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MODIFICATION OF ELECTROSTATIC PRECIPITATOR
PERFORMANCE BY USE OF FLY-ASH CONDITIONING AGENTS

T. D. Brown, G. K. Lee and N. Sekhar

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MODIFICATION OF ELECTROSTATIC PRECIPITATOR PERFORMANCE
BY USE OF FLY-ASH CONDITIONING AGENTS

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T. D. Brown*, G. K. Lee** and N. Sekhar***

ABSTRACT

Pilot-scale (75 kg/h) combustion trials using a pulverized western Canadian coal of low sulphur content have shown that fly-ash resistivity can be significantly modified by use of SO_3 , H_2SO_4 , $\text{NH}_2\text{SO}_2\text{H}$, NH_3 , $(\text{NH}_4)_2\text{SO}_4$, $(\text{C}_2\text{H}_5)_3\text{N}$ and Na_2SO_4 as fly-ash conditioning agents. These conditioning agents were added as solutions to the combustion products and also, in some instances, as solids in the coal feed to the pulverizer.

The measured fly-ash resistivity was found to decrease exponentially from its base level of 5×10^{11} ohm-cm to a limiting value as the concentration of the conditioning agent increased. Optimum electrostatic precipitator efficiency always occurred at a resistivity of 5×10^9 ohm-cm. Reduced resistivity, however, was not always synonymous with improved precipitator performance.

* Research Scientist, ** Manager, Canadian Combustion Research Laboratory, Energy Research Laboratories, Canada Centre for Mineral and Energy Technology (CANMET), Department of Energy, Mines and Resources, Ottawa, Canada. *** Research Chemist, Chemical Research Department, Ontario Hydro, Toronto, Canada.

CONTENTS

	<u>Page</u>
Abstract	i
Contents	ii
Introduction	1
Experimental Program	1
Pilot-scale Boiler	1
Flue-gas Conditioning Agents	1
Resistivity Measurements	2
Electrostatic Precipitator Efficiency Measurements	2
Effect of Conditioning Agents on Fly-ash Resistivity	3
Effect of Conditioning Agents on Precipitation Rate Parameter	4
Conclusions	5
References	5

TABLES

<u>No.</u>	<u>Page</u>
1. Analysis of the Experimental Coal	7

FIGURES

<u>No.</u>	<u>Page</u>
1. Pilot-scale Research Boiler	8
2. Effect of Selected Conditioning Agents on Fly-ash Resistivity {SO ₃ , H ₂ SO ₄ , NH ₂ SO ₂ OH, NH ₃ }	9
3. Effect of Selected Conditioning Agents on Fly-ash Resistivity {(NH ₄) ₂ SO ₄ and (C ₂ H ₅) ₃ N}	10
4. Effect of Sodium Sulphate on Fly-ash Resistivity	11
5. Effect of Selected Conditioning Agent on Electrostatic Precipitator Performance {SO ₃ , H ₂ SO ₄ , NH ₂ SO ₂ OH, NH ₃ }	12
6. Effect of Selected Conditioning Agents on Electrostatic Precipitator Performance {(NH ₂) ₂ SO ₄ and (C ₂ H ₅) ₃ N}	13

7.	Effect of Na_2SO_4 on Electrostatic Precipitator Performance	14
8.	Enhancement of the Precipitation Rate Parameter	15

INTRODUCTION

A joint research project between Ontario Hydro and the Canadian Combustion Research Laboratory (CCRL) was commenced in October 1975 to investigate the potential of various conditioning agents for enhancing electrostatic precipitator efficiency when burning low-sulphur coals. The work was done as part of the CANMET Energy Research Program which is dedicated to energy self-reliance through such approaches as advancing the utilization of Canadian coals.

The effects of selected conditioning agents on the physico-electrical characteristics of hot fly-ash particles were evaluated in a pilot-scale research boiler designed to accurately duplicate combustion conditions in full-scale boilers.

The coal used was a western Alberta bituminous coal, containing 0.3% sulphur, 13% ash and more than 30% low-reactivity macerals. Exploratory combustion trials showed that the fly-ash electrical resistivity was strongly dependent on its combustible content which must be held below 4% to ensure a baseline resistivity (i.e. no conditioning agent) above 1×10^{11} ohm-cm. Combustible content was in turn dictated to a certain degree by the concentration of low-reactivity macerals such as semi-fusinite and fusinite in the coal structure.

EXPERIMENTAL PROGRAM

Pilot-scale Boiler

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

Flue-gas Conditioning Agents

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

The conditioning agents described in this paper 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 sulphur trioxide, SO_3 ; sulphuric acid, H_2SO_4 ; ammonia, NH_3 ; sulphamic acid, $\text{NH}_2\text{SO}_2\text{OH}$; ammonium sulphate, $(\text{NH}_3)_2\text{SO}_4$; sodium sulphate Na_2SO_4 ; and triethylamine, $(\text{C}_2\text{H}_5)_3\text{N}$.

SO_3 was injected by evaporation from stabilized liquid SO_3 (tradename Sulfan) immediately downstream of the air heater giving a residence time of 3 seconds between the injection point and the electrostatic precipitator. The remaining conditioning agents were injected as aqueous solutions at the same location. Sodium sulphate was also injected into the pulverizer.

Resistivity Measurements

In-situ fly-ash resistivity was measured using a point-plane measuring probe inserted into the flue gases(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 at one end of a measuring cell. Fly ash deposits electrostatically on the plane at the opposite end of the cell. When an adequate dust layer has been collected, the high voltage corona is removed and the voltage/current characteristics of the dust layer and its thickness are measured; the resistivity is then calculated.

Electrostatic Precipitator Efficiency Measurements

Electrostatic precipitator efficiencies were calculated from measurements of fly-ash concentrations at the precipitator inlet and outlet. 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 relatively flat across the inlet section of the precipitator; thus, 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 precipitator inlet immediately prior to a 45-minute operation of the precipitator, 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.

EFFECT OF CONDITIONING AGENTS ON FLY-ASH RESISTIVITY

The effect of the conditioning agents on fly-ash resistivity is shown in Figures 2, 3 and 4. The experimental data indicate that, with the exception of Na₂SO₄ conditioning the resistivity decreased to a limiting value as the gas phase concentration of the conditioning agent increased. This suggests that surface adsorption and/or reaction of the conditioning agent has reached a saturation level, producing a "saturation resistivity".

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

$$\text{Log } R - \text{Log } R_S = A e^{-k(c)}$$

where R = resistivity of fly ash, ohm-cm

R_S = resistivity of fly ash at saturation

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

A, k = constants

At $c = 0$,

$A = \text{Log } R_0 - \text{Log } R_S$

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

The resultant equation used to describe the data is:

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

The numerical value of R_0 is a characteristic of the fly ash and the values of R_S and k are characteristics of the interactions between the fly ash and a specific conditioning agent.

In the absence of any synergy, the effect of aqueous NH₂SO₂OH on fly-ash resistivity should be the direct sum of the effects of its dissociation products, SO₃ and NH₃. Combination of the equations representing SO₃ and NH₃ effects on resistivity with those representing dilute H₂SO₄ and NH₃ effects on resistivity showed that the H₂SO₄ + NH₃ combination represents

the $\text{NH}_2\text{SO}_2\text{OH}$ data more closely. Both numerical combinations supported conclusions 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 effect on fly-ash resistivity when triethylamine was injected as an aqueous solution at the exit from the air heater is shown in Figure 3. The injection rate, which has been reported as "Equivalent $(\text{C}_2\text{H}_5)_3\text{N}$ ", has been calculated from the measured injection rates and flue gas velocities assuming no dissociation or decomposition of the triethylamine. Figure 3 shows that across the concentration range investigated, the fly-ash resistivity was between 10^{10} and 10^9 ohm-cm. This represents a reduction of about two orders of magnitude from the base level of 4×10^{11} ohm-cm.

There is some evidence of a continued decrease in resistivity as the triethylamine injection rate increased but this is masked by the scatter in the data. The results are analogous to those recorded using ammonia as a conditioning agent, in which case injection rates across the concentration range 4 ppm to 140 ppm equivalent NH_3 produced an essentially constant resistivity.

One singular characteristic of triethylamine was its capacity to maintain resistivity values below 10^{10} ohm-cm for 16 h after injection was stopped. With all other conditioning agents stopping the injection produced an instantaneous reversion of the fly-ash resistivity to its baseline level. This unique memory effect of triethylamine persisted even after the boiler fireside surfaces were water washed.

EFFECT OF CONDITIONING AGENTS ON PRECIPITATION RATE PARAMETER

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:

$$\text{Efficiency } \% = 100 \left[(1 - \exp(-Aw/V)) \right],$$

where A = collection surface area

V = volume of gas handled

w = particle migration velocity

This fundamental collection equation has more than theoretical usefulness since it has been observed that experimental data from full-scale units follow 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.

Precipitator efficiency measurements made in these experiments (see Figures 5, 6 and 7) were used to calculate a normalized precipitation-rate parameter; $N = \frac{w_2}{w_1}$ where w_2 and w_1 are the precipitation-rate parameters with and without a conditioning agent respectively.

Calculated values of the precipitation-rate parameter ratio for the conditioning agents that produced improvement in precipitator performance are shown in Figure 8. The inorganic acid conditioning agents (SO_3 , H_2SO_4) produced more than a two-fold increase in the precipitation rate parameter whereas the two amino-compounds NH_2SO_2OH and $(C_2H_5)_3N$ produced an increase of less than 50%.

CONCLUSIONS

Pilot-scale experiments have shown that the use of SO_3 , H_2SO_4 , NH_2SO_2OH and $(C_2H_5)_3N$ reduced the electrical resistivity of fly ash from an Alberta bituminous coal; these resistivity changes were accompanied by a marked increase in electrostatic precipitator efficiency from 85% to values ranging between 90% and 99%.

Reductions in resistivity were not, however, inevitably accompanied by improved electrostatic precipitator performance. Use of Na_2SO_4 reduced fly-ash resistivity from 5×10^{11} to 1×10^9 ohm-cm and increased precipitator performance from 75% to between 80% and 85%, while $(NH_4)_2SO_4$ reduced fly-ash resistivity from 5×10^{11} to 7×10^8 ohm-cm but also reduced precipitator efficiency from 75% to below 50%.

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2. Southern Research Institute, Birmingham, Alabama, "A Manual of Electrostatic Precipitator Technology. Part 1 - Fundamentals". Prepared under Contract CPA 22-69-77 for the National Air Pollution Control Association, Division of Process Control Engineering.
3. Deutsch., W., "Ann. der Physik". 68 1922. pp 335 et seq.

TABLE 1

Analysis of the Experimental Coal	
Proximate Analysis, %	
Moisture	6.30
Ash	12.91
Volatile Mater	31.70
Fixed Carbon	49.09
Ultimate Analysis, %	
Carbon	63.41
Hydrogen	4.32
Sulphur	0.31
Nitrogen	0.95
Oxygen	11.80

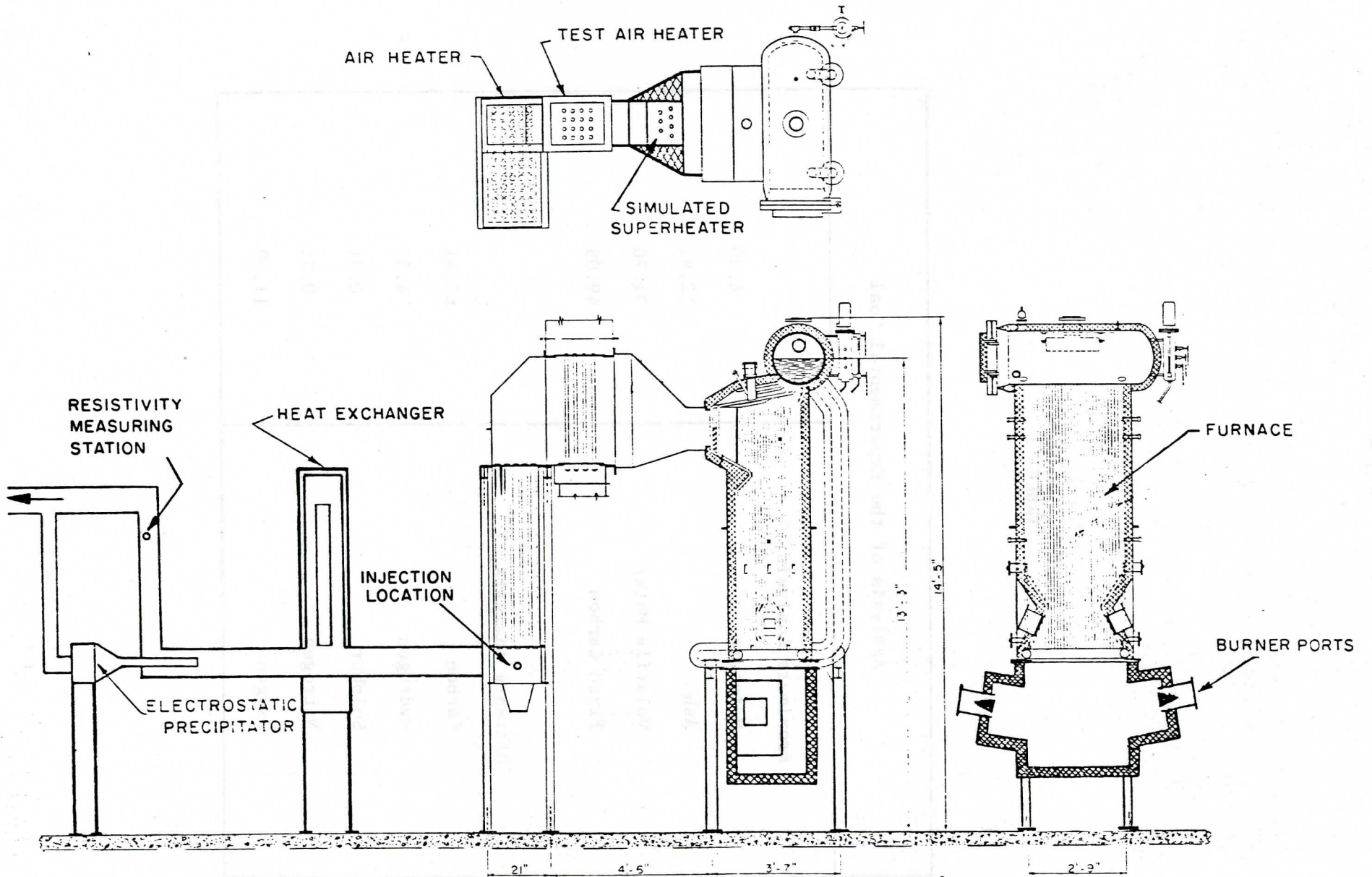


FIGURE 1. Pilot-scale Research Boiler

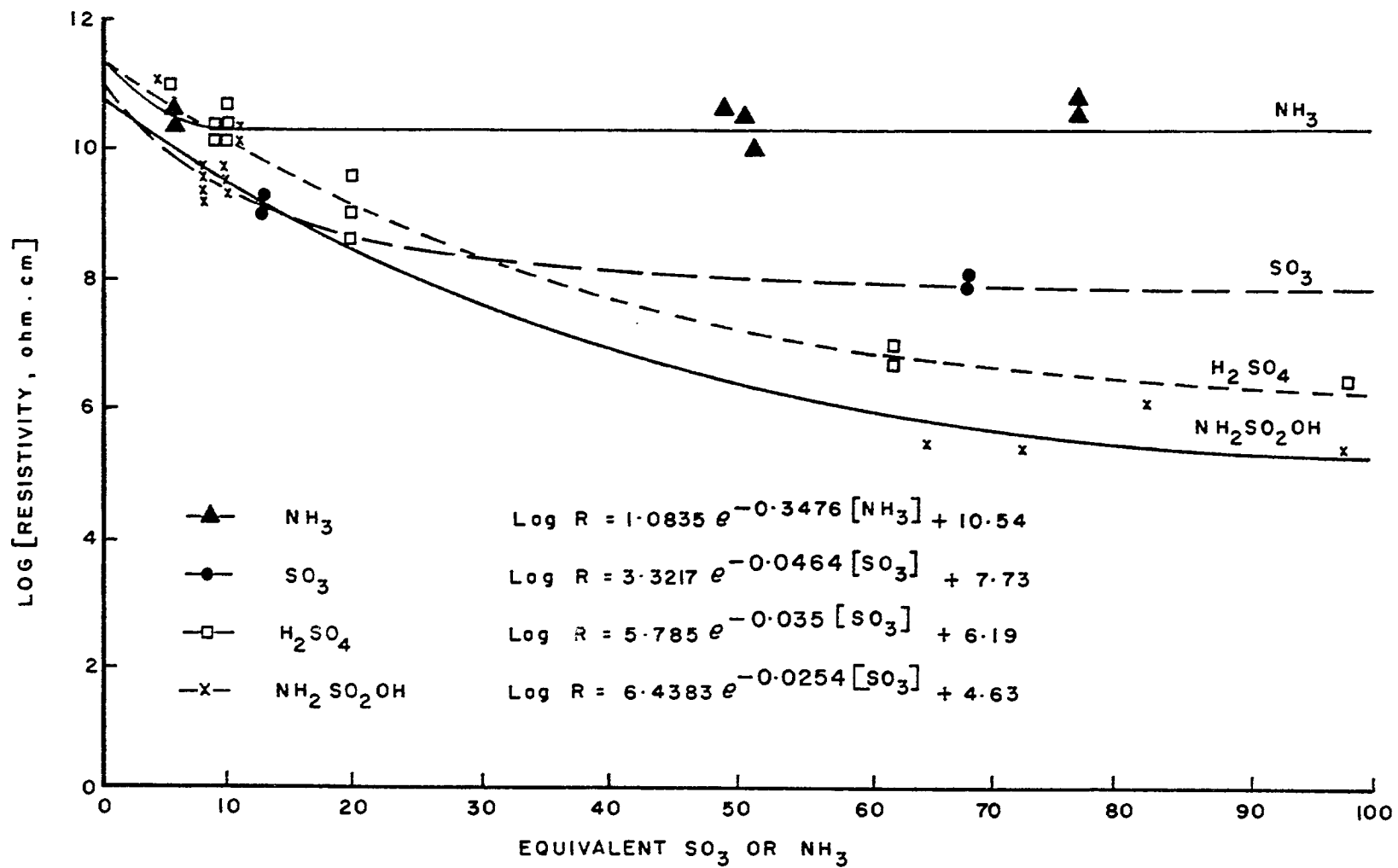


FIGURE 2. Effect of Selected Conditioning Agents on Fly-ash Resistivity { SO_3 , H_2SO_4 , $\text{NH}_2\text{SO}_2\text{OH}$, NH_3 }

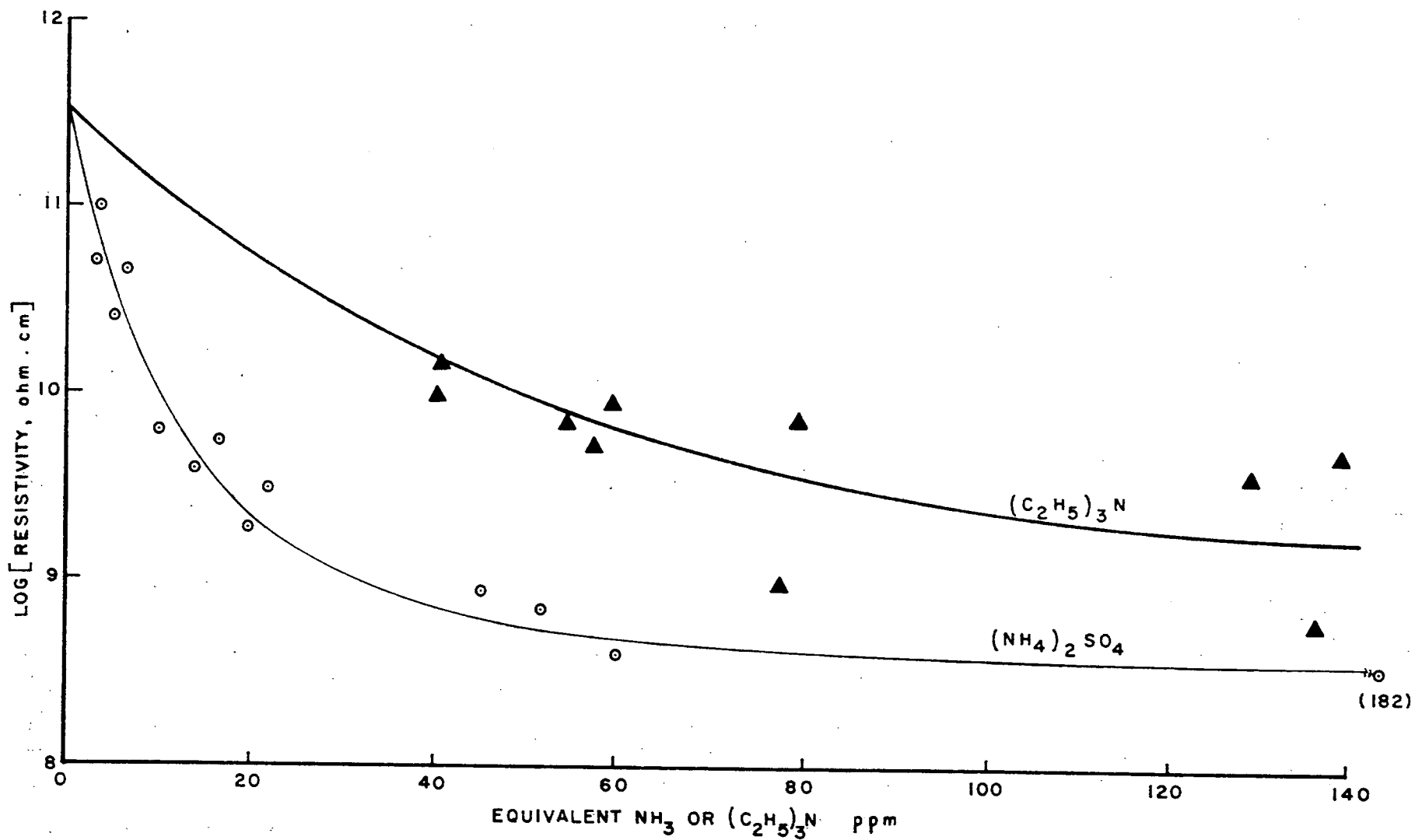


FIGURE 3. Effect of Selected Conditioning Agents on Fly-ash Resistivity $\{(NH_4)_2SO_4$ and $(C_2H_5)_3N\}$

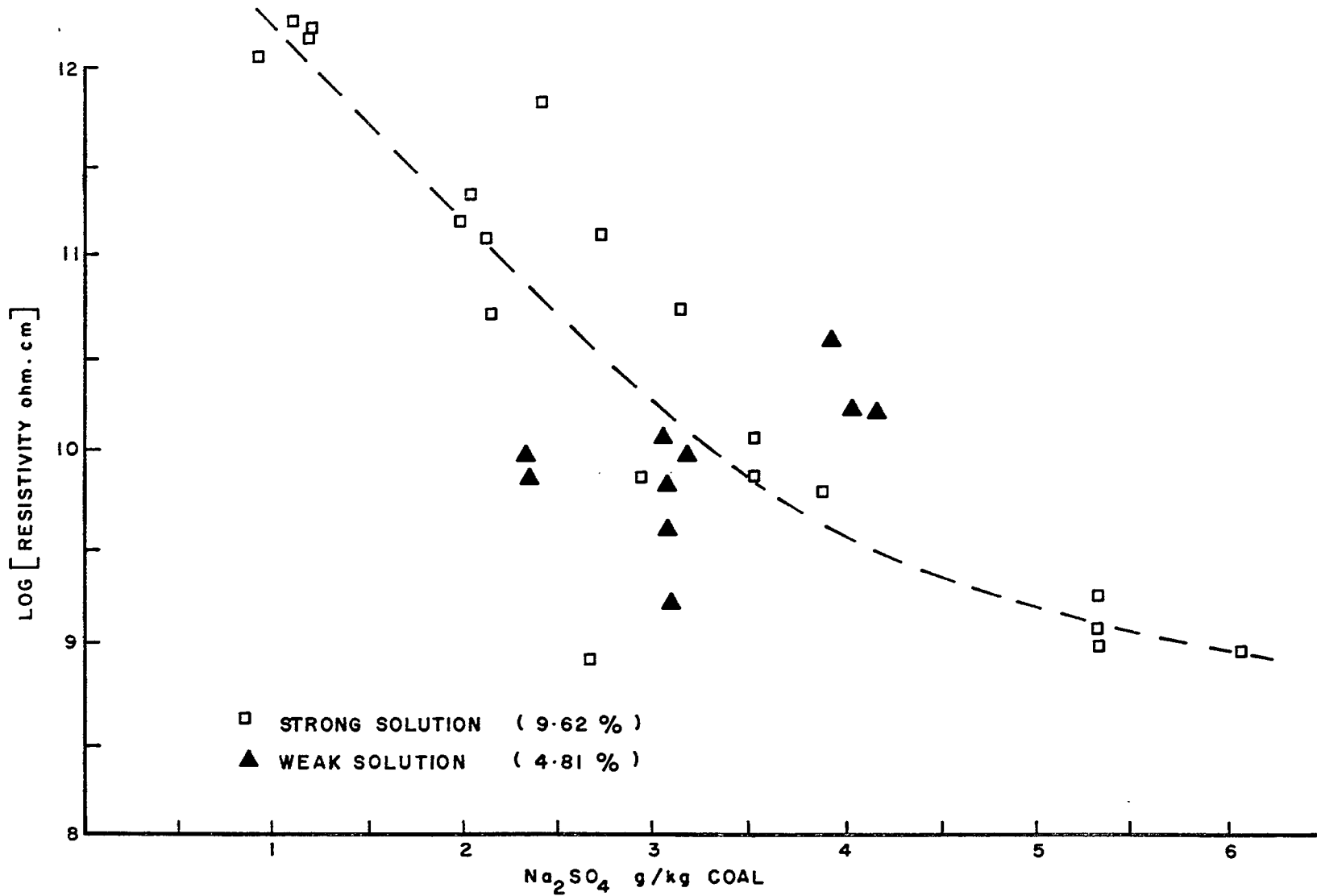


FIGURE 4. Effect of Sodium Sulphate on Fly-ash Resistivity

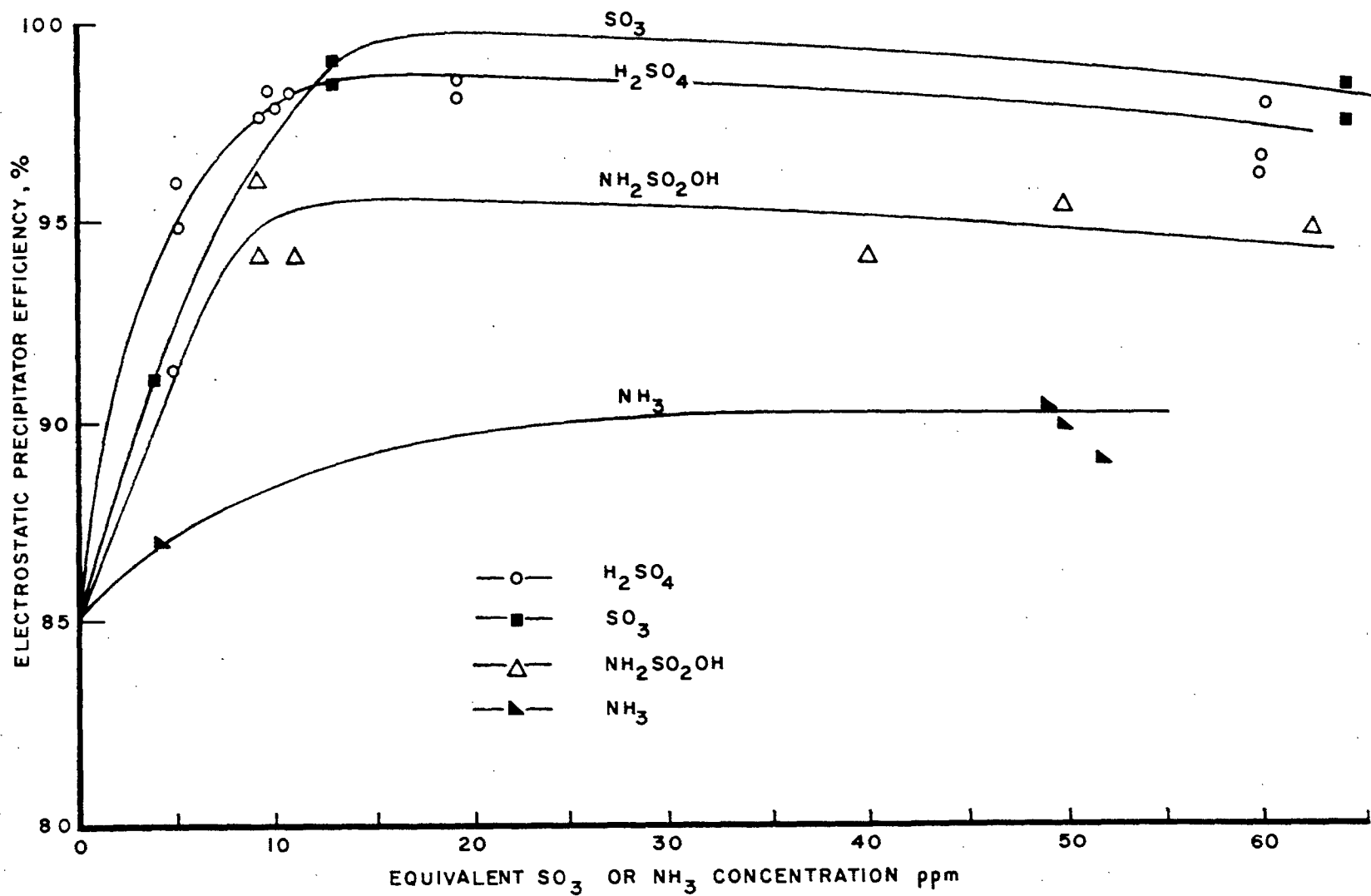


FIGURE 5. Effect of Selected Conditioning Agents on Electrostatic Precipitator Performance { SO_3 , H_2SO_4 , $\text{NH}_2\text{SO}_2\text{OH}$, NH_3 }

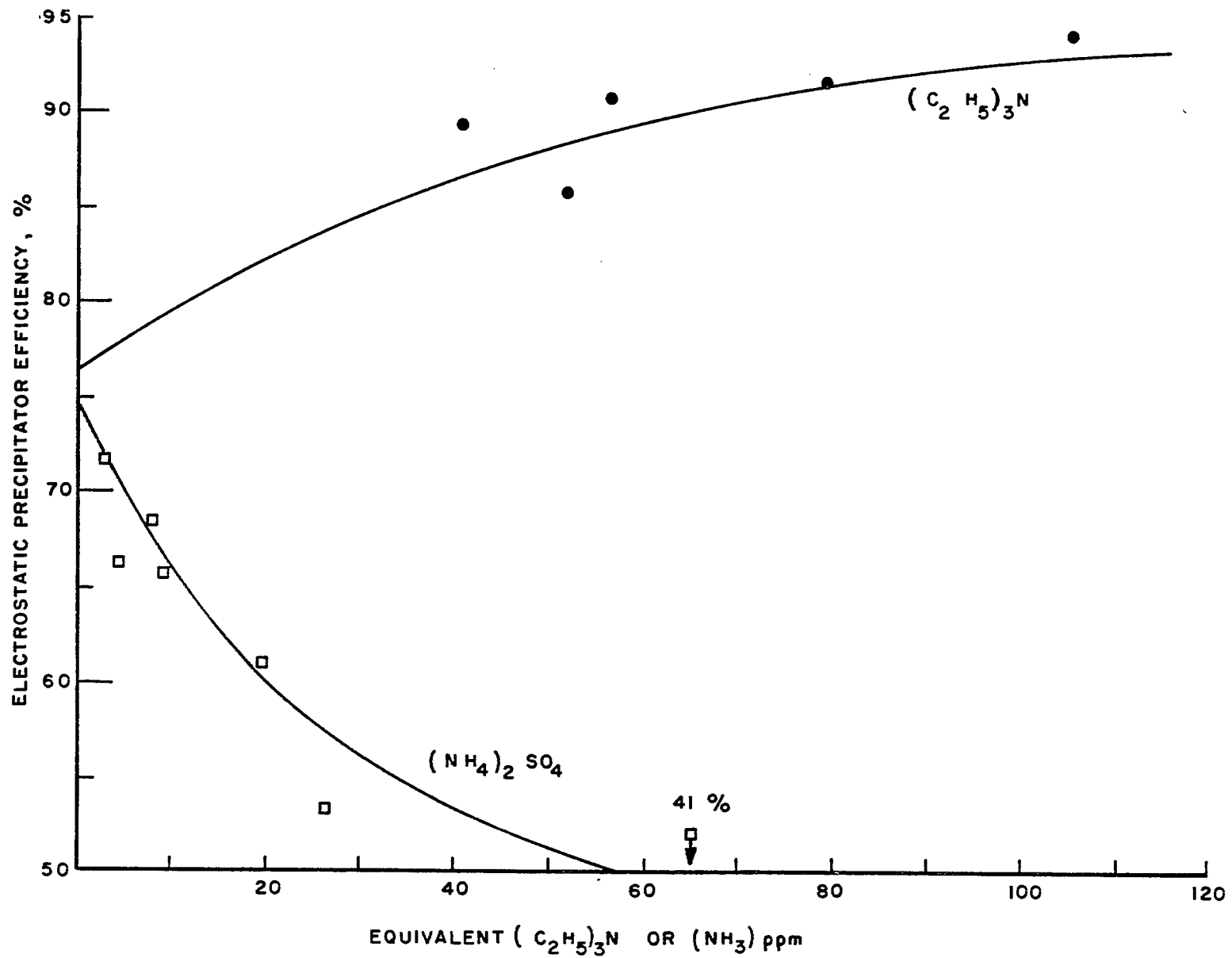


FIGURE 6. Effect of Selected Conditioning Agents on Electrostatic Precipitator Performance $\{(NH_2)_2SO_4$ and $(C_2H_5)_3N\}$

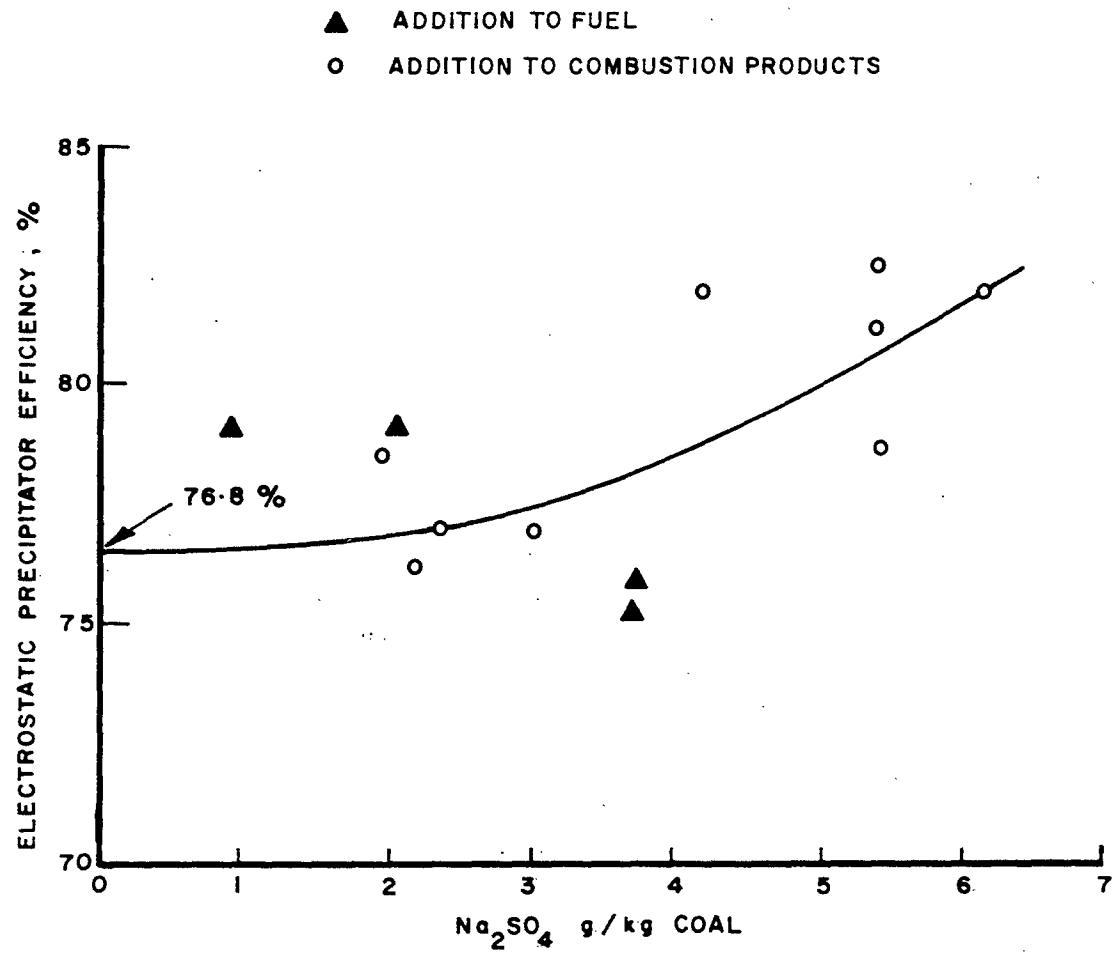


FIGURE 7. Effect of Na₂SO₄ on Electrostatic Precipitator Performance

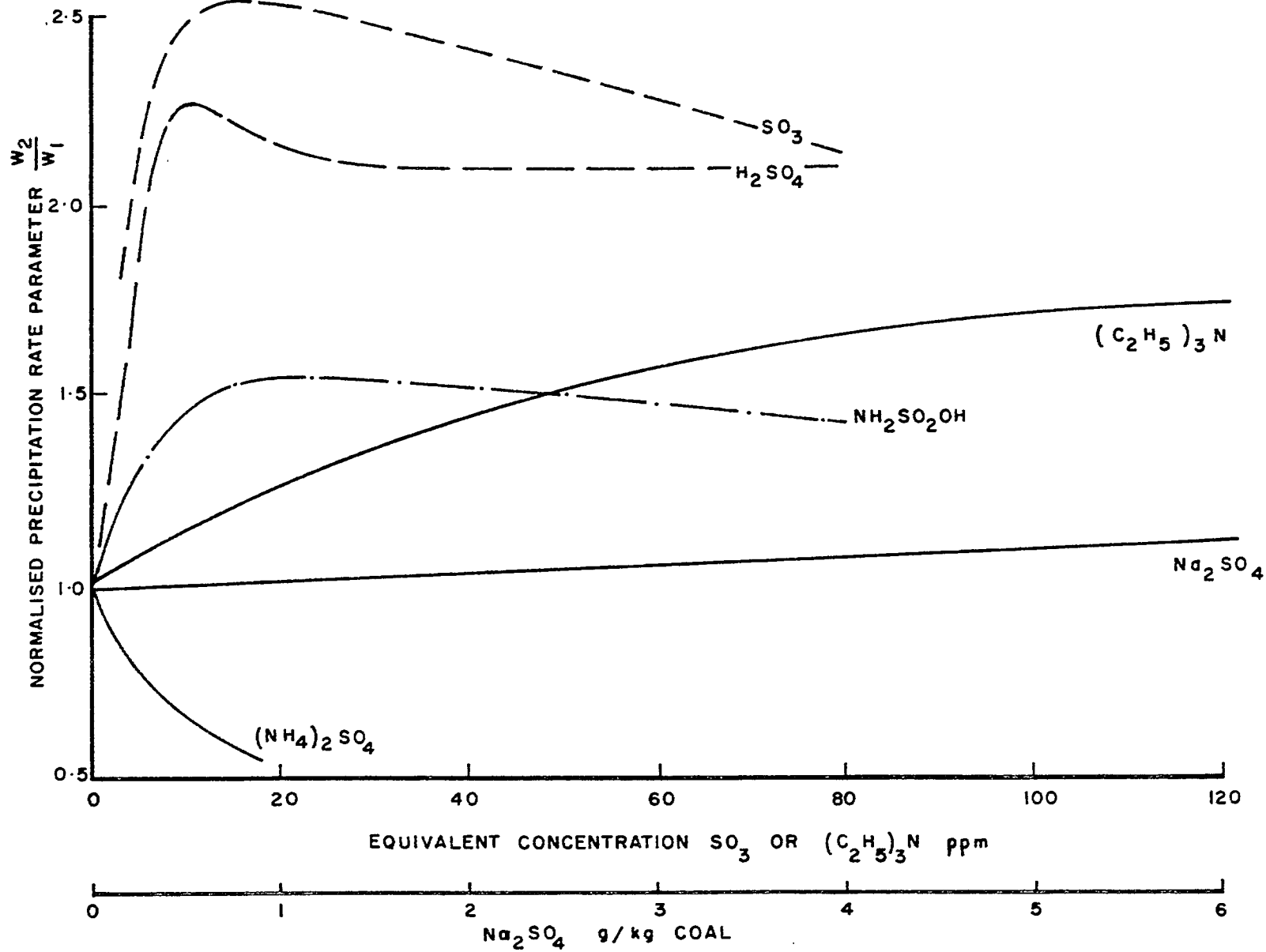


FIGURE 8. Enhancement of the Precipitation Rate Parameter