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論　　文

Time Dependent Performance Degradation in Some Hot Side ESP's Collecting Fly Ash

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This paper is the first of a series of four papers describing the recognition of and solution to a time dependent degradation in performance of a class of electrostatic precipitators (ESP's) installed on the high temperature side of the air preheater (Hot Side) in coal fired steam electric power generating plants. This paper describes the background investigations that led to the development of the hypothesis for sodium depletion in a thin residual layer of fly ash on the collection electrodes causing the formation of a high resistivity limited performance in these ESP's.

1. Introduction

The electrostatic precipitator (ESP) is currently the dominant particulate control device for the electric utility industry. Initially the purpose for the dust collection device was to protect the induced draft fan from erosion. During the 1960's, a general concern developed throughout the world for air pollution. Initially, the particulate emissions were addressed. The coal-fired generating stations were located in the more populous areas of the countries. These populous areas were in the eastern half in the United States. In this area, the dominant coal supply was eastern high sulfur coal. This high sulfur coal produced fly ash that is low in resistivity, in the temperature range of 150°C. Therefore the precipitator was installed on the low temperature side of the air preheater to take advantage of the reduced gas volume and advantageous resistivity value at that point in the generation system.

The next evolutionary step in air pollution control addressed the emissions of sulfur oxides. This, coupled with the abundance of low sulfur coal in the western United States, led to a significant increase in the use of the low sulfur coals. The fly ash that resulted from the combustion of these coals exhibited a much higher resistivity than that from the high sulfur coals in the 150°C temperature range. These high resistivity fly ashes required a much larger electrostatic precipitator when the control device was located on the low temperature side of the air preheater in a generating system.

In an attempt to reduce the physical size and thus the cost of the control device, the users and suppliers of electrostatic precipitators investigated alternative locations for the precipitator. A study of the resistivity as a function of temperature led to the conclusion to install the ESP's on the high temperature side of the air preheater, where the particulate resistivity was typically less than the critical value of 2×10^{10} Ω•cm.[1] Figure 1 illustrates this resistivity vs. temperature behavior for a typical eastern and western coal.[2]

It was obvious that the installation of the ESP at the temperature of 300°C rather than 150°C would require a larger collection electrode area because of the increase in actual gas volume. Approximately 35% more actual gas volume is present just because of this difference in temperature. This fact alone required a collection electrode area increase of a similar amount, if other factors were equal.

It was recognized in many cases, that other

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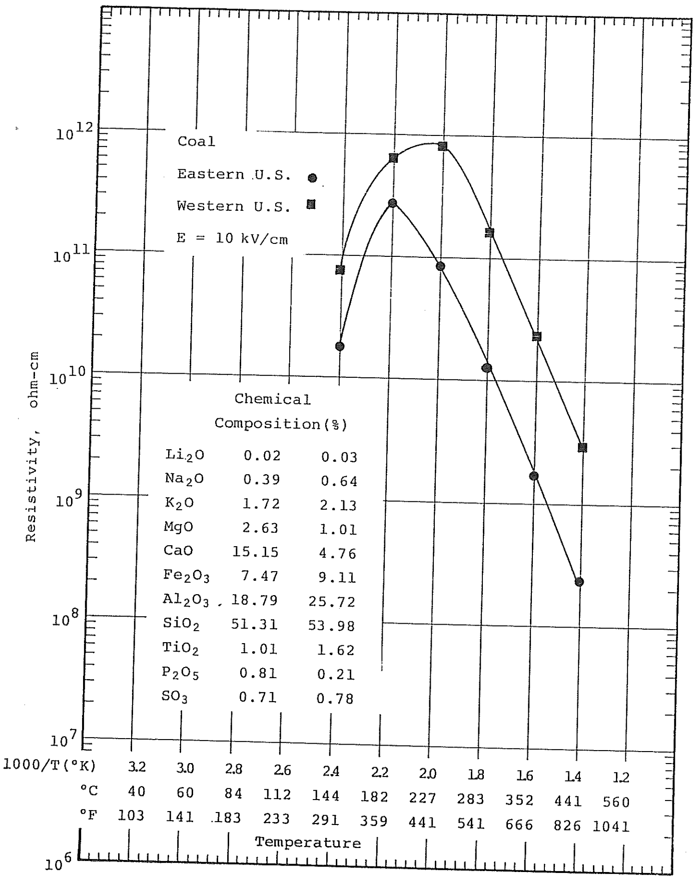

Fig. 1 Resistivity vs. temperature behavior (predicted values typical eastern and western United States fly ash).

factors were not equal. The primary difference was in the resistivity. This factor dictated an increase in collection electrode area of a factor of two or more at the lower temperature region to accomplish a comparable collection efficiency. Thus in many instances, the electrostatic precipitator was installed on the high temperature side of the air preheater.

After several installations were completed and operating, a few units exhibited less than anticipated performance, while the majority of the installations behaved as expected.

The author and his colleagues conducted a study of these problem installations to determine the cause of their poor performance and to find the means for their correction.

This paper is the first one of the four series reports[3-5] describing the results of our study, and it reports our finding that the performance degradations were of a time dependent nature probably caused by sodium depletion in a layer causing high resistivity to develop in the fly ash deposit on the collecting electrode. This recognition was of fundamental importance for the later series of investigations which led to a technical solution for this problem.

2. Recognition of the Problem

When we were introduced to the problem, no one was aware that the problem was time dependent. We only knew that the precipitators were not achieving acceptable collection efficiencies. By coincidence, these problem installations were all located in the western United States at altitudes greater than

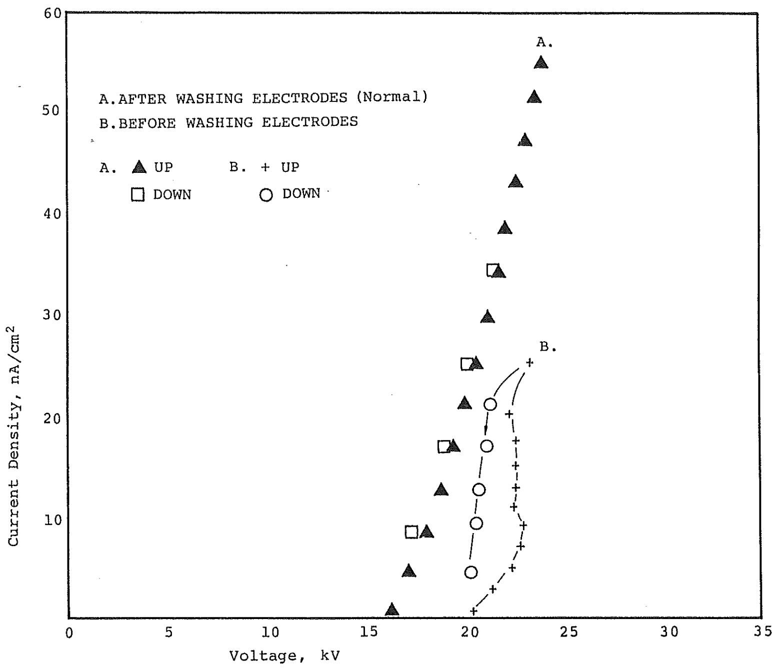

Fig. 2 Voltage vs. current density characteristics; hot-side ESP.

Table 1 Typical ash analysis—Four stations exhibiting difficulties with hot side electrostatic precipitator (% by weight and resistivity).

	Navajo	Hayden	Lansing Smith	J.T. Deely
Li_2O	—	—	Und.	0.1
Na_2O	1.8	1.7	0.4	1.8
K_2O	1.2	0.9	0.5	0.5
MgO	1.7	1.1	3.6	3.9
CaO	7.4	4.2	7.8	22.5
Fe_2O_3	5.0	3.4	4.1	6.7
Al_2O_3	23.9	32.2	35.9	21.5
SiO_2	56.4	53.6	38.7	35.9
TiO_2	2.1	0.9	1.5	2.1
P_2O_5	0.5	1.4	2.0	3.5
SO_3	0.4	0.1	4.8	1.2
Undetermined	(—0.4)	0.5	0.7	0.2
Resistivity at 370°C (Ω•cm)	1.5×10^9	2.4×10^9	1.7×10^{10}	1.5×10^9

1,500 m.

Our research started with a study of the secondary voltage vs. current characteristics for these installations. In each case, the voltage vs. current curves exhibited a back corona type of behavior[2] as suggested in Fig. 2. This figure includes a normal voltage vs. current characteristics with one that is representative of a back corona. Since the characteristics suggested back corona, our next step was to conduct a study of the resistivity of the fly ash. In all cases the measured laboratory resistivity was less than the critical value of 2×10^{10} Ω•cm. Thus we concluded that high resistivity was not the factor responsible for this substandard performance. Table 1 presents the results of these resistivity measurements, together with the chemical analyses of the fly ashes.

The next step was based on the observation that all of the problem installations were operating at altitudes greater than 1,500 m above sea level. It was conjectured that the combination of reduced atmospheric pressure and temperatu res in excess of 300°C was causing an unexpected modification in the conduction mechanisms in the gas stream.

We constructed a small model ESP with plate spacings and corona wires representative of a full-scale one. We conducted measurements of the voltage vs. current characteristics with the actual flue gas and the particulate

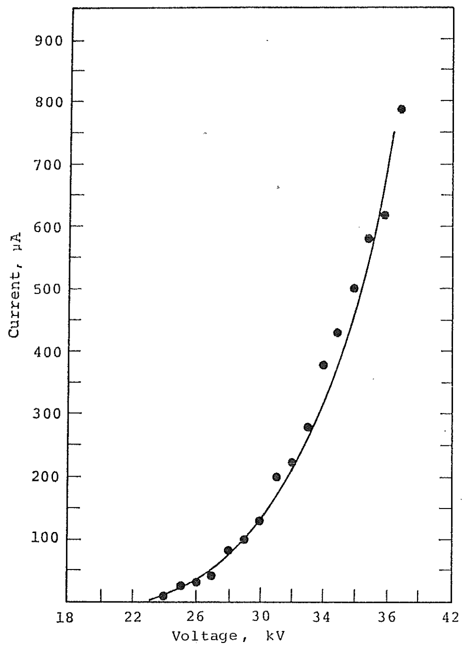

Fig. 3 Measured vs. theoretical voltage vs. current curves for a temperature of 350°C (model ESP).

suspended in this gas. The actual behavior was in fact essentially coincident with what was expected theoretically. Figure 3 shows the measured versus theoretically predicted voltage vs. current curves for this test.

This voltage vs. current curve is consistent with an effective gas ion mobility of 4×10^{-4} $m^2/V \cdot s$. This effectively ruled out any unusual limitation in performance caused by anomalous gas behavior. Immediately following this field study we became aware of similar substandard performance in a hot side ESP operating near sea level. This problem installation supported the conclusion that the problem was not associated with high altitude (reduced atmospheric pressure) operation.

At this point, we concluded that there was a fundamental limitation in performance in these installations that could not be explained by known electrostatic precipitator theory. This observation led to the development of a fundamental research effort to define this new aspect of electrostatic precipitation theory.

3. Significance of Sodium Ions in Electrical Conduction of Fly Ash

In order to formulate a research program to define the factors responsible for the substandard performance we reviewed the existing theoretical relationships in electrostatic precipitation. At this point the following items were known:

a) The voltage vs. current characteristics were indicative of back corona,

b) Laboratory measurements of resistivity from fresh samples did not indicate high resistivity,

c) The basic electrical conduction characteristics of the gas were consistent with known theory,

d) No known theory explained the substandard performance for this class of problem.

Notwithstanding the above facts, the overriding point was that the voltage vs. current curves were like those that were in reality caused by back corona. This back corona is associated with an electrical breakdown in the dust layer caused by electrical conduction through a high resistivity layer.[1] This observation was in direct opposition to the fact that a measurement of resistivity consistently gave values less than the published critical value of 2×10^{10} $\Omega \cdot$cm. A review of the above led to a detailed analysis of the factors that relate to the electrical behavior of the dust layer.

In 1973, we conducted a research program to identify the cause of the difference in performance of pilot scale electrostatic precipitators collecting fly ash from power stations burning what was described as two identical coals.[6] The power stations, Wabamun and Sundance stations of Calgary Power in Alberta, Canada, were mine mouth operations. The mines were located on opposite sides of a lake. Both the ash and coal analyses were considered to be identical, while the fly ash resistivity differed by about two orders of magnitude. Detailed studies showed that the only detectable difference between these two ashes was that the Wabamun ash contained about 0.3% sodium when reported as sodium oxide while the Sundance ash contained about 2.5%. At this time, this difference was not considered to be significant.

We then conducted transference experiments with these two ashes and determined that the principal electrical charge carrier was the positive sodium ion migrating from the surface of the collection (positive polarity) electrode towards the surface of the ash layer. This observation led to the hypothesis that the difference in resistivity of these two ashes could be attributed to the difference in the number of electrical carriers available, related to the different sodium concentrations.

This hypothesis was tested by the addition of sodium containing compounds into the furnace with the coal. Sodium carbonate and sodium sulfate was tested individually. In both cases, the addition of sufficient quantities of sodium to the Wabamun ash to bring the total sodium concentrations in the ash from the naturally occurring amount of 0.3% by weight up to the 2.5% contained in the Sundance ash caused the *in-situ* resistivity values to match. This confirmed the hypothesis of the significance of the sodium carrier.

4. Hypothesis of Sodium Depletion in Fly Ash Layer as a Cause of Time Dependent Performance Degradation

A review of this background information led to the postulation of a hypothesis for the development of a high resistivity limited type of behavior in the electrostatic precipitators under study. In the normal operation of a dry type electrostatic precipitator, the particulate material is collected for some period, such time that is deemed necessary to collect a reasonable quantity of material. Following this, an acceleration is applied to the collection electrode by its rapping system to remove this material. Notwithstanding this, there always remained a thin residual layer of particulate material on the collection electrode. The total corona current must flow through this layer. Since this flow of current corresponded to the actual migration of sodium ions from the plate surface towards the surface of the ash layer, a long-term depletion of available carriers was expected.

It was known that the resistivity of fly ash was inversely related to the sodium concentration, thus a depletion of carriers was expected to lead to an increase in the electrical resistivity of this layer. Therefore, one would expect an increase in the resistivity of this residual layer with time if this hypothesis is correct.

During this study we followed the performance of several installations very closely. In particular we worked very closely with personnel in the Research Department of Southern Company Services on the behavior of the Lansing Smith Station near Panama City, Florida. We recommended that the ESP be completely washed to remove all the fly ash from the precipitator. The plant personnel reluctantly agreed to this experiment.

After the precipitator was completely washed and the plant was returned to service, the performance of the precipitator increased significantly. The efficiency was on the order of 99.8% and the opacity was less than 5%. The power level into the precipitator had increased and no evidence of back corona was present.

After about two weeks of operation, the performance of the precipitator had decreased with a decrease in power level. This degradation in performance continued until after two months the plant was again shut down for washing. This periodic washing was continued in order to maintain acceptable performance in the station while we continued the research program.

At this point, we had formed an hypothesis for the cause of the development of a high resistivity layer in the hot side ESP. The field test had confirmed that the problem was one of high resistivity and that the behavior was time dependent.

5. Conclusion

The development of a high resistivity layer in a hot side precipitator can be explained by the migration of electrical carrier ions (sodium) from a thin residual layer on the collection electrodes. Since the resistivity of fly ash is inversely related to the sodium content, the removal of these carrier ions causes the resistivity of this layer to increase with time.

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