DEVELOPMENT OF EMPIRICAL RELATIONS FOR FLY ASH RESISTIVITY BASED ON EXPERIMENTAL MEASUREMENT FOR INDIAN BASED THERMAL POWER PLANTS

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Abstract:

This paper presents a new model to calculate fly ash Resistivity based on its chemical composition, for fly ash generated in Indian thermal power plants, which is one of the critical parameter that influences the fly ash collection, sizing and performance of electrostatic precipitator. The model developed for calculating the electrical Resistivity was verified through, experiments, which were conducted for the measurements of electrical Resistivity over a wide range of temperatures (90 - 455) ^{0}C as per IEEE standards. Around 50 samples were obtained from different power plants in India for the Resistivity measurements, the chemical composition of each sample were determined. These empirical relations provide better agreement with experimental values compared to those developed by Bickelhaupt and those developed earlier in this lab in the working range of operations of Indian ESPS.

***Keywords*:** Fly ash resistivity measurement; prediction of fly ash resistivity; particulate matter emission; coal-fired thermal power plant

1 Introduction.

Electrostatic precipitator (ESP) is still one of the most cost effective means of controlling particulate emissions from large industrial process plant. Traditionally, ESP's used metal plates as collecting surfaces for capture of particles in flue gas. However, back corona and re-entrainment of particles into flue gases hinder with the performance of ESP in collection of fine particulate matter (PM2.5)[1]. In order to meet the stringent emission levels from power plant, it is necessary to have knowledge of the properties of fly ash, sizing and operation of ESP. Retrofit methods can be applied to an ESP depending on the electrical and chemical properties of the fly ash. China and India have large plants of expanding coal-based power plants. At present India has got 61,175 MW installed coal based power capacity which is expected to rise 1, 14,500 MW by the year 2012 [2].

The design and operation of ESP depends largely on the properties of coal burned and fly ash generated in the boilers. The properties of coal used in difference plants across India vary widely. In many of the power plants, the ash contents of coal are high up to 45%, and the coals have low calorific values (3500-4200) Kcal/kg. As a result Indian coal generates about 6 to 7 times more ash to collect compared to U.S. or European coal for similar electricity generation. [3] Besides, low sulfur content (≤0.5%) result in the resistivity is (100-1000) time higher as compared to desired range of resistivity (1×10^{7}- 2×10^{10}) ohm-cm. for efficient ESP.[4]

At the high resistivity of the order of 10^{12} ohm-cm or more, typically found in Indian coals with low sulfur contents, the ESP collection efficiency is poor, requiring very large plate collector area to achieve higher efficiencies. A series of experiments have been performed to study the variation of fly ash resistivity with temperature for low sulfur coals and it was confirmed that Indian fly ash has higher resistivity as compared to those of western coals and is therefore, difficult to precipitate[4]. The reason for low precipitation is the generation of back corona near the collecting electrodes even at very low current densities. The electrical resistivity depends on its chemical composition, temperature, and moisture. A number of empirical relations have been developed to predict the electrical resistivity of fly ash as a function of various parameters mentioned earlier [5, 6]. A set of correlations for predicting fly ash resistivity based on the composition and the coal analysis have developed by Bickelhaupt [7,8] and are widely used in USA, primarily for those fly ashes which are based on western coals. Southern Research Institute Birmingham USA is also using similar relations [9] for evaluating the resistivity. In India, however, there are varieties of coal used in different power plants across the country,

2 EXPERIMENTAL ARRANGEMENT AND PROCEDURE:

An experimental test arrangement was set up per IEEE standard criteria and guidelines [10] for the fly ash resistivity measurements as shown in fig.1. The current across the fly ash layer under test is limited to 2×10^{-5} amp/cm^2 to avoid the ohmic heating of the fly ash sample. The test apparatus includes four electric resistivity test cells enclosed in such a manner that the test cells are housed in a thermally controlled chamber so that resistivity can be determined at temperature range of 90-455 ^{0}C. A dc high voltage power supply was used to impress the required magnitude of electric field strength. The environment was maintained as per the standard. The environmental water concentration was introduced by bubbling a portion of dry gas through distilled water maintained at a selected temperature in a thermostatically controlled water bath. It was 9% by volume at the specified temperature in the present study. The oven is capable of operating in the desired temperature range, within 0.01 ^{0}C accuracy. The resistivity test cell has parallel plate construction made from SS 304 steel. The resistivity cell current was measured using a sensitive electrometer capable of reading current in the range o 10^{-3} to 10^{-11} amp. With an accuracy of $\pm$ 2% of the full-scale reading. Fly ash samples were prepared in accordance with the IEEE standard and placed in the test cell in a grounded environmental chamber. The upper electrode is gently placed on the top of ash with a defined pressure. The oven is started and once the desired temperatures are reached, the readings are taken for the temperature, voltage and current using the instrumentation provided in the test facility. The fly ash resistivity ρ is calculated from standard relation:

$$\rho = \left(\frac{V}{I}\right)\left(\frac{A}{l}\right)$$

Where, V and I are the voltage and current across the fly ash sample, l and A represent the thickness and area of cross-section of sample of fly ash cell. The resistivity is calculated for more than 250 different fly ash samples from Indian coal fired thermal power plants for the temperature range of 90 ^{0}C to 460 ^{0}C. However, 20 representative samples have been selected whose chemical composition is known, for the development of model for ash resistivity.

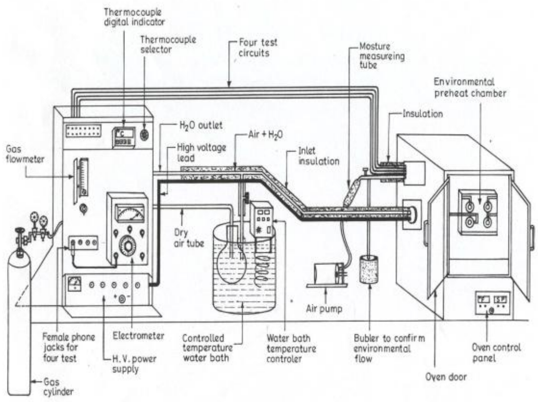

Fig 1. Schematic diagram of ash resistivity measurement

3.EMPIRICAL RELATIONS FOR PREDICTION OF FLY ASH RESISTIVITY:

Based on the chemical compositions of representative fly ash samples, shown in Table 1, the electrical Resistivity has been calculated using Bickelhaupt [5] correlations, which are described the following section. During the calculation of it has been observed that results were not showing better agreements because of the different nature of coal composition of Indian coal.

The volume resistivity is:

$$\rho_V = \exp\begin{bmatrix} -1.8916\ln X - 0.9696\ln Y + 1.237\ln Z + 3.62876 \\ -\ 0.069078\ E + \ 9980.58/T \end{bmatrix} \quad (1)$$

The surface resistivity is:

$$\rho_S = \exp\begin{bmatrix} 27.59774 - 2.233348\ln X - 0.00176W \\ -0.069078E - 0.00073895W\ \exp\ 2303.3/T \end{bmatrix} \quad (2)$$

The adsorbed acid resistivity is:

$$\rho_a = \exp\begin{bmatrix} 59.0677 - 0.854721CSO_3 \\ -13049.47/T - 0.069078E \end{bmatrix} \quad (3)$$

For Z > 3.5% or K < 1.0 %

The resultant resistivity is:

$$\frac{1}{\rho_{vsa}} = \frac{1}{\rho_{vs}} + \frac{1}{\rho_a} \quad (4)$$

$$\text{where, } \frac{1}{\rho_{vs}} = \frac{1}{\rho_v} + \frac{1}{\rho_s} \quad (5)$$

4. Proposed correlation for fly ash resistivity of Indian coal

A new mathematical model for Indian fly ash is developed based on the Bickelhaupt relations' developed earlier .The new predicted developed model was used to calculate the resultant resistivity for fly ash generated in Indian thermal power plants. To compare the results Bickelhaupt model and earlier developed model in equations was used to compare the resultant resistivity for the fly ash samples of Indian power plants. Comparison between calculated and experimental fly ash resistivity values for these samples is presented in figures1 & 2 in ascending and descending modes of resistivity. It has been observed that Bickelhaupt model results differ appreciably from experimental values in the lower temperature range (90-160 ^{0}C). It may be due to significant difference in concentration of elements like sulfur, lithium, sodium and moisture contents as well as alumina plus silica components among the Indian and US coals. The sulfur concentration in coal regulates the adsorbed acid resistivity. Keeping these points in view, the fly ash resistivity for Indian coals was re-calculated in terms of surface and volume conduction. Since the concentration of sulfur is very less in Indian coals, it is worthwhile to assume that very little or zero adsorbed acid conductivity is present. The negligible adsorption of SO_3 conduction may also be due to formation of glassy alumina-silicate surface that hinders the adsorption of SO_3 on the fly ash surface. The total conduction in fly ash is thus assumed entirely due to surface and volume conduction. The Bickelhaupt expressions for surface and volume resistivity are therefore, modified for the Indian coals. Analysis of the coefficients in new developed correlations for surface and volume Resistivity shows that the conduction is mainly due to Na + K ion is quite significant in Indian coals while as compared to US coals where conduction is mainly due to Na +li is more significant. Table 1 shows some of the chemical composition which were used to develop the new mathematical correlations for predicting fly ash Resistivity of Indian fly ash. Regression procedure based on the Marquardt-Levenberg algorithm is used to find the coefficients of the independent variables of volume and surface resistivity that give the best fit between the proposed correlations and the experimental data. The modified correlation for the volume and surface Resistivity is:

Correlation for the volume resistivity:

$$\rho_V = \exp\left[-a_v \ln X - b_v \ln Y + c_v \ln Z + d_v\ -\ e_v\ E + g_v/T \right] \quad (6)$$

Correlation of the surface resistivity

$$\rho_S = \exp\left[a_s - b_s \ln X - c_S W - d_s E - e_S W\ \exp\ g_S/T \right] \quad (7)$$

The resultant resistivity is:

$$\frac{1}{\rho}=\frac{1}{\rho_V}+\frac{1}{\rho_S} \qquad (8)$$

5. RESULTS AND DISCUSSION:

Using the above mathemitical correlations (6) and (7), the surface (ρ_s), the volume (ρ_v) and hence the overall resistivity (ρ) of the fly ash particles were calculated for different experimental conditions. The calculated and experimental fly ash resistivity has been plotted for different fly ash samples in Fig 2 and 3 in ascending and descending modes of resistivity. For the sake of comparison, the values obtained from Bickelhaupt model and earlier developed model are also shown in these figures. It can easily be observed that a much better agreement has been obtained between the experimental and calculated values, using proposed model in the lower temperature range (≤160^{0}C). The agreement at higher temperature range is also comparatively better by using the expressions developed by Bickelhaupt for volume conduction. As the working range of electrostatic precipitator is in the range 130-180^0 C, the relations developed in the present studies for surface conduction are more useful. The new predicted model based on the fly ash composition show a better agreement as compared to Bickelhaupt and older models developed earlier.

NOMENCLATURE:

A electrode phase area (cm^2)

CSO_3 concentration of CSO_3 (ppm, dry)

E applied electric field (kV/cm)

I measured current (amperes)

K potassium Percent atomic concentration

l ash layer thickness (cm)

T absolute temperature (K)

V applied d.c. Potential (volts)

W moisture in flue Gas (Volume %)

X K+Na, Percent Atomic Concentration

Y Fe, Percent Atomic Concentration

Z Mg+Ca, Percent Atmoic Concentration

Greek Letters:

ρ = Resistivity (ohm-cm)

Subscripts:

v volume
s surface
a adsorbed Acid

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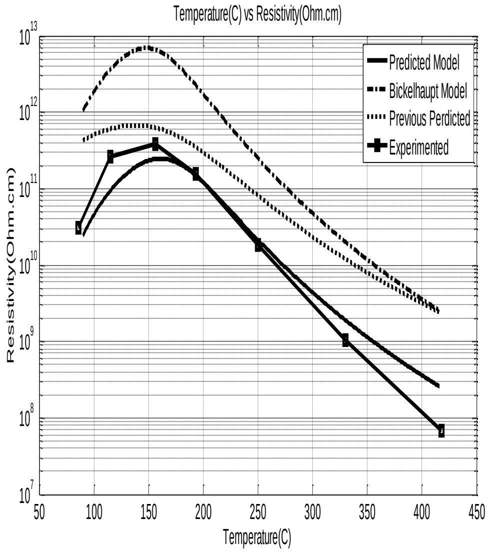

Fig 2 Effect of the chemical composition (Na,Ca, Fe K, Mg) on the fly Ascending Resistivity Ohm .cm vs Temperature ^{O}C

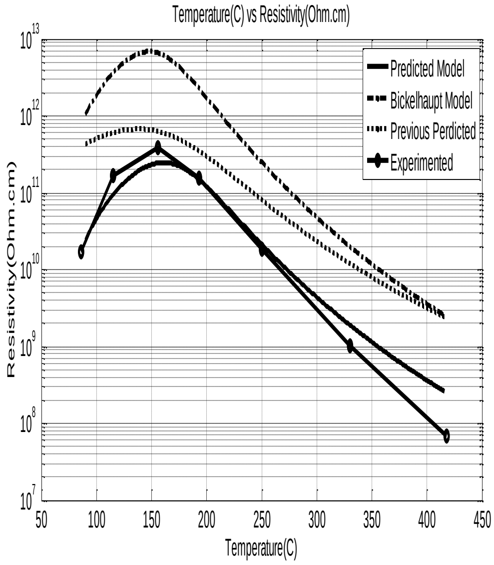

Fig 3 Effect of the chemical composition (Na, Ca, Fe K, Mg So_3) and moisture on the fly Resistivity Ohm .cm in Descending mode vs Temperature ^{O}C

Chemical compositions of the typical fly ash samples (weight percent as the oxide)											
Elements	1	2	3	4	5	6	7	8	9	10	11
Al_2O_3	33.87	28.48	39.55	34.23	43.7	37.65	43.95	36.58	39.96	24.63	18.88
CaO	10.92	10.55	1.8	2.89	5.32	1.35	1.3	9.34	4.58	0.9	5.08
Fe_2O_3	4.89	6.06	5.7	9.35	6.28	4.28	5.49	4.89	7.1	4.69	4.26
MgO	0.77	0.89	1.01	0.87	0.92	0.56	0.29	0.56	0.4	0.29	0.36
P_2O_5	0.19	0.19	0.35	0.37	0.31	0.41	0.27	0.45	0.38	0.48	0.42
K_2O	0.15	0.15	0.01	0.02	0.05	0.04	0.03	0.45	0.29	28.19	31.37
SiO_2	39.26	48.7	49.82	51.01	36.65	48.33	45.15	32.23	22.21	21.39	20.68
Na_2O	0.02	0.03	0.03	0.02	0.02	0.03	0.03	0.64	0.37	1.54	1.83
TiO_2	0.42	0.54	0.05	0.11	0.31	0.12	0.13	0.48	0.35	0.5	0.52
SO_3	0.31	0.25	0.3	0.37	0.35	0.25	0.17	0.24	0.26	0.27	0.26

Table 1 Chemical compositions of the typical fly ash samples (weight percent as the oxide)