The Effective Collection of Fly Ash At Pulverized Coal-Fired Plants

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The relationship between sulfur in coal, boiler exit gas temperature, and the carbon portion of fly ash have a major effect on the electrical properties of fly ash. Whether effective collection of fly ash is obtained by the electrostatic precipitator installation alone or the precipitator—mechanical combination depends primarily on a knowledge of this relationship. Fly ash electrical properties can range from a highly "resistive" to a highly "conductive" state which can appreciably alter the precipitator collection performance. A correlation of coal sulfur and boiler exit flue gas temperature is given to indicate the probability of expecting an optimum voltage—current relationship with different combinations of these factors. Carbon affects the electrical conditioning of fly ash by providing parallel paths of current leakage through the deposited dust layer. Therefore, removal of the carbon particles in a mechanical collector placed before the precipitator can alter the precipitator electrical characteristics.

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The effective collection of fly ash in pulverized coal-fired plants which utilize electrostatic precipitators depends primarily on the effect of coal sulfur content, the gas temperature, and the carbonaceous content of the fly ash on the precipitator electrical power input.

While the majority of precipitator installations are effective fly ash collectors, an abnormal change in any of the above factors can sometimes adversely affect collector performance. A knowledge of the interaction of these three factors and the ability of the mechanical collector to alter precipitator electrical characteristics will often enable the operator to explain and possibly correct a decrease in precipitator efficiency. The purpose of the paper is to discuss these phenomena.

The Electrostatic Precipitator

Since the first installation in 1923, the electrostatic precipitator has effectively collected fly ash from flue gases. Precipitation occurs when the ash particles are driven to the collecting plate under the influence of an electrical field. The movement of the particle toward the collector can be represented by a migration velocity, w (cm/sec).[1]

$$w = \frac{a\,E_0\,E_p}{2\pi\Theta}$$

where:

a = particle radius, microns
E_0 = strength of field in which particles are collected, statvolts per cm (normally the field close to the collecting plates)
E_p = strength of field in which particles are charged, statvolts per cm
Θ = viscosity or frictional resistance coefficient of the gas, poises

Factors Affecting Precipitator Power

The migration velocity, w, is quite sensitive to the voltage since the electrical field appears twice in the above equation. Therefore, the precipitator design objective is to obtain maximum voltage with proper corona current flow for a maximum collection efficiency. The factors that determine optimum power characteristics are[2]:

(1) Applied voltage frequency and wave-form
(2) Spark-over characteristics
(3) Electrode characteristics
(4) Gas flow rate
(5) Gas flow distribution
(6) Dust concentration
(7) Dust composition, including particle size and resistivity
(8) Gas temperature and humidity
(9) Collector rapping

The above factors, either singly or in combination, can have a substantial effect on precipitator performance by altering the fly ash electrical characteristics. A complex relationship exists between these variable factors especially when the precipitator performance is sub-normal. However, when high voltage fields exist on a fly ash precipitator installation, factors such as poor gas flow distribution or poorly designed collector rapping can often be obscured by a satisfactory over-all performance.

A 50 percent reduction in the quantity of fly ash emitted from one station was noted when the precipitator voltage was raised from 35 to 40 kv.[3] A typical curve in Fig. 1 shows how collection efficiency increases with precipitator voltage and maximum voltage depends primarily on the electrical characteristics of fly ash.

Particle resistivity will determine the nature of the reaction of the deposited dust layer on the collector surface to a bombardment of corona current. Electrical ash characteristics can range from a "highly resistive" to a "highly conductive" state depending on the presence of a conditioning agent and the boiler exit gas temperature. The abnormally high ash "resistivity," or its reciprocal "conductivity" can adversely affect precipitator performance.

Effect of High Ash Resistivity on Precipitator Electrical Characteristics

High resistivity in fly ash usually causes a voltage breakdown between electrodes, severely limiting the corona power input to the precipitator. When this occurs, corona current flow is substantially reduced because of the increased dielectric property of the ash deposited on the collecting plate. The voltage drop across the dust layer is subtracted from the available voltage, thereby producing lower field gradient between the discharge wire and the collection plate.[4] Factors associated with high resistivity fly ash are:

(1) Absence of conditioners, specifically sulfur trioxide, to treat the surface of the ash particles.
(2) Insufficient carbon or combustible composition in the ash to aid conductivity.

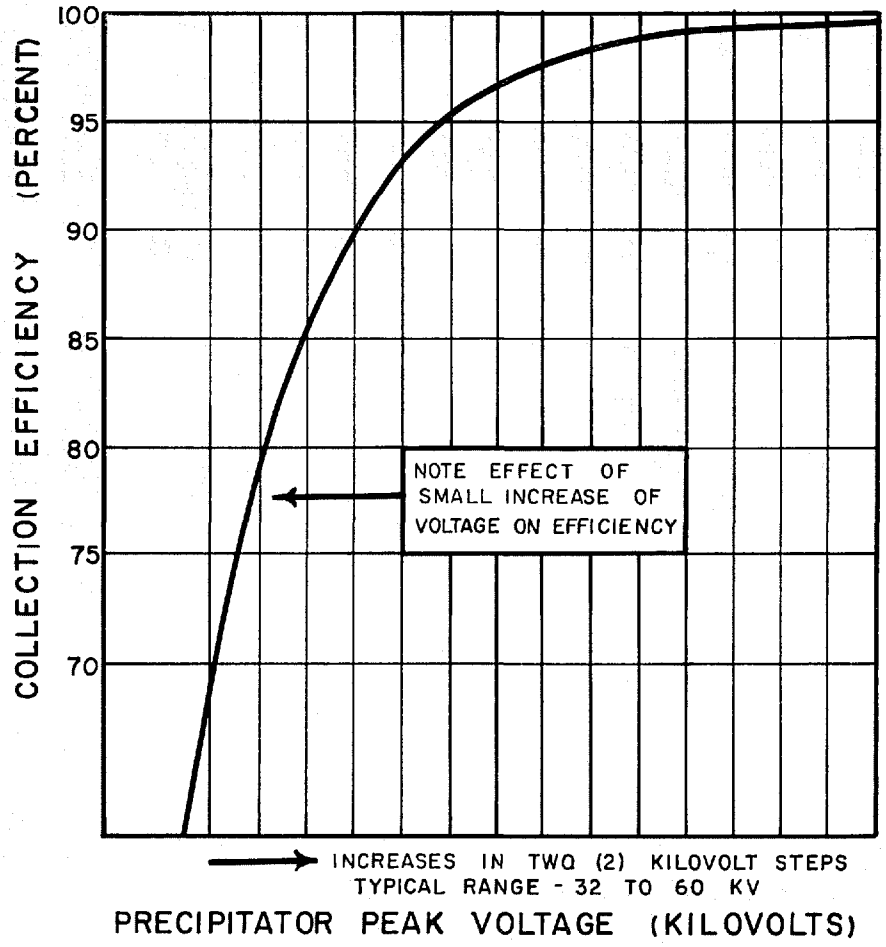

Fig. 1. A typical electrostatic precipitator peak voltage versus dust collection efficiency curver.

(*3*) Gas temperature at the precipitator inlet from 300 to 400°F.

Factors Affecting Resistivity

Years of laboratory and field work have associated the water-soluble portion of fly ash with its electrical characteristics.[4–6] Specifically, sulfur trioxide formation on the ash surface is the major conditioning agent.

Sulfur in coal oxidizes to a flue gas SO_2 content of about 0.1 percent to 0.25 percent by volume; the conversion to SO_3 normally is only one percent to three percent of the SO_2 value. The particle surface adsorption of SO_3 increases as the gas temperature decreases.

Since surface conductivity is enhanced by increased SO_3 adsorption, a dust layer will pass corona current by surface contact from particle to particle. Sufficient carbon can also provide beneficial effects by providing a conducting lattice through the ash layer.[6]

Gas temperatures below 350°F can increase the SO_3 particle adsorption, especially below 300°F. High gas moisture will also provide a catalytic base for surface adsorption of sulfur compounds. Although moisture alone has a distinct effect on the electrical dust characteristics of particles,[7] the narrow moisture range normally found in fly ash applications does not materially alter the SO_3 conditioning phenomenon.

However, neither the gas temperature or moisture, in the normal range found in fly ash precipitators, should alter the carbon effect. Carbon particle size and concentration will be a factor though; and while the unburned portion of the ash generally is greater than 10 microns, some smaller particles can be found.

Effect of Resistivity Magnitude on Electrical Properties of Fly Ash

Field and laboratory experience indicates that when particle resistivity becomes greater than 2×10^{10} ohm-cm, reduced precipitator performance may result from an excessive sparking condition.[5, 8] The curve in Fig. 2 shows the relationship between resistivity and gas temperature for a typical fly ash.

When the ash resistivity approaches 1×10^{13} ohm-cm, a condition characterized by greatly reduced voltage and high current densities without sparkover, and known as back corona can develop. Corona discharge from the dust layer can produce enough positive ions to counteract the negative space charge and significantly reduce the migration rate. Fortunately, this condition does not usually occur in practice.

When ash exhibits values lower than 1×10^5 ohm-cm, a high conductivity condition can possibly cause a precipitator characteristic similar to the back-corona phenomenon.

Effect of High Ash Conductivity on Precipitator Performance

High ash conductivity can produce a high corona power situation in the precipitator, but the collecting performance may actually suffer because of the existence of low voltage and excessive ash re-entrainment from the collecting plate. Charged particles will migrate across the electrical field with sufficient migration velocity but on contacting the collector they rapidly lose their charge and bounce back into the gas stream.[9] This process can occur repeatedly and involve the same particles throughout the length of the precipitator, until particles finally exit from the collector. The primary cause of this condition is probably the trend toward reduced flue gas temperatures.

Several general precipitator operating characteristics can be listed under the highly resistive and highly conductive ash categories.

(*1*) Highly Resistive Ash (Resistivity greater than 2×10^{10} ohm-cm)
- (*a*) Lower power input to each electrical section due primarily to spark-over.
- (*b*) Spark-over occurs at random throughout the electrical sections.
- (*c*) Ash exhibits strong cohesive properties.

(*2*) Highly Conductive Ash (Resistivity less than 1×10^5 ohm-cm)
- (*a*) High power input to each electrical section without sparkover. However, low voltage fields and excessive corona current is associated with this condition.
- (*b*) Ash exhibits poor cohesive properties and tends to be re-entrained.
- (*c*) Re-entrainment during rapping becomes a minor portion of the total dust loss.

An interesting facet of the electrical characteristics of fly ash is the possible influence a mechanical collector before the precipitator can have on the power input and performance of the precipitator.

The Mechanical Cyclone as a Supplemental Collector

Various designs of mechanical cyclones have been used successfully for the collection of fly ash particles usually larger than approximately five to 10 microns in projected area diameter. Mechanical collectors have been applied in series with the precipitator, especially

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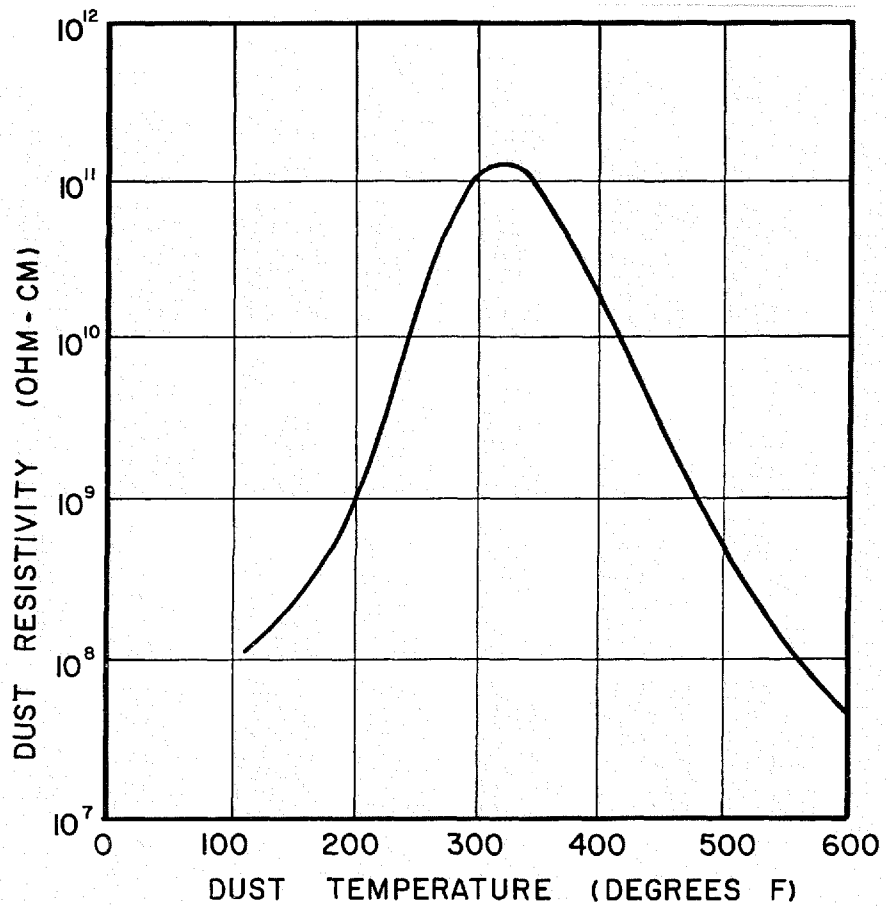

Fig. 2. A typical dust resistivity versus temperature curve.

where large carbon or grit particles predominate in the effluent gases.

In some applications, cyclone-precipitator combinations are installed with the mechanical collector immediately preceeding the precipitator. Other installations have the mechanical collector following the precipitator. Several authors have discussed the advantages and disadvantages of both applications. I will now briefly discuss the effect of a mechanical unit on precipitator operation, as related to the two adverse electrical conditions noted earlier.

Factors Affecting Conductivity

The main factors contributing to ash characterized by high conductivity are:

(*1*) Low gas temperature at the precipitator, i.e., approximately 290°F and lower.

(*2*) Sufficient sulfur trioxide deposition on the surface area of the ash (in the magnitude that would normally give optimum electrical conditions in the gas temperature range of 320 to 380°F).

(*3*) High carbon composition of the ash, although this will have less influence than the sulfur trioxide formation.

Precipitator Operating Characteristics Based on the Electrical Properties of Fly Ash

High ash resistivity and high ash conductivity described above have been related to the sulfur trioxide, flue gas temperature, and carbon content of the ash. High sulfur coal attendent with low exit gas temperatures can produce a precipitator sub-normal performance, as can low sulfur coal with higher gas temperatures. An understanding of these characteristics can often explain performance with varying coal compositions and seasonal gas temperatures in the critical range between 270°F and 320°F. Gas temperature changes of 10°F and 15°F in the critical range can substantially alter the electrical properties of fly ash.

The operator will normally strive for low sulfur in coal, low combustible in fly ash, and low exit gas temperatures. The range of these variables depend on economics and modern equipment design.

Field experience indicates that a rough approximation of precipitator electrical characteristics can be correlated with sulfur versus gas temperatures. Exception can arise because of the complexity of boiler and precipitator variables, with carbon being one of the other factors that complicate this type of correlation. In Table I, the words "Poor," "Fair," and "Good" indicate the probability of expecting an optimum voltage-current relationship in each of the combinations shown.

Table I

Sulfur content of coal, %	—Precipitator Gas Temperature— 250-290	290-380°F	380-460°F
0–1	Good	Poor	Fair
1–2.5	Fair	Fair	Fair
2.5 and above	Poor	Good	Good

Ash Electrical Properties Affected by Mechanical Collector Preceding Precipitator

The resistivity characteristics of the fly ash can be altered by placing a mechanical collector before the precipitator. This can occur under the following conditions.

(*1*) If the ash is highly resistive in the 300 to 400°F range, a minor reduction of carbon from the remaining ash segment entering the precipitator may result in further deterioration of electrical conditions. A finer fly ash would have a tendency to pack on the collecting plates and increase the sparking characteristics.

(*2*) If the carbon content of the fly ash has a major role as a conditioner, an improvement in precipitator performance may result when the high conductivity phenomenon is experienced in association with low gas temperatures. Two factors can predominate.

(*a*) An actual increase in resistivity would aid in the cohesiveness of the deposited ash layer on the collector.[10] The finer ash would have less tendency to be re-entrained in the gas stream.

(*b*) The higher ash resistivity would help optimize the precipitator voltage—current relationship under the high conductivity condition.

(*3*) If the carbon content of the fly ash is a major ash conditioner, removal of these particles may cause an excessive sparking problem in the precipitator.[11] This situation may occur when the sulfur content of the coal range between 0.5 percent to 2 percent and the flue gas temperature ranges between 300 and 350°F.

Mechanical Collector Located Downstream of the Precipitator

The location of the mechanical collector after the precipitator would not affect the precipitator electrical characteristics. However, if a severe re-entrainment problem exists with highly conductive ash, which may tend to agglomerate as it passes through the precipitator, then the mechanical collector could aid the over-all collection efficiency.

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Summary and Conclusions

The effective collection of fly ash in pulverized coal-fired plants where an electrostatic precipitator is the prime collector depends primarily on the effect of ash resistivity on the precipitator electrical characteristics. The main factors affecting the precipitator electrical characteristics are:

(1) The coal burned, specifically the sulfur content and its eventual conversion to sulfur trioxide gas as a particle surface conditioner.
(2) The flue gas temperature, which is usually between 380 and 270°F and which can, in various combinations with ash conditioners, cause the ash resistivity to range from high to low values.
(3) The carbon segment of the effluent gases can affect ash resistivity by providing parallel leakage paths through the deposited dust layer on the collector.

A knowledge of the interaction of these factors will permit the operator to interpret changes in precipitator performance following alteration of one of these factors. It is conceivable that by altering the coal burned, flue gas temperature, or the particle size distribution of the pulverizers, the plant operator could correct a sub-normal collector performance.

The mechanical collector can aid or hinder precipitator performance when the ash electrical characteristics are critical.

While other factors of precipitator and gas system design can affect the voltage-current relationship and spark-over conditions, sulfur content of coal, gas temperature, and carbon are items of major interest in the proper application of collector systems in pulverized coal fired plants.

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