERFORMANCE

BY USE OF FLY-ASH CONDITIONING AGENTS

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ABSTRACT

Pilot-scale (75 kg/hr) combustion trials using a pulverised western Canadian bituminous coal of low sulphur content have shown that the fly-ash resistivity can be significantly modified by adding SO_3 , H_2SO_4 , $\text{NH}_2\text{SO}_2\text{OH}$ and NH_3 to flue-gases as fly-ash conditioning agents. The measured fly-ash resistivity (R) when using these conditioning agents was found to decrease exponentially from its original level (R_0) to a limiting value (R_{Sat}) as the concentration of the conditioning agents was increased:

$$\frac{\text{Log } (R) - \text{Log } (R_{\text{Sat}})}{\text{Log } (R_0) - \text{Log } (R_{\text{Sat}})} = e^{-k(c)}$$

For each conditioning agent k is a constant and (c) is the gas-phase concentration of the conditioning agent. The dissociation products (SO_3 and NH_3) of $\text{NH}_2\text{SO}_2\text{OH}$ act independently and cumulatively in their effect on the resistivity of the fly-ash from Luscar coal.

The resistivity reductions produced by SO_3 , H_2SO_4 and $\text{NH}_2\text{SO}_2\text{OH}$ were accompanied by increases in precipitator efficiency from the base level of 85%. Maximum efficiencies were recorded at additive concentrations in the range 10-15 ppm SO_3 :

$$\begin{aligned} E_{\text{max}}(\text{SO}_3) &= 99\% \text{ at } 13 \text{ ppm } \text{SO}_3 \\ E_{\text{max}}(\text{H}_2\text{SO}_4) &= 98\% \text{ at } 10 \text{ ppm } \text{SO}_3 \\ E_{\text{max}}(\text{NH}_2\text{SO}_2\text{OH}) &= 95\% \text{ at } 10 \text{ ppm } \text{SO}_3 \end{aligned}$$

Ammonia was not found to be an effective conditioning agent with this coal:

$$E_{\text{max}}(\text{NH}_3) = 90\% \text{ at } 45 \text{ ppm } \text{NH}_3$$

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INTRODUCTION

A joint research project of Ontario Hydro and the Canada Centre for Mineral and Energy Technology has been carried out at the Canadian Combustion Research Laboratory to investigate the value of various fly-ash conditioning agents for enhancing electrostatic precipitator efficiency when using a selected low-sulphur coal. Plant experience had established that the substitution of a western Canadian bituminous coal (sulphur 0.5%) for an equivalent U.S. bituminous coal (sulphur 1.5%) could lead to an environmentally unacceptable degradation in precipitator efficiency from 99% to 70%.

The project called for a pilot-scale investigation of the effects of a series of conditioning agents on the physico-electrical characteristics of hot fly-ash particles. Particular attention was to be given to fly-ash electrical resistivity (abbreviated here to resistivity) and its relationship to the performance of a pilot-scale electrostatic precipitator.

THE EXPERIMENTAL PROGRAM

The Pilot-scale Boiler

The pilot-scale research boiler used in the combustion trials has been described elsewhere(1) and is illustrated in Figure I. The twin, opposed burners are fired tangentially into a refractory-lined furnace bottom and the incoming pulverised coal is ignited and largely burned-out prior to the flame being subjected to any significant thermal load.

The Experimental Coal

The coal used throughout the conditioning trials was the western Canadian bituminous coal known as Luscar. This coal contains over 30% of the relatively unreactive macerals, fusinite and semi-fusinite. (See Table 1). Exploratory combustion trials showed that the electrical resistivity of the fly-ash was strongly dependent on its carbon content and it was essential that this be held below 4% to ensure a base-line resistivity (i.e. no conditioning agent) above 1×10^{11} .

The mean values of the primary combustion conditions maintained throughout the experimental program are listed in Table 2.

The Flue-gas Conditioning Agents

The electrical resistivity of deposited fly-ash should not allow sparkover within the deposited material on the collecting electrodes. Ions generated by this characteristic "back corona" can neutralise the charge on incoming dust and reduce precipitator efficiency. This phenomenon is considered to be a potential problem when the resistivity is above 10^{10} ohm-cm(2).

The conditioning agents described in this report were selected because they produce surface films of polar molecules on the fly-ash and thereby facilitate a surface charge transfer through the layers of deposited dust. The conditioning agents used were SO_3 , H_2SO_4 , NH_3 and $\text{NH}_2\text{SO}_2\text{OH}$.

NH_3 , H_2SO_4 and $\text{NH}_2\text{SO}_2\text{OH}$ were injected as aqueous solutions immediately downstream of the air-heater giving a residence time of 3.0 seconds between the injection point and the electrostatic precipitator. SO_3 was injected at the same location in the gas-phase by evaporation from a stabilized liquid SO_3 (Sulfan).

Resistivity Measurements

Fly-ash resistivity was measured using a point-plane measuring probe inserted into the flue gases. Detailed descriptions of this type of probe have appeared elsewhere (2). Before measurements are taken the probe is allowed to reach thermal equilibrium with the gas stream and then a voltage sufficient to generate a corona is applied to the point which is located at the opposite end of the measuring cell. When an adequate dust layer has been collected the high voltage corona is displaced and the voltage/current characteristics of the dust layer and its thickness are measured and the resistivity calculated.

Electrostatic Precipitator Efficiency Measurements

Electrostatic precipitator efficiencies were calculated from measurements of the fly-ash concentrations at the inlet and outlet of the electrostatic precipitator. The inlet concentration was measured using an isokinetic sampling system developed at CCRL; this system contains a cyclone separator, a coarse filter and a fine filter in series and allows an approximate size distribution of the fly-ash to be obtained. Exploratory trials showed that the concentration profile was closely uniform across the inlet section of the precipitator and centre-line samples were generally representative of the overall concentration. Outlet dust loadings were measured simultaneously at three locations in the same plane of the outlet ductwork under isokinetic sampling conditions.

The usual procedure was to measure the particle concentration at the inlet to the precipitator immediately prior to operation of the precipitator. The precipitator was then operated for a 45-minute period during which time nine outlet dust samples were taken. The inlet dust

loading measurement was then repeated. Precipitator efficiencies were calculated using the mean values of these determinations.

FLY-ASH RESISTIVITY

The effect of four conditioning agents on fly-ash resistivity is shown in Figures 2, 3, 4 and 5. The experimental data indicate that, for all the conditioning agents used, the resistivity decreases to a limiting value as the gas phase concentration of the conditioning agent is increased. This suggests that surface adsorption and/or reaction of the conditioning agent has reached a saturation level producing a "saturation resistivity". The acidic conditioning agents (SO_3 , H_2SO_4 and $\text{NH}_2\text{SO}_2\text{OH}$) produce significantly greater reduction in fly-ash resistivity than the basic conditioning agent (NH_3).

The equation that has been fitted to the experimental data accomodates this behaviour:

$$\text{Log } (R) - \text{Log } (R_{\text{Sat}}) = Ae^{-k(c)}$$

where R = resistivity of fly-ash, ohm cm.

R_{Sat} = resistivity of fly-ash at saturation

c = gas-phase concentration of conditioning agent assuming no adsorption or reaction,

A, k = constants

At $c = 0$

A = $\text{Log } (R_0) - \text{Log } (R_{\text{Sat}})$

where R_0 = resistivity of fly-ash in the absence of conditioning agents

The resultant equation used to describe the data has the form:

$$\frac{\text{Log } (R) - \text{Log } (R_{\text{Sat}})}{\text{Log } (R_0) - \text{Log } (R_{\text{Sat}})} = e^{-k(c)}$$

The numerical value of R_o is a characteristic of the fly-ash and the values of R_{Sat} and k are characteristics of the interactions between the fly-ash and a specific conditioning agent.

An iteration of (R_{Sat}) was performed alternately with a linear least squares regression analysis to obtain the maximum correlation coefficient for the exponential function. In all cases the correlation coefficient for the curves illustrated was above 0.98.

In the absence of any synergy, the effect of NH_2SO_2OH on fly-ash resistivity should be the direct sum of the effects of its dissociation products, SO_3 and NH_3 . Combination of the equations representing 1) SO_3 and NH_3 effects on resistivity and 2) H_2SO_4 and NH_3 effects on resistivity are shown in Figure 6 where the curves have been superimposed on the experimental measurements of resistivity made during conditioning experiments using NH_2SO_2OH .

Figure 6 shows that the $(H_2SO_4 + NH_3)$ combination represents the NH_2SO_2OH data more closely. Both numerical combinations support the conclusion that SO_3 and NH_3 affect resistivity independently; it can be concluded that these two conditioning agents adsorb and/or react at different sites on the fly-ash surface. The active capacity of the fly-ash for NH_3 as defined by the $(R_o - R_{Sat})$ value is small and saturation of adsorption and/or reaction sites is complete at gas stream concentrations as low as 4 ppm equivalent NH_3 . The active capacity of the fly-ash for SO_3 as defined by the $(R_o - R_{Sat})$ value is greater and lies in the range 50 - 60 ppm equivalent SO_3 .

ELECTROSTATIC PRECIPITATOR EFFICIENCY

Electrostatic precipitator efficiencies measured during the combustion experiments are summarised in Figure 8. The acidic conditioning

agents improved precipitator efficiency significantly at all concentrations; a maximum efficiency was observed for each conditioning agent at closely similar equivalent SO_3 concentrations:

$$\begin{aligned} E_{\max} \text{SO}_3 &= 99\% \text{ at } 13 \text{ ppm equivalent } \text{SO}_3 \\ E_{\max} \text{H}_2\text{SO}_4 &= 98\% \text{ at } 10 \text{ ppm equivalent } \text{SO}_3 \\ E_{\max} \text{NH}_2\text{SO}_2\text{OH} &= 95\% \text{ at } 10 \text{ ppm equivalent } \text{SO}_3. \end{aligned}$$

The alkali conditioning agent (NH_3) produced less dramatic improvements in precipitator efficiency; a maximum efficiency was observed at an equivalent NH_3 concentration of 50 ppm:

$$E_{\max} \text{NH}_3 = 90\% \text{ at } 50 \text{ ppm equivalent } \text{SO}_3.$$

FLY-ASH RESISTIVITY AND PRECIPITATOR PERFORMANCE

It has been shown(3) that the collection efficiency of the charged particles in an electrostatic precipitator can be related to the collection surface area, the gas volume handled and the particle migration velocity by the equation:

$$\text{Efficiency \%} = 100 (1 - \exp(-Aw/Vg))$$

A = Collection surface area

V_g = Volume of gas handled

w = Particle migration velocity

This simplest form of fundamental collection equation has more than theoretical usefulness since it has been observed that experimental data from full scale units follows a relationship of the same form. The particle migration velocity is now calculated from performance data rather than from particle mechanics considerations and is called the Precipitation-rate Parameter. This parameter has been found to be related to fly-ash resistivity in the fashion illustrated in Figure 7(3).

The precipitator efficiency measurements made in these experiments were used to calculate a normalised precipitation-rate parameter as a function of the concentration of conditioning agent. The results of this calculation are presented in Figure 9 where it can be seen that both SO_3 and H_2SO_4 produce at least a doubling of the precipitation-rate parameter at all addition rates above 8 ppm equivalent SO_3 whereas $\text{NH}_2\text{SO}_2\text{OH}$ produced an increase of 50% in the same parameter.

The normalised precipitation rate parameter can be used in conjunction with the Deutsch-Anderson equation(3) to produce a tentative extrapolation of the experimental data from these trials to the actual situation when Luscar coal will be burned on a large scale. The precipitator from the following relationship:

$$E_2 = 100 \left(\frac{E_1}{100} - 1 \right) \left(\exp(-A(N-1)w_1/V_g) \right) + 1$$

E_1 = Full scale precipitator efficiency;

E_2 = Full scale precipitator efficiency

A = Collection surface area

V_g = Volume of gas handled

w_1 = Precipitation-rate parameter measured without conditioning

N = Precipitation-rate parameter ratio, determined appropriately from Figure 8.

This tentative prediction procedure incorporates effects due to resistivity changes and particle aggregation when using these conditioning agents but does not make any allowance for re-entrainment due to rapping.

CONCLUSIONS

Pilot-scale experiments have shown that the use of SO_3 , H_2SO_4 , and $\text{NH}_2\text{SO}_2\text{OH}$ significantly reduced the resistivity of the fly-ash from Luscar coal. The reductions approached a limiting value as the concentration of conditioning agent was increased. It appears that the dissociation products (SO_3 and NH_3) of $\text{NH}_2\text{SO}_2\text{OH}$ are independent and additive in their effect on the resistivity of the fly-ash from this coal.

The reduced resistivity produced by these conditioning agents was accompanied by an increase in precipitator efficiency which reached a maximum in the concentration range 10 - 15 ppm equivalent SO_3 .

$$E_{\max} \text{SO}_3 = 99\% \text{ at } 13 \text{ ppm equivalent } \text{SO}_3;$$

$$E_{\max} \text{H}_2\text{SO}_4 = 98\% \text{ at } 10 \text{ ppm equivalent } \text{SO}_3;$$

$$E_{\max} \text{NH}_2\text{SO}_2\text{OH} = 95\% \text{ at } 10 \text{ ppm equivalent } \text{SO}_3.$$

The use of NH_3 as a conditioning agent produced a reduction of one order of magnitude in the fly-ash resistivity at all concentrations and a maximum precipitator efficiency of 90% at an equivalent NH_3 concentration of 45 ppm.

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TABLE 10

Proximate, Ultimate and Maceral Analyses
of the Western Canadian Bituminous Coal (Luscar)
as Fired

Proximate

Moisture	% wt	5.54
Ash	% wt	13.36
Volatile	% wt	31.96
Fixed Carbon	% wt	49.14

Ultimate

Carbon	% wt	63.73
Hydrogen	% wt	4.18
Sulphur	% wt	0.36
Nitrogen	% wt	1.06
Ash	% wt	13.36
Oxygen	% wt	12.27

Calorific Value

(Gross)	Btu/lb	11030
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Maceral Component

Vitrinite	% vol	52.2
Micrinite	% vol	5.8
Fusinite	% vol	17.4
Semi Fusinite	% vol	16.8
Exinite	% vol	7.8

TABLE 2

Combustion Conditions throughout the Experimental Period

Combustion Condition		Mean Value	RMS Deviation
Firing Rate	kg/hr	73.5	± 3.5
Steaming Rate	kg/hr	548	±23.6
CO ₂	%	16.0	± 0.5
O ₂	%	3.2	± 0.5
Fly-ash Loading	g/m ³	2.751	± 0.565
Combustible Content of Fly-ash	%	3.22	± 2.4

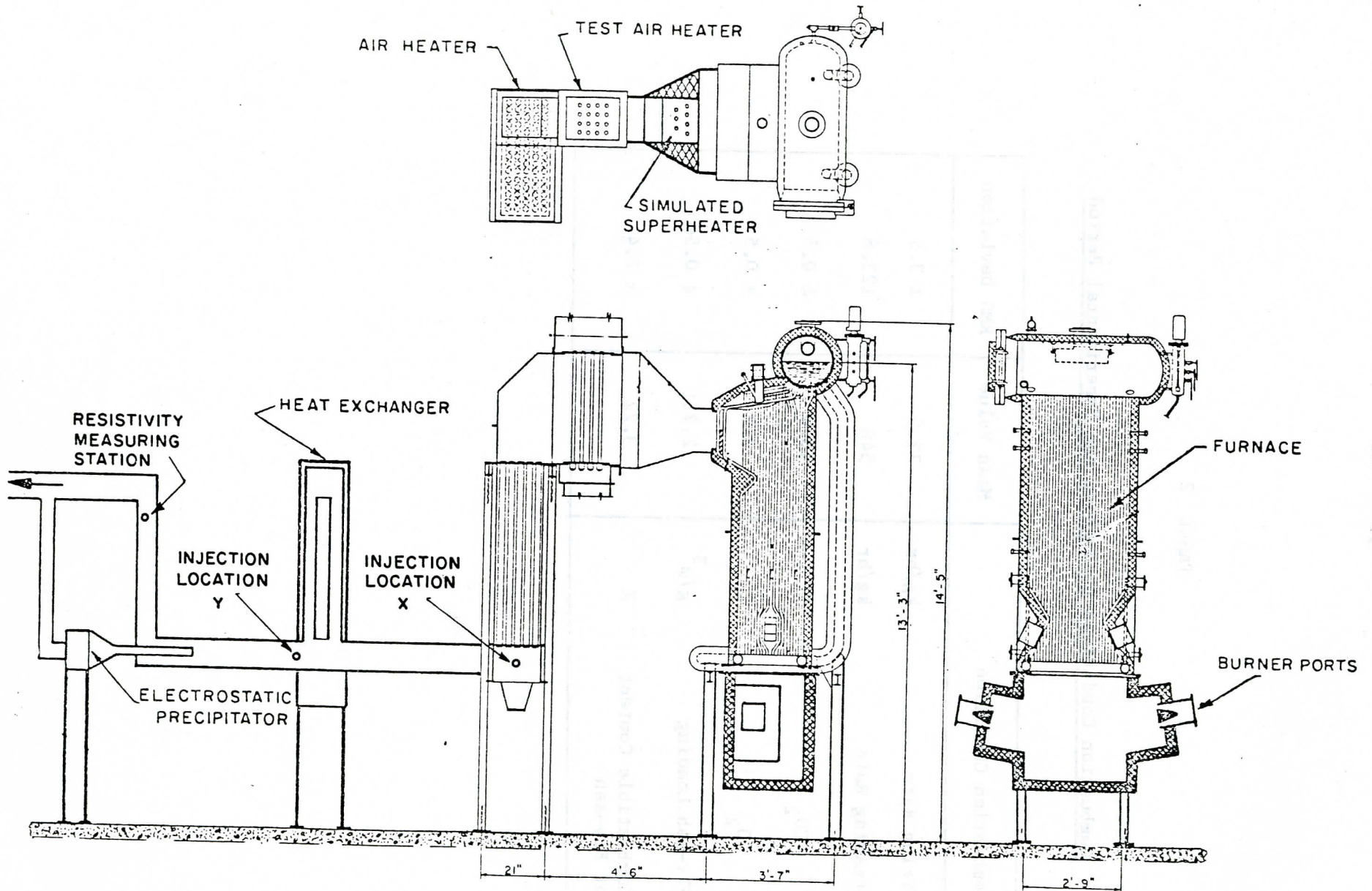


FIGURE 1. The Pilot-scale Research Boiler

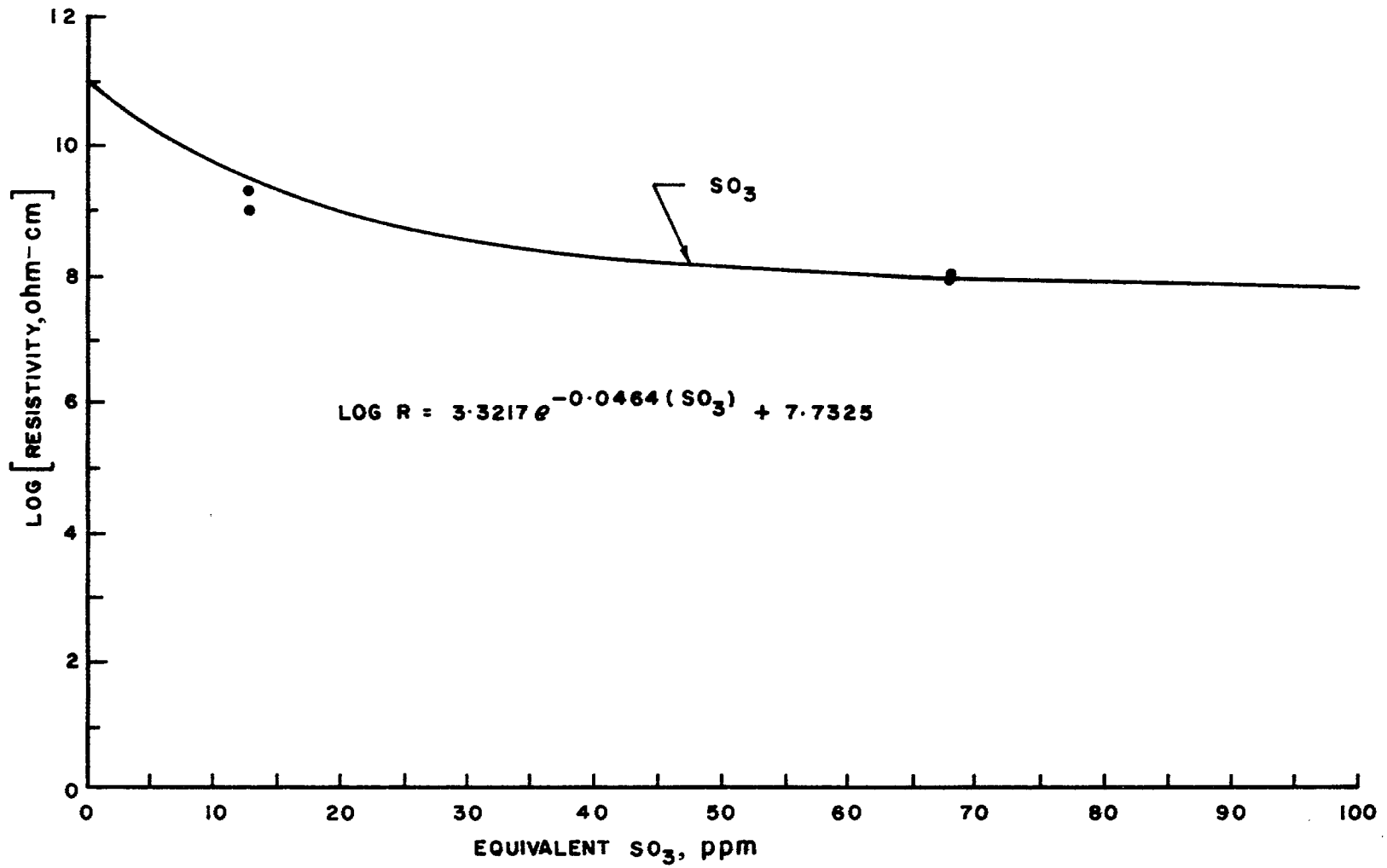


Figure 2: The Effect of SO₃ on Fly-ash Resistivity

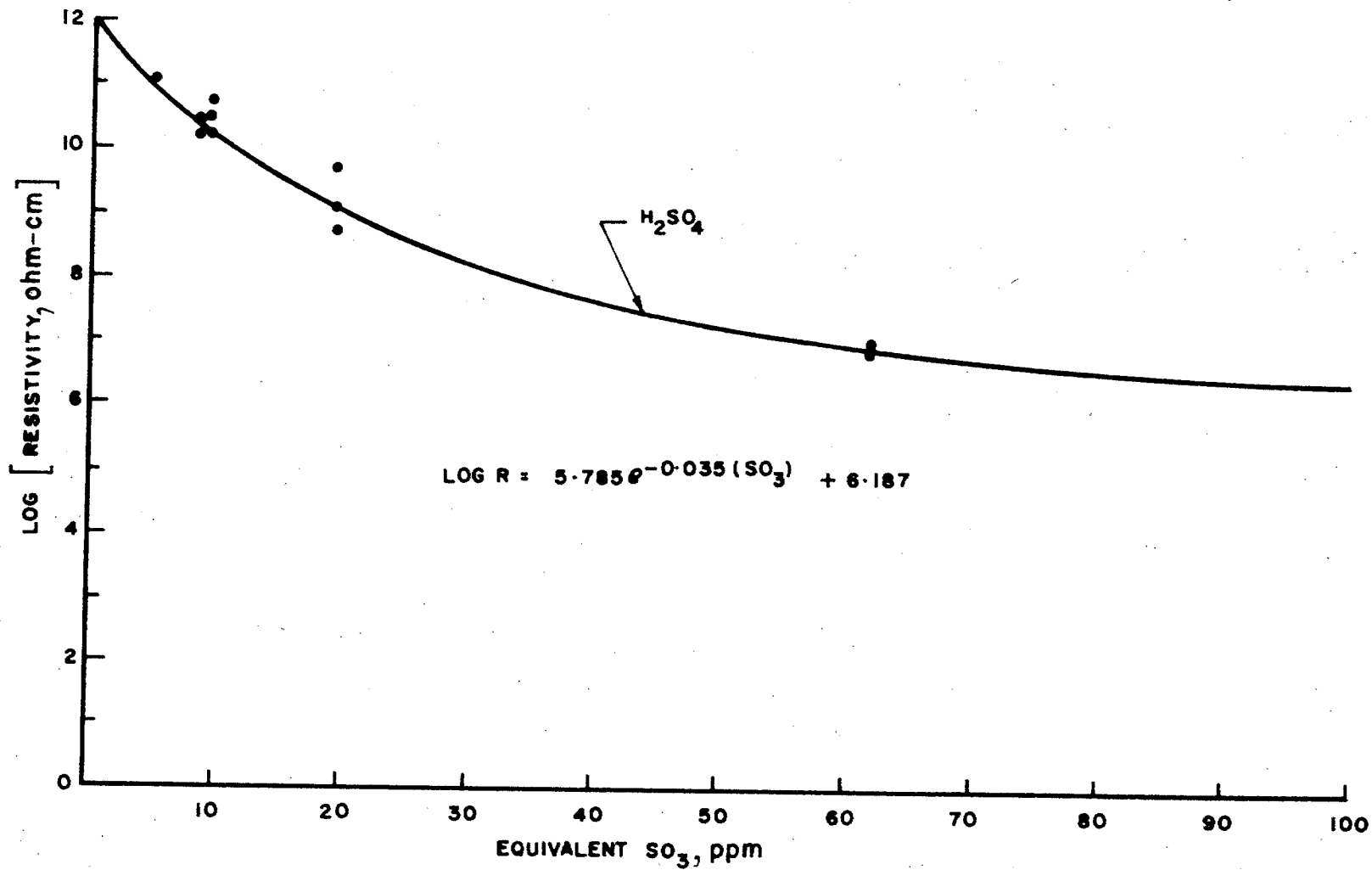


Figure 3: The Effect of H₂SO₄ on Fly-ash Resistivity

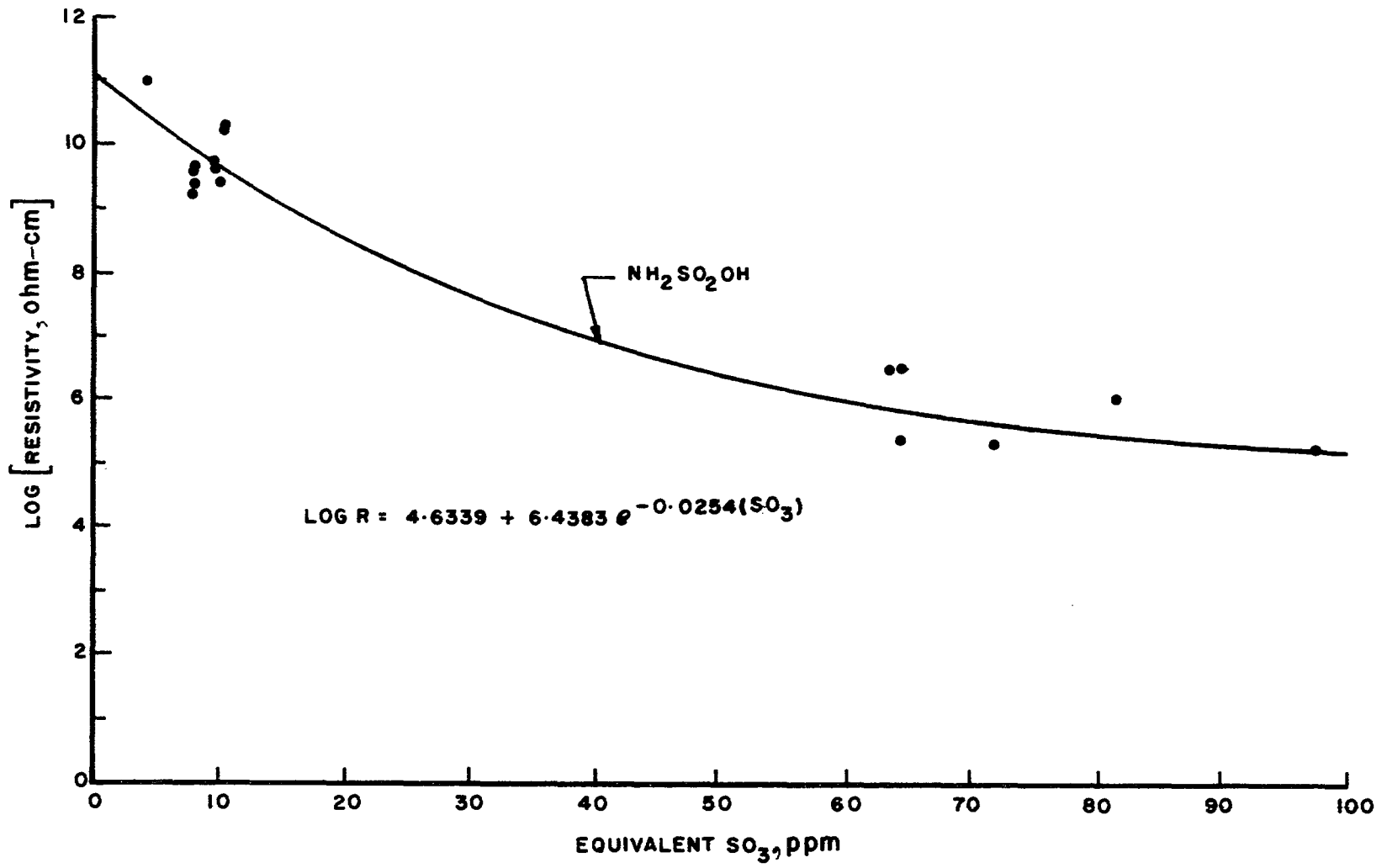


Figure 4: The Effect of NH₂SO₂OH on Fly-ash Resistivity

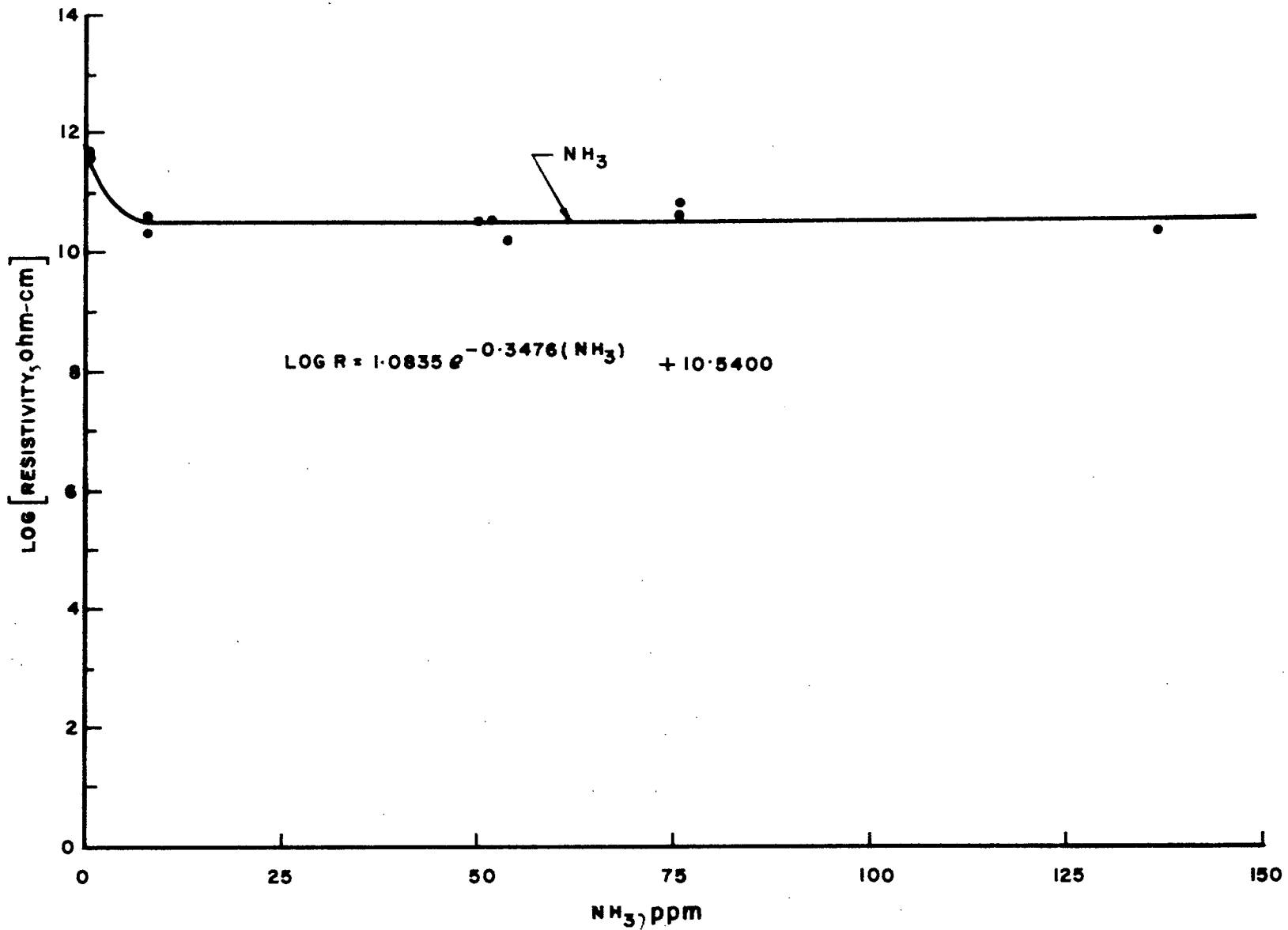


Figure 5: The Effect of NH₃ on Fly-ash Resistivity

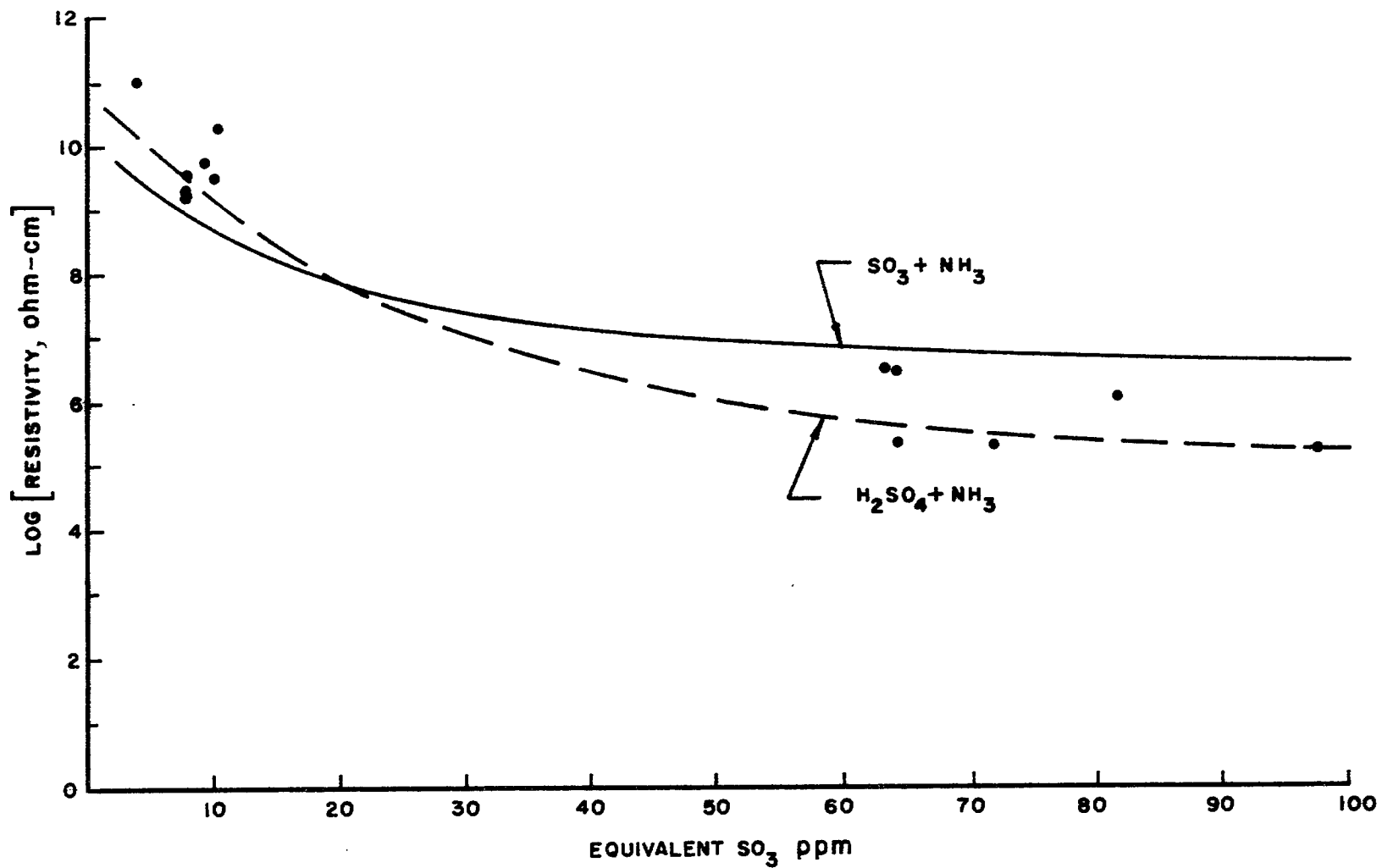


Figure 6: Predicted Effect of (NH₂ + SO₃) and (NH₃ + H₂SO₄) on Fly-ash Resistivity and Comparison with Experimental Data from NH₂SO₂OH Addition

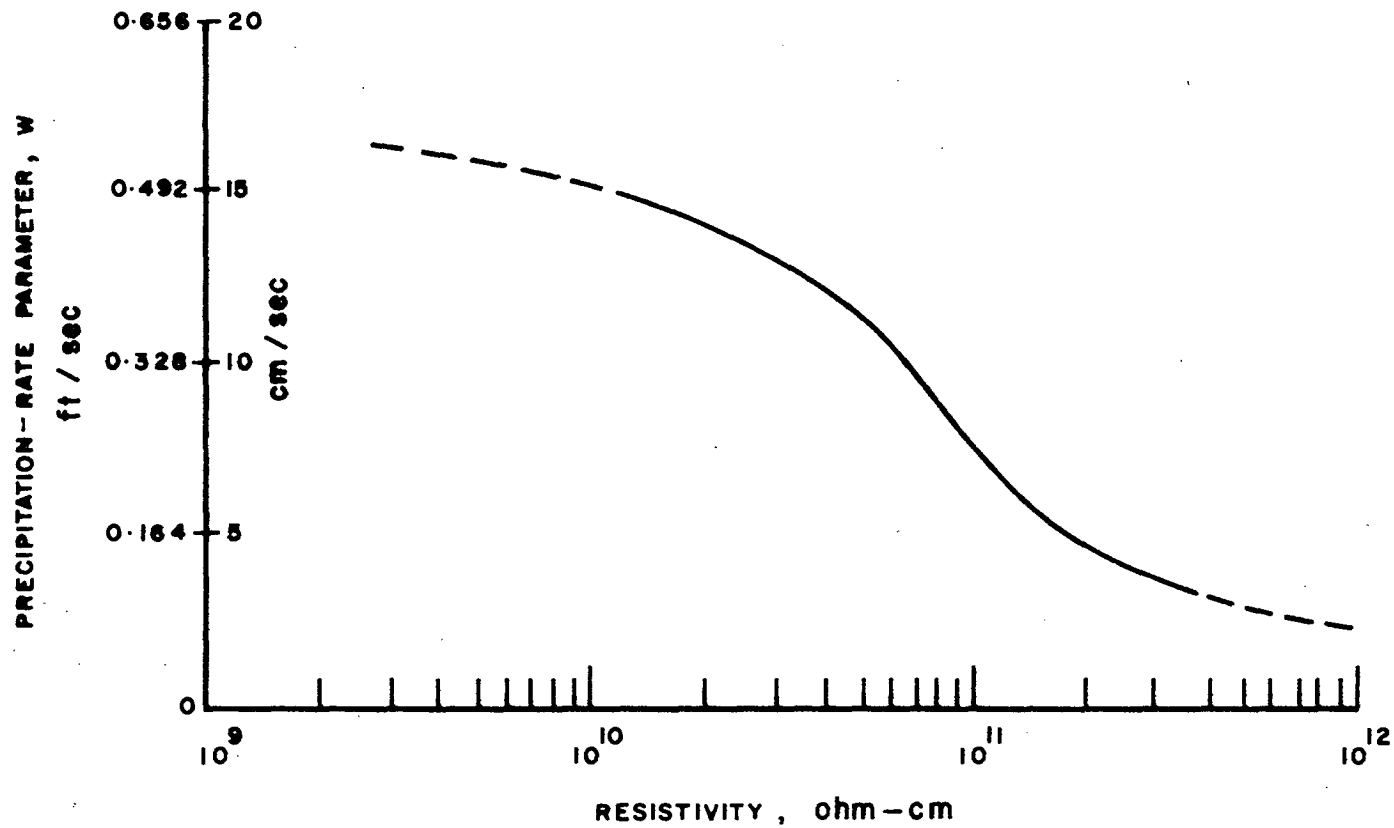


Figure 7: The Effect of Resistivity on Precipitation-rate Parameter (after White)

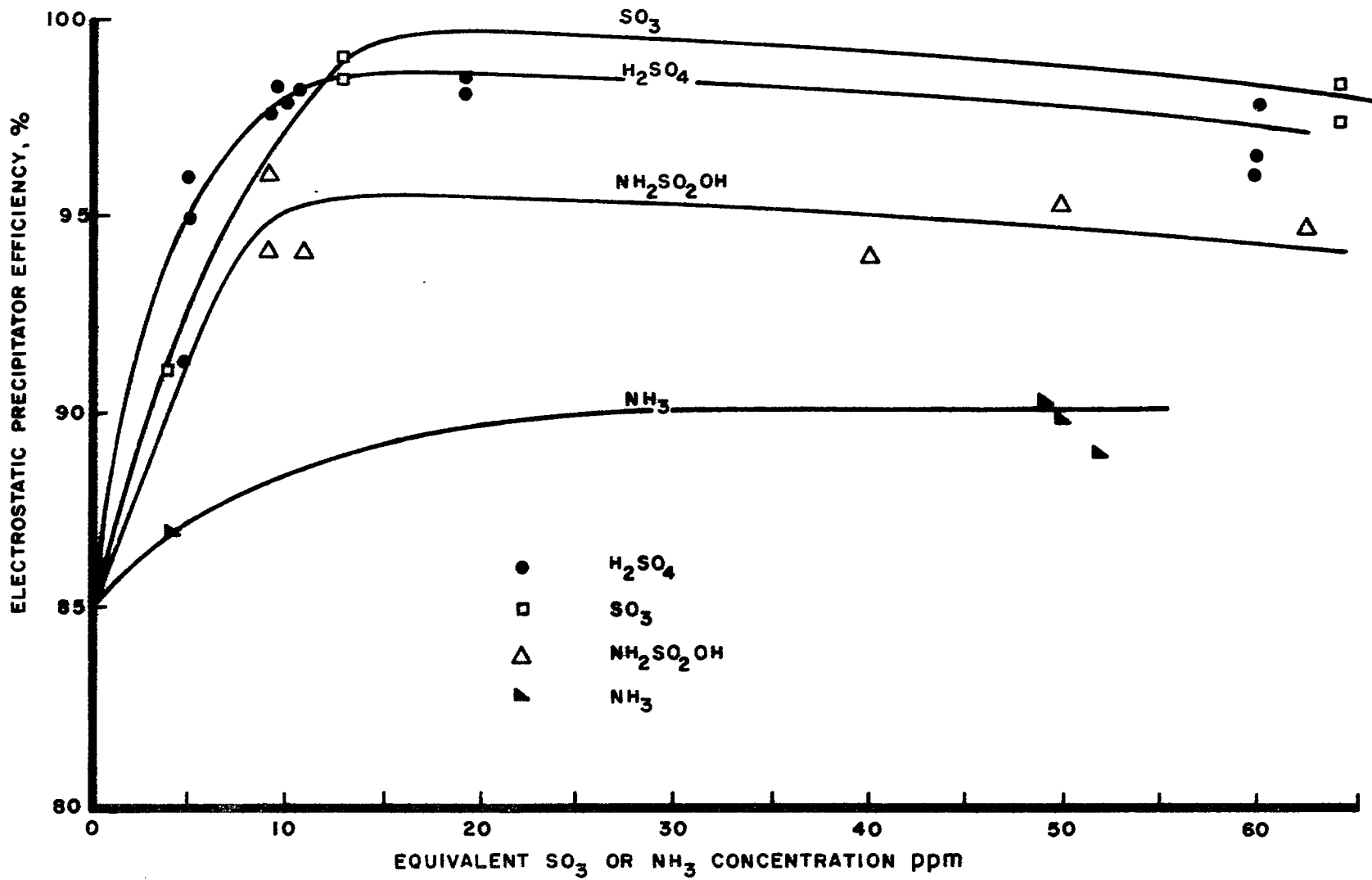


FIGURE 8 The Effect of the Conditioning Agents on Electrostatic Precipitator Efficiency

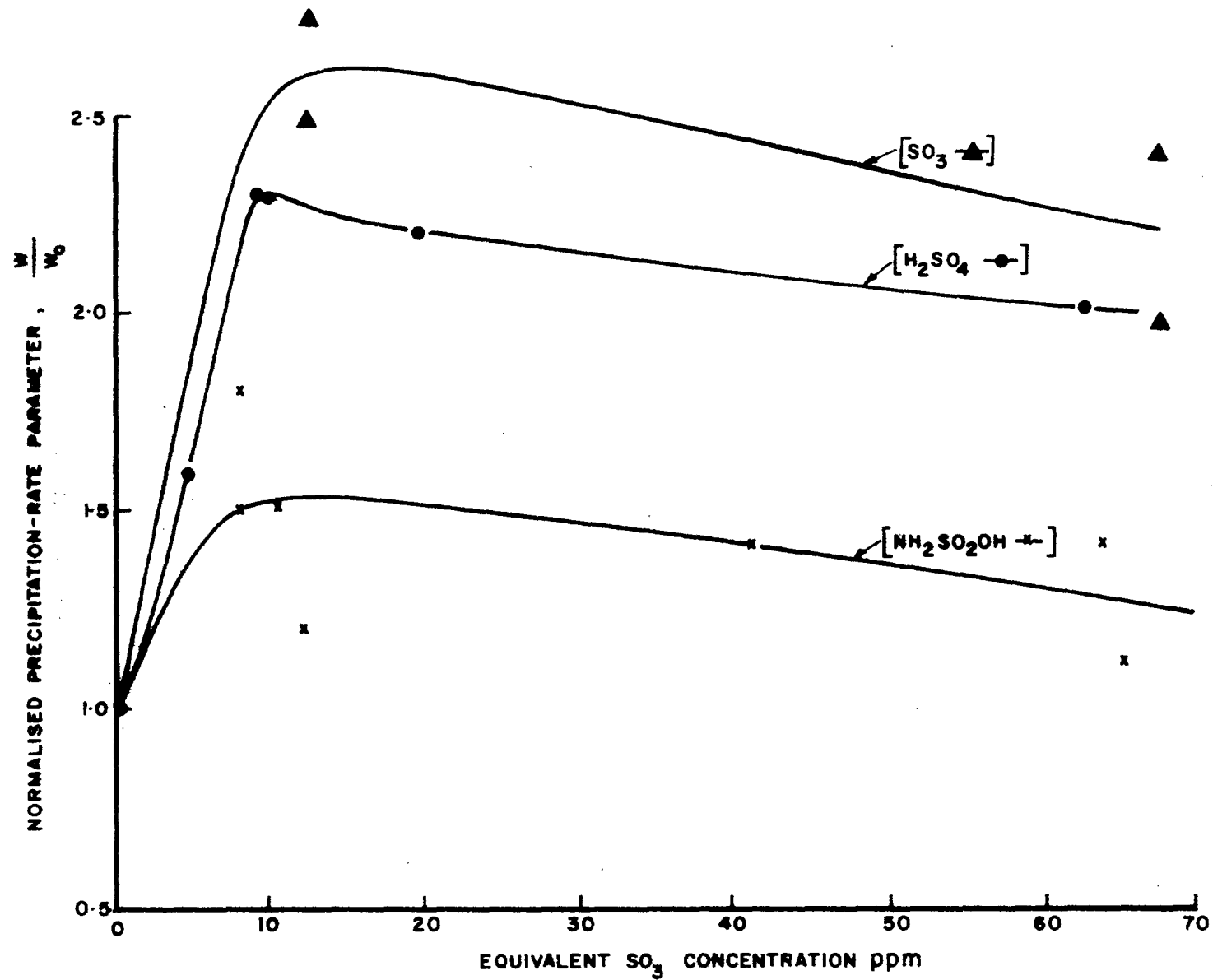


Figure 9: The Effect of SO₃, H₂SO₄ and NH₂SO₂OH on the Normalized Precipitation-rate Parameter