EXPERIMENTAL DETERMINATION OF OHMIC RESISTIVITY OF FLY ASH FOR DESIGN OF ELECTROSTATIC PRECIPITATORS

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ABSTRACT

The objective of the present work is to determine the ohmic resistivity of fly ashes collected at electrostatic precipitators (ESP) attached to boilers burning Brazilian coals. An experimental device for fly ash resistivity measurement was designed and constructed, and tests were conducted according to accepted standards in other countries. It was the first time that this kind of measurement was conducted for Brazilian coals.
The tested materials were collected from ESP operating in the southern part of Brazil, where the mineral coal is commonly used. The ohmic resistivity of the tested materials was smaller compared to mineral coals from abroad. The resistivity of the fly ash increased when the temperature was raised, which is in accordance with the published results for mineral coals from abroad. The tests with particulate material collected from ESP of a biomass boiler showed that its ohmic resistivity is much lower than the resistivity of the mineral coal fly ash. It means that the ESP for biomass boiler should be smaller, which is in accordance with the industrial practice.
Based on the experimental results, practical comments about ESP sizing were addressed in order to assist engineers and technicians dealing with the problem of gas treatment in coal combustion.

Keywords: *Electrostatic Precipitator, ohmic resistivity, mineral coal, fly ash.*

1. INTRODUCTION

Coal is widely used in fired boilers in many countries because it is abundant and cheap. On the other hand, due to the environmental concerns nowadays, its use as energy source requires the attachment of many environmental protection equipments to treat the combustion gases.

The Brazilian coal is very cheap and a large quantity of coal is available in the southern part of Brazil. However, it has high quantity of ash and its combustion in boilers produces pollution in the gas stream (dust, particulate material). These ashes must be collected and good disposal must be done in order to lower its impact on the environment. Electrostatic precipitators are commonly used to solve this kind of problem and its use should increase from now on.

On the other hand, the technology of the electrostatic precipitators used in Brazil comes from abroad. The design constraints were established by using the physical properties of the foreign coal. It is important that the Brazilian engineers and technicians are able to design, manufacture, install and conduct performance tests on site, with reliable technical information about the precipitation process and the characteristics of the coal.

In Brazil, there are few research works focusing on electrostatic precipitators. Particularly, there is no work concerning the ohmic characteristic of fly ash of mineral coals.

The aim of this study is to evaluate the ohmic resistivity of fly ash from mineral coals used in Brazil. The ohmic resistivity of the fly ash is an important design parameter because it furnishes information for the engineer to design the electrostatic precipitator, defining its size and specific collecting area in order to achieve the aimed performance. It also allows the engineer to predict the electric behavior of electric collecting fields, calculate the existing electrostatic precipitator efficiency and evaluate the quantity of outlet particulate material after the electrostatic precipitator.

2. ELECTROSTATIC PRECIPITATOR (ESP)

An electrostatic precipitator is a device that removes particles from a gas stream. It accomplishes particle separation by the use of an electric field that imparts a negative charge to the particle, which is attracted to an oppositely charged plate or tube. The particles are removed from the collecting plate to a hopper by vibrating or rapping the collecting plate.

From the equilibrium between electrostatic force and drag force applied in the particle, it is possible to calculate the migration velocity of the particle (relative to the gas stream) *w*, assuming the Stokes' dragging.

$$F_{Drag} = 6\pi\mu\, a\, w = 4\pi\varepsilon_o\, p a^2 E_e E_p = F_{Electrost.} \qquad (1)$$

$$p = \left[2 \cdot \left(\frac{\kappa - 1}{\kappa + 2}\right) + 1\right] \qquad (2)$$

In the above equation, μ is the air viscosity, a, the particle radius, ε_o, the electrical permissivity of air, κ, the di-electrical constant of air, and E_e and E_p are the electrical fields for electrification and precipitation. Then, from the above equation, the migration velocity can be calculated by:

$$w = \frac{2\, p\, \varepsilon_o E_e E_p a}{3\, \mu} \qquad (3)$$

Considering the migration velocity w, the volumetric gas flow rate V_g and the total collecting area A, the expression below was deduced to estimate the precipitator efficiency (Deutsch apud White (1962):

$$\eta = 1 - e^{-A \cdot w / V_g} \qquad (4)$$

It is noteworthy that the precipitator efficiency is a function of the particle size.

3. CONCEPT OF OHMIC RESISTIVITY OF PARTICLE

For the flying particles to deposit on the collecting surface of precipitators, they must possess a certain value of electrical conductivity in order to conduct the ionic current from the corona discharge to the ground. The minimum value of electrical conductivity, as known by theory and experience, is around 10^{-10} (ohm.cm) $^{-1}$. From the practical point of view, this value of conductivity is comparable to that of common metals, but it is larger than the conductivity of electrical insulating materials. Particles with the electrical conductivity lower than the critical value of 10^{-10} (ohm.cm)-^{1} is known as particle of high resistivity.

The ohmic resistivity is defined by the following equation.

$$\rho = \frac{E}{j} \tag{5}$$

In the above equation, ρ is the ohmic resistivity, E is the electrical field between electrodes, and j is the electrical current density.

The operation of precipitators with high resistivity particles is usually followed by instability of the electrical condition. It may produce excessive sparking in high voltage or by excessive current in low voltage. These effects cause the reduction of collecting efficiency of the precipitator (decrease of particulate collecting). When the resistivity increases above 10^{11} ohm-cm, it becomes too difficult to achieve reasonable efficiencies with conventional precipitators. In this case, special types of ESP must be used or, more commonly, measures should be taken to reduce the resistivity.

4. TECHNIQUES TO ADEQUATE THE RESISTIVITY AS DESIGN PARAMETER

Figure (1) shows the effect of the particle's resistivity on the migration velocity of ESPs (White, 1962). The results were obtained from a pilot plant experiment in laboratory scale with cement particulate. It is clearly noticeable that the migration velocity of particle drops from 15 cm/s at 10^{10} ohm-cm to just 3 cm/s at 10^{11} ohm-cm. The particle resistivity can be modified by the addition of humidity or some chemical components in the gases or in the fly ashes.

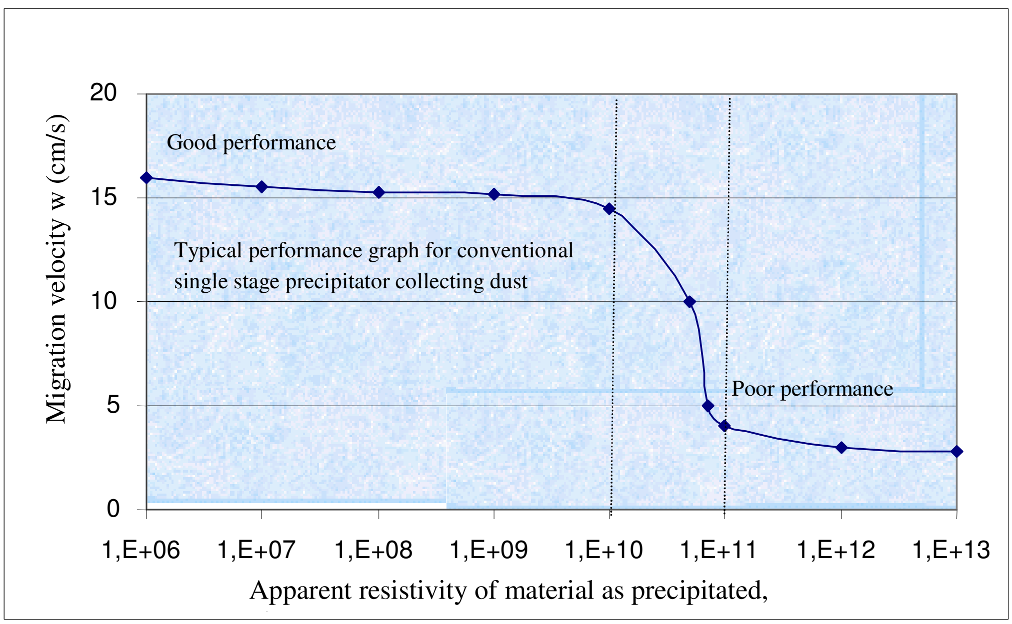

Figure 1: Effect of particle of high resistivity on ESP performance (White, 1962).

Suzuki and Tachibana (1984) burnt 30 types of coals in a pilot plant and measured the precipitability of the fly ashes they produced. They found that the sulfur has a major effect on the fly ash collecting efficiency in a cold ESP (ESP with temperature lower than 250 ºC). The precipitability of fly ash increases when there is injection of SO_3, depending on the kind of the coal.

Chae and Seo (1998) conducted a study about the improvement of ESP performance by pulse energization in order to collect fly ashes with high resistivity and very fine dust. The supply of appropriate electric pulse, according to the dust characteristic and design of ESP, can produce a high collecting performance.

Fujishima e Tsuchiya (1998) developed a cold type ESP for coal fired boiler with high efficiency. The technique consists in placing the ESP downstream a heat exchanger, reducing the gas temperature to around 90 ºC. As result, the dust resistivity is reduced and the collecting efficiency becomes higher.

5. THE EXPERIMENTAL METHOD AND DEVICE.

The experimental apparatus used for the conductivity measurement is shown in Fig. (2). It consists of a small plate that encloses a quantity of fly ash, serves as the negative pole and is called the discharge electrode. Another plate serves as the positive pole, where the particles are attracted to and is called the collecting electrode. The basic test cell and the test species are placed inside an insulated box with an electrical heating element in order to keep the temperature constant.

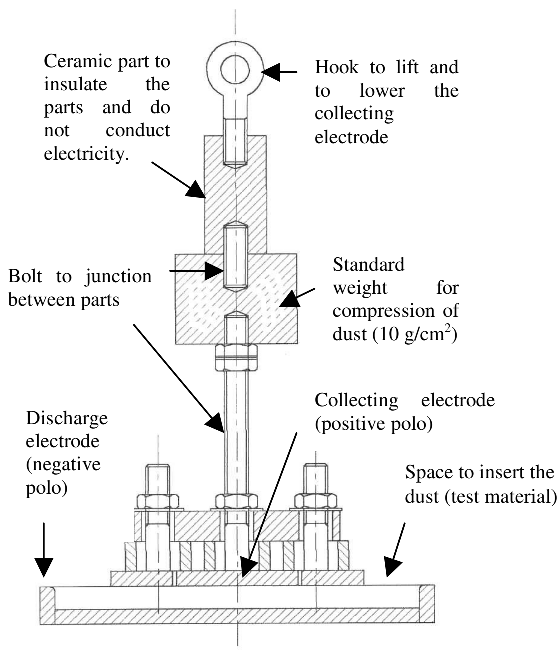

Figure 2: Description of experimental apparatus.

The dust is submitted to an increasing voltage V [V] and the breakdown current I [A] is measured just before the electrical sparking occurs. The ohmic resistance of dust R [ohm] is calculated by these two measured parameters, as shown in Eq. (6).

$$R = \frac{V}{I} \tag{6}$$

The resistivity ρ is calculated by Eq. (7):

$$\rho = R \cdot \frac{A}{t} \tag{7}$$

in which A (cm^2) is the plate area where the dust is deposited and t (cm) is the thickness of the dust layer.

The experimental procedure consists of the following steps. The lower plate (discharge electrode) is filled with the dust that forms a uniform layer. The upper plate (collecting electrode) is placed on the dust layer. The dust compactness is defined by the upper plate mass, which has a standard weight. The temperature is varied assuming three distinct values (ambient temperature, T= 50 ºC and T= 70 ºC) and the humidity is measured by a wet bulb thermometer. The electrical voltage is increased slowly (500 V each step) and the start of the back corona or the formation of glow on dust layer is detected. The breakdown voltage can be estimated or determined by direct measurement. This standard technique for measuring the resistivity is described in the ASME PTC 28 document - Determination of Proprieties of Particulate Material. The test cell was constructed according to this standard. The experimental data (voltage V and current I) were taken when sparking or electrical breakdown occurred. The electrical voltage breakdown could be observed by four different manners: due to the instability of the electrical supply voltage control; due to the instability of the electrical current indicator; due to a visible electrical discharge, as voltaic arc; and due to the typical noise from an electrical discharge. After three measurements for the same sample, the value of the voltage V was estimated to be 0,95 of the average breakdown voltage. The experimental data obtained with this procedure had great repeatability.

6. EXPERIMENTAL RESULTS AND DISCUSSION

In this experiment, fly ashes from four different sources were tested: fly ashes collected in a ESP at CGTEE (Companhia de Geração Térmica de Energia Elétrica), fly ashes collected in a ESP at COPESUL (Companhia Petroquímica do Sul), mineral coal used by CGTEE and the dust from a biomass boiler.

For the CGTEE's fly ash, the collecting process begins at the voltage of 1425 V (electrical field of 2850 V/m), which represents about 40% of the electrical breakdown voltage. In the experiment, due to the continuous electrical supply, the dust adheres strongly to the collecting electrode. As the transformer rectifier used in the experiment was limited to 6 kV, the smaller particles were collected first, and the larger particle was kept in the discharge electrode (lower plate). The bigger particles do not move to the collecting electrodes because the weight of the particle is bigger than the electrostatic force. So, at an initial stage, the dust is separated by granulometry.

The part of dust considered unburned (0,10% to 3,42 % - carbon rich fragments, with typical black color) is collected first. It means that the dust with a larger amount of unburned content is easier to be collected, because the fly ash layer conducts ions easily. An undesirable effect to combustion (the incomplete combustion in boiler) gets a favorable effect to the fly ashes collecting process. This result agrees well with the conclusions of Potter (1984) and Shibuya and Mochizuki (1984).

The experimental results presented in Fig. (3) shows that the ohmic resistivity increases with the temperature (temperature range: ambient temperature to 70ºC). The surface conductivity is predominant for low temperature and wet conditions. This result agrees with the published results for fly ashes of mineral coals from other countries (Oglesby and Nichols, 1978). The CGTEE´s fly ash has a lower resistivity compared to some fly ash from abroad. It is possible to say that back corona, due the high resistivity of fly ash, will not occur in this case, which is favorable to the electrostatic precipitation process and the precipitator sizing. The CGTEE´s fly ash can be classified as dust with low or medium ohmic resistivity. The ohmic resistivity for the experiment with smaller dust thickness is larger and is more sensitive to the temperature change (Fig. (3)). This may be explained by the geometrical factors affecting the relative dust compactness.

Comparing materials from different sources (Fig. (4)), it was observed that the dust from biomass boilers have much smaller resistivity compared to the fly ash from other a mineral coal. It is in accordance with the industrial practice, as the ESP of biomass boilers are smaller than the ESP of coal fired boilers, considering the same volumetric gas flow rate. It occurs because the dust of biomass boilers has high sulfur content (from wood chips) and, consequently, low resistivity. The CGTEE`s fly ash has smaller resistivity than the COPESUL fly ash and larger resistivity than the own coal that produces the fly ash.

Analyzing the chemical composition of the CGTEE's coal, the content of Fe_2O_3 ranges from 6% to 10,60%. Dalmon (1984) verified that this amount of Fe_2O_3 is favorable to the precipitation process due to the increase of the effective migration velocity. The sulfur content is medium, from 1,52% to 2,18%, which is also favorable to collect the dust, as described by Suzuki and Tachibana (1984). The surface resistivity increases with the reduction of the sulfur contented in the coal (Moleshi, 1983). Concerning the CaO content (0,63% to 0,92%), the CGTEE's coal can be classified as low calcium content (CaO < 2,5 %).

The uncertainty analysis was carried using the ASME PTC 19.1 methodology. The main sources of uncertainty were the evaluations of area and dust thickness. The relative uncertainty obtained for the ohmic resistivity measurement was 10 %.

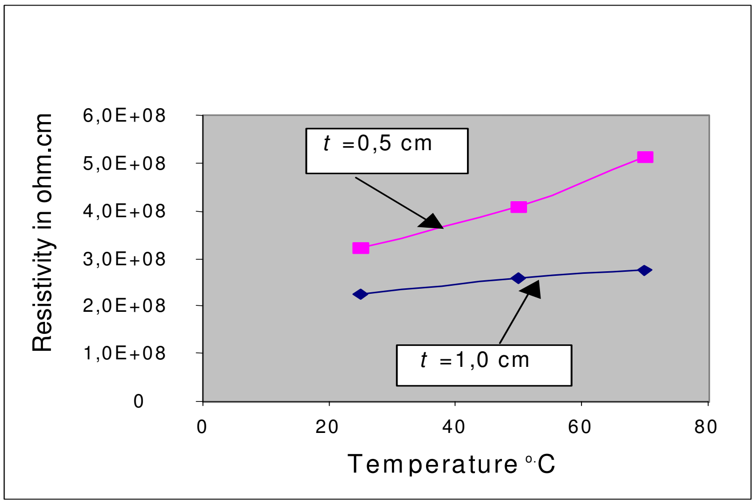

Figure 3 : Resistivity x Temperature

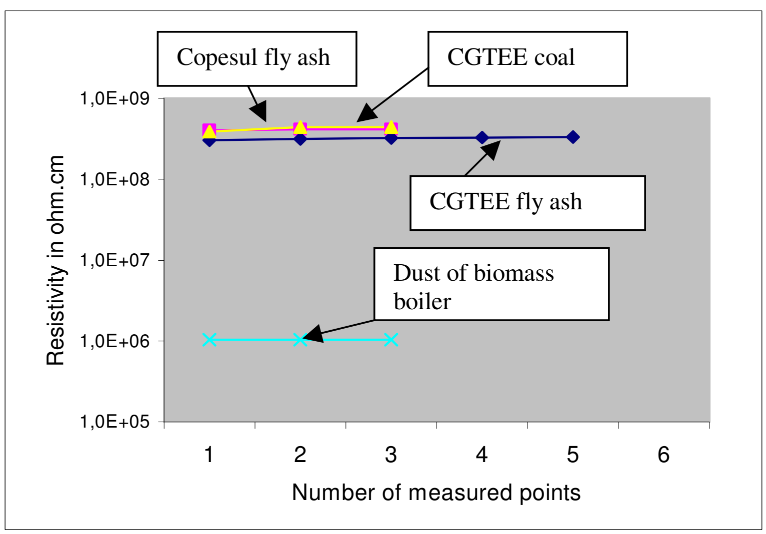

Figure 4 : Comparison for different materials

7. CONCLUSIONS

The objectives of the present research were successfully attained. An experimental device for fly ash resistivity measurement was designed and constructed, and tests were conducted according to accepted standards in other countries. The tested materials were obtained from industrial sites that use Brazilian coals. It was the first time that this kind of measurement was conducted for Brazilian coals.

The CGTEE`s fly ash does not present high ohmic resistivity, with values ranging from 3,04 x 10^8 to 5,35 x 10^8 ohm.cm. The collecting process starts at a low voltage, indicating that due to the particle's low resistivity, the ESP can collect the fly ash at normal electrical voltage. Chemical-conditioning agents is not necessary as resistivity reducers.

The resistivity of the CGTEE's fly ash increases when the temperature increases. This trend is in agreement to the measurement results for mineral coals from abroad. As the CGTEE`s fly ash does not have high resistivity ($\rho > 10^{11}$ ohm .cm), it is expected that the back corona effect should not occur. When electrical sparking happens, the collecting process of dust is interrupted and a small cloud of dust is formed. This effect is undesirable to the industrial electrostatic precipitation process as the efficiency decreases and the dust goes out from the stack.

The tests with particulate materials from ESP of a biomass boiler showed that their ohmic resistivities are much lower than the resistivity of the Brazilian mineral coal. It means that the ESP for biomass boiler should be smaller, which is in accordance with the industrial practice.

The low ohmic resistivity means, from the practical point of view, that the migration velocity is higher and therefore, smaller ESPs are required. The Brazilian fly ash has low to medium resistivity and is likely absent of undesirable back corona effect. Therefore, the ohmic resistivity should not be a key design concern for ESP attached to boilers burning Brazilian mineral coals. The design engineer must pay attention to other design parameters such as the internal velocity of gases and how to deal with the excess of fly ash content in the coal (up to 50%).

8. NOMENCLATURE

a	: Half diameter of particle	[μm]
A	: Total collecting area of ESP	[m^2]
A	: Area of collecting disc	[cm^2]
E_e	: Media intensity of electrical field for electrification	[V/m]
E_p	: Media intensity of electrical field for precipitation	[V/m]
E	: Electrical field	[V/m]
F_{Drag}	: Viscous drag force	[N]
$F_{Eletrost}$	: Electrostatic force	[N]
I	: Electrical current	[A]
J_A, j	: Electrical current density	[A/m^2]
SCA	: Specific collecting area	[$m^2/m^3/s$]
T	: Temperature	[ºC]
t	: Thickness of dust layers	[mm or cm]
UR	: Relative humidity	[%]
V_g	: Total gas flow rate	[m^3/s]
V	: Voltage	[V]
w	: Migration velocity	[cm/s]

Greek symbols

ε_o	: Electrical permissivity of air	[F/m]
κ	: Di-electric constant of air	[-]
μ	: Dynamic viscosity of air	[kg/m.s]
η	: Collecting efficiency by DEUTSCH	[%]

ρ, ρ_A	: Resistivity	[ohm.cm]
ρ_g	: Gas resistivity	[ohm.cm]
ρ_d	: Resistivity of dust	[ohm.cm]

Subscripted

$_g$: gas

10. ACKNOWLEDGEMENT

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