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ELECTROSTATIC PRECIPITATOR PERFORMANCE IN INDIAN PULVERIZED COAL BASED THERMAL POWER STATIONS - PROBLEMS AND SOLUTIONS

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ABSTRACT

Coal used in Indian thermal power stations is of inferior grade having low heat value and high ash content due to drift origin. However, Indian power coal ash is specially known by its refractory in nature and low sulphur (below 0.5%) and alkalis (less than 1.5%) contents. Due to presence of low sulphur and alkalis and consequently having very high ash resistivity (10^{12} – 10^{14} Ω cm) it is difficult to achieve good E.S.P. performance. Majority of Indian thermal power stations have E.S.P. for ash collection.

In the present paper various attempts have been made to analyze the causes of problems in terms of the chemical constituents of ash, resistivity, conductivity, etc. A special emphasis was given to correlate the different forms of sulphur (organic, pyretic and sulphate sulphur) on E.S.P. performance. The total sulphur can not predict the E.S.P. performance; it is the forms of sulphur that decides the performance. Organic sulphur in coal mainly improves the ash resistivity through SO_3 adsorption from flue gas whereas pyretic sulphur is responsible for slag and clinker formation in the boiler and evacuated through bottom hoper as bottom ash in dry bottom furnace.

In addition, the paper deals with the concept of predicting ash resistivity based on conductivity measurement of ash - extract which may help to take necessary action for improvements of E.S.P. performance in thermal power stations. The paper also discusses the remedial measures to be taken in terms of use of additive (sodium / sulphur based) or biomass like horticultural waste having high alkalis (4 – 6 %) for blending in appropriate proportion with coal depending on characteristics.

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INTRODUCTION

Many countries around the world, including India, depend on coal and other fossil fuels to produce electricity. 65% of the total installed power generation is coal-based. 230 - 250 million tones of coal are being used every year. Indian coal used in power stations is of inferior grade having high ash contents varying from 30 to 50%. The final result of burning of fossil fuels, particularly coal, is the emission of fly ash. Ash comes from mineral matter present in the fuel (Raask, 1976). For a pulverized coal unit, nearly 80% of ash leaves with the flue gas. In India 95 million tones of ash generated every year. Ash generation is likely to reach 170 million tones by 2010. There are many techniques (Dalmon, 1980 and Potter, 1978) to collect fly ash but electrostatic precipitator is the best. A precipitator is a relatively simple device(Fig.1)which separates particles from a gas stream by passing the carrier gas between pairs of electrodes across which a unidirectional, high – voltage potential is placed. The particles are charged before passing through the field and migrate to an oppositely charged electrode. It has collection efficiency of more than 99%, but does not work well for fly ash with a high electrical resistivity (as commonly results from combustion of low-sulfur coal).

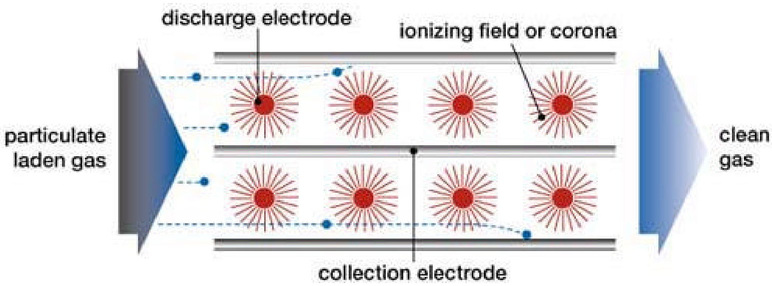

Figure 1: Top View of ESP Schematic Diagram [Source: Powerspan Corp.]

The flue gas laden with fly ash is sent through pipes having negatively charged plates which give the particles a negative charge. The particles are then routed past positively charged plates, or grounded plates, which attract the negatively-charged ash particles. The particles stick to the positive plates until they are collected. The air that leaves the plates is then clean from harmful pollutants (Fig 2.).

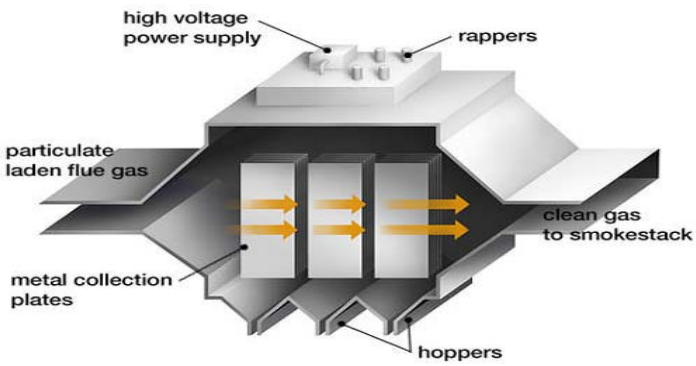

Figure 2: Side view of ESP Schematic Diagram [Source: Powerspan Corp.].

Electrostatic precipitators can achieve over 99% cleaning efficiency (White 1963). However, this depends on many factors. Indian coals used in power sectors, in general, produce ash that can be very difficult to precipitate. This coal has approximately 35 – 50% ash, which is comprised of 60 - 70% quartz. This makes the ash quite difficult to collect efficiently. Results obtained by Bickelhaupt(1975)suggested one major factor in precipitator efficiency is the chemical composition of the gas and particulates. The precipitation of difficult ash was studied in details by Lowe, Dalmon and Hignett (1965).

STUDY OF INDIAN POWER COAL TO VISUALIZE THE ESP PERFORMANCE

To see the impact of Indian power coal on collection of ash by ESP some experiments were carried out using Indian non-coking coals collected from seven different sources spread all over India.

EXPERIMENTAL

Material

Seven coal samples (coal - a to coal - g) were collected from different coal sources used in different coal based thermal power stations in India.

Sample Preparation

Test samples were prepared by coning, quartering and grinding to pass through 75 µm sieve. Proximate analysis, gross calorific value and total and different forms of sulphur content were determined by standard procedures: IS 1350, part - I, ASTM D 3286, ASTM D3177 & ASTM D 2492 respectively.

Ash Analysis (Coal Ash & Fly ash)

To see the effect of ashing temperature on conductivity and resistivity coal ash samples were prepared at various temperatures (400°, 600° & 1000°C) in the muffle furnace to control minimum loss of sulphur due to heating. Fly ash samples were collected from ESP hoppers (rows 1-5) in dry form. Ash samples collected from different rows were mixed together to make it a representative one. The chemical analysis of ash was carried out by atomic absorption spectrophotometer.

Determination of Conductivity and Resistivity

Sample Preparation

Powered coal samples (passing through 200 # mesh, 75 µm) were kept in a well ventilated furnace at 400°, 600° and 1000°C for 30, 8 & 2 hrs respectively for preparation of ash samples for determination of conductivity and resistivity of ash.

Conductivity

5.0 gm of coal ash (400°, 600° and 1000° C) and fly ash samples were refluxed in conductivity water till complete leaching (~ 2½ hrs). The leached solution was cooled to room temperature and filtered through Whatman No. 42 filter paper. The volume of filtered solution was made up to 100 ml with conductivity water. The conductivity was measured by conductivity meter.

Resistivity

For determination of resistivity all the samples were sintered at 300° C before pressing them into pellets (~1.0 cm in diameter and 2.0 mm in thickness) in batches. The pre-sintered samples were then pressed into pellets with 10% poly vinyl alcohol binder in Vanjax hydraulic press. The samples were again sintered to about 350°C for 6 hrs to remove the binder. On these sintered pellets electrodes were prepared by silver paste on both the sides. Its DC resistivity was measured. The DC resistivity measurements were carried out using two- proves methods. The measurement set up was calibrated with the standard aluminum sample. The measurement error was about ± 2.0 %. The sample to be measured is loaded in the sample holder. A known voltage is applied to the sample. The corresponding current was measured using nanometer for each voltage applied. From these quantities and dimension of the samples the resistivity were calculated. The measurements were carried out three times at room temperature at different timings. The sample holder was kept in the temperature controlled oven at 200°C for the DC resistivity measurements to see the temperature effect. Other techniques of predicting fly ash resistivity were suggested by Bickelhaupt(1979) and Tidy(1986).

Additive

Preparation of Samples to Study the Effect of Additive on Resistivity

Nearly 50.0 gm of pulverized coal samples (- 200 # mesh, 75 µm) were treated with appropriate quantities of additive under study and blended thoroughly for homogeneous mixing. The mixture was then burned in the furnace at 600°C for 2 hrs and resistivity was measured of individual mixture.

RESULTS & DISCUSSION

Nature of Coal Properties on Ash Resistivity/Conductance

Proximate Parameters

The Proximate analysis data and GCV of coal samples are given in Table 1.

Table 1: The Proximate analysis data and GCV of coal samples (air dry basis)

Sample	Station	Proximate data (wt%)				GCV
		Moistue	Ash	V.M.	FC	(kCal/kg)
Coal -a	A	5.0	19.0	31.0	45.0	5070
Coal- b	B	2.1	24.0	34.0	40.0	5353
Coal-c	C	2.7	39.0	24.5	33.5	4200
Coal-d	D	4.1	42.8	25.5	27.6	3800
Coal-e	E	3.8	44.4	23.0	28.5	3650
Coal-f	F	3.6	47.4	21.00	28.0	3060
Coal-g	G	5.5	45.7	26.0	22.7	3330

The data reveals that the coals (Coal–a to Coal–g) used in various stations under study are of poor grade having low heat value (3060 - 4200 kCal/kg) and high ash content (39 – 45 %) except in two stations (station – A & station – B) where the ash is low (19 & 24 %) and GCV is high (5070 - 5353 kCal/kg).The high ash and low heat value coal demand high coal feeding in the furnace generating high fly ash consequently high loading on ESP. As such the proximate data (especially V.M., FC & GCV) have no direct effect on ash resistivity and conductivity. However, the presence of moisture (Johnson, 1996), nature of chemical composition of ash (Harkar and Pimkarkar, 1988) and temperature have effect on ash resistivty. The effect of temperature on ash resistivity was studied in details by Cumming (1980). The effects of humidity, temperature and chemical composition of ash on ash resistivity are given in Fig.3 & Fig.4.

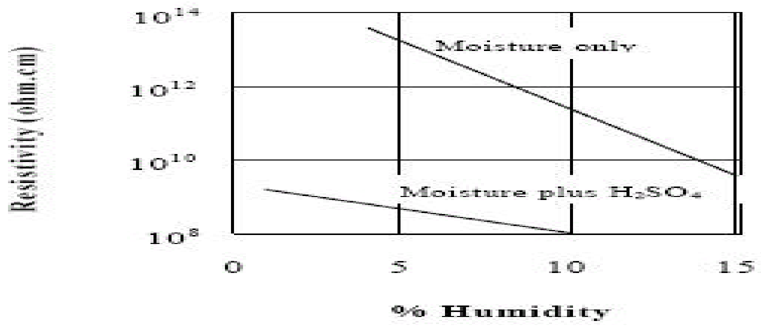

Figure3 : The effect of Humidity(moisture) on resistivity

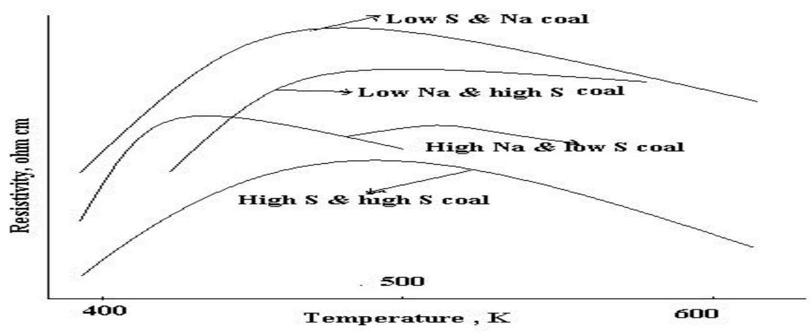

Figure 4: The effect of temperature on resistivity of different types of coals of varying chemical compositions

Mineral Matter / Ash Constituents

The presence of mineral matter and different ash constituents has an effect on ash resistivity and conductance. Indian non-coking coals are rich of a-quartz (10 -20%) and kaolinite (60 – 70%). The various minerals present in Indian coal are given in Table 2 and the ash composition of coal ashes are given in Table 3.

Table 2: Mineral present in Indian coal (non-coking)

Sample		Phases present	
	Most predominant	Predominant	Small amount
Indian coal	a-Quartz, Kaolinite	Hematite, Siderite, Rutile	Pyrite, Gypsum

The resistivity of the flue gas borne ash in coal fired boilers generally varies from 10^4 – 10^{14} ohm cm. The pulverized ash after passing through the boiler flame consists of silicates, silicon dioxide, iron oxide, sulphate, alkaline earth metal oxides, alkali metal oxides and unburned carbon. All these compounds have some effects on ressitivity of ash and ultimately the performance of ESP. The resistivity decreases with increase of some elements like sulphur, alkalies, alkaline earths and iron contents. A high silica and alumina rich ash are high resistivity ash and reduces the ESP performance. Indian power coal generally contains very high silica of the order of 55 – 65 % and alumia of the order of 25 – 35 %. The silica present in the coal is in the form of a- quartz and alumina in the form of kaolinite. The iron

Table 3: The Chemical composition of ash samples

Sample	Ashing Temperature(ºC)	Parameter(wt%) SiO$_2$	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	S
Coal - a	600	61.7	25.6	4.5	1.6	1.2	0.1	0.6	0.4
Coal - b	600	58.7	22.4	3.8	3.8	3.4	0.1	1.0	0.7
Coal - c	600	63.2	25.2	4.7	1.5	0.8	0.1	0.8	0.6
Coal - d	600	60.6	27.5	3.9	1.7	1.2	0.1	0.5	0.7
Coal - e	600	58.5	28.3	5.6	1.4	1.0	0.1	0.8	0.6
Coal - f	600	58.8	26.9	6.2	1.7	0.9	0.1	0.7	0.4
Coal - g	600	58. 8	23.6	9.9	1.0	1.0	0.1	1.0	0.4
Fly ash	-	62.0	24.6	4.7	3.8	1.4	0.1	1.3	-
Fly ash	-	55.4	33.0	4.9	3.0	1.0	0.1	1.0	-

present in the order of 4 – 12 % is in the form of hematite, siderite and pyrite. These minerals have the effect on ash resistivity and also dictate the selection of suitable additive(s) for ash conditioning to reduce the resistivity of ash to make it favourable for ash collection by ESP. The values of resistivity and conductance of different ash samples used in the study are given in Table 4.

Table 4: The values of resistivity and conductance of different ash samples (400°, 600°&1000 °C) at different temperatures.

Sample	Resistivity x 10^{12} (ohm cm) Temperature of Experiment (°C) Room	200°C	Conductance µS / cm	Temperature of ashing (°C)
Coal-a	1.7	-	566	600
Coal-b	0.5	0.2	1507	600
Coal-c	4.9	3.1	267	600
Coal-d	1.3	-	688	600
Coal-e	0.2	-	805	400
	1.0	-	574	600
	5.2	-	95	1000
Coal-f	0.7	-	577	600
Coal-g	0.8	2.7	-	600
Fly ash				
Station - B	6.5	2.0	-	-
Station - C	7.7	2.3	-	-
Station - D	8.6	2.6	-	-
Station - G	1.8	-	-	-

Effect of Sulphur Content in Coal on Fly Ash Resistivity

The major contribution of ash resistivity depends on the content of sulphur in coal (Bickelhaupt, 1978). It was observed that resistivity / conductance of ash mainly depends on the following factors:

i) Forms of sulphur (organic, pyretic & sulphate sulphur)
ii) Organic sulphur has more potential to reduce ash resistuvity than pyretic or sulphate sulphur in the pulverized coal fired boiler.
iii) Availability of SO_3 in flue gas rather than sulphur content in coal.
iv) Rate of conversion of SO_2 to SO_3.
v) Presence of other SO_3 absorbing chemicals like alkalis and calcium content in fly ash.

The origin of three forms of sulphur in coal is available in the literature (Mandal,2003).During burning of pulverized coal in the furnace the organic sulphur present in coal gets evolved at higher temperature and generally burns at upper layer of the furnace and get entry into flue gas. On the other hand, sulphur present in mineral part of coal (e.g. pyritic, FeS2 and sulphate sulphur, $CaSO_4.2H_2O$) decompose at early stage of combustion at relatively lower temperature which is further lowered at reducing atmosphere and get entry into the bottom part of the furnace. Coal used in the present study is of low sulphur coal and major share comes from organic sulphur in total sulphur content. The total and different forms of sulphur in coals
(Coal - a to Coal - g) are given in Table 5.

Table 5: Total sulphur and different forms sulphur (wt%, air dry basis).

Sample	Total Sulphur	Pyritic Sulphur	Sulphate Sulphur	Organic Sulphur
Coal-a	0.39	0.070	0.004	0.316
Coal-b	0.73	0.110	0.038	0.600
Coal-c	0.63	0.094	0.013	0.523
Coal-d	0.68	0.051	0.012	0.617
Coal-e	0.58	0.080	0.009	0.491
Coal-f	0.42	0.082	0.019	0.319
Coal-g	0.36	0.120	0.040	0.200

By comparison of Data of Table 2, Table 3 & Table 4 it was observed that the resistivity values varied according to the values of sulphur content especially organic sulphur.

REMEDIAL MEASURES

The coals used in Indian power stations are generally non-coking low sulphur and alkali content coals. The total silica and alumina content is more than 90% making the ash high resistivity ash. The problem become many fold due to low heat value and high ash coal which demand higher coal feeding and resulting very high ash loading on ESP. Another source of problems is in designing of PC fineness which is not as per coal reactivity and not maintaining the fineness level in many power stations leading to very fine PC and get entry in the furnace with generation of sub-size ash particles. In some of the stations it was found that more than 35% of ash particles are below 10 µm. Fineness has tremendous effect on ESP performance. The effect of fineness on ESP ash collection is given in Fig. 5.

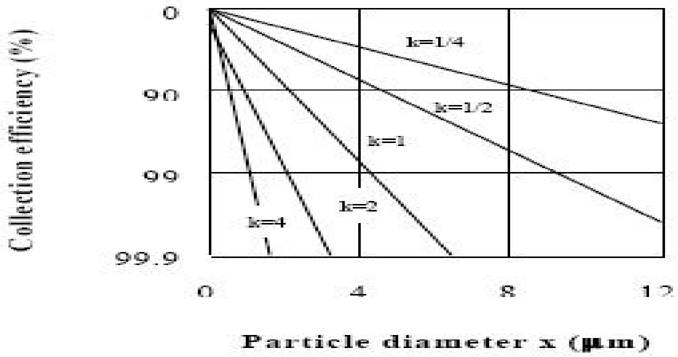

Figure 5: Effect of particle size on collection efficiency

Improvement of electrostatic precipitator performance was suggested by Parker (1976) and Schrader (1970). The study on Indian non-coking coals for possible improvement in ESP collection efficiency by means of optimization of various operating parameters like gas flow, temperature, size, etc in ESP systems or by up gradation of coal quality in terms of sulphur and alkali content, PC fineness, etc are not sufficiently available. So to assign various steps for remedial measures for Indian power coal is very difficult. However, the following possible remedial measures can be adopted to improve the ESP performance of Indian high resistivity ash:

i) Operating gas temperature control
ii) Intermittent energization
iii) Wide – pitch electrodes
iv) Pulsed power supply or semi pulsed operation
v) Coditioning of flue gas (ammona, ammonium sulphate , sodium carbonate, SO_3, sodium conditioning by sodium sulphate, etc).
vi) To change coal properties by blending with high sulphur and high heat value coal. For example, north east coals (S, 5-6%) or biomass like horticultural waste having high alkalis (4 – 6 %) or mustered cropes waste (high sulphur content) may be blended with coal in appropriate proportion depending on the sulphur / alkali content. Ash collection efficiency of Electrostatic Precipitator (ESP) varies greatly according to the electrical resistivity of the collected ash(Fig. 6).

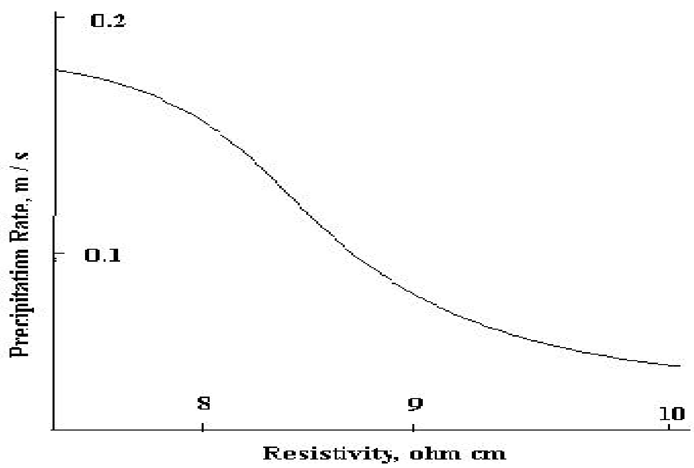

Figure 6: The effect of resistivity on ash precipitation rate.

Additive for improving the performance of electrical precipitators
Extensive research work has been carried out to reduce the resistivity of ash to improve the ash collection efficiency of ESP (Raask, 1976). The comparison of various chemical additives was studied in details by Dalmon and Tidy (1972).

The effect of various additives on ash resistivity is given in Fig.7 & Fig. 8.

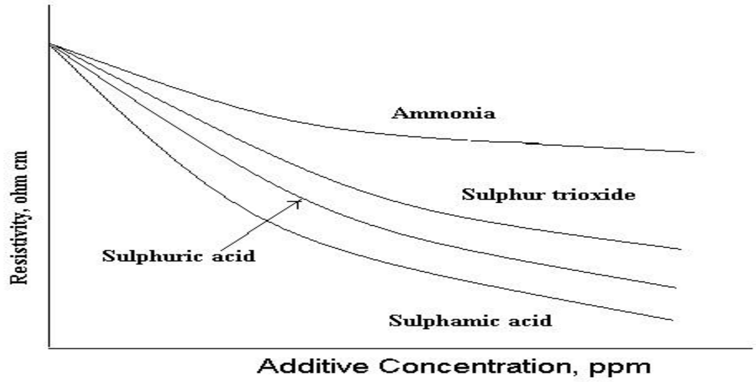

Figure 7: The effect of different additives on ash resistivity

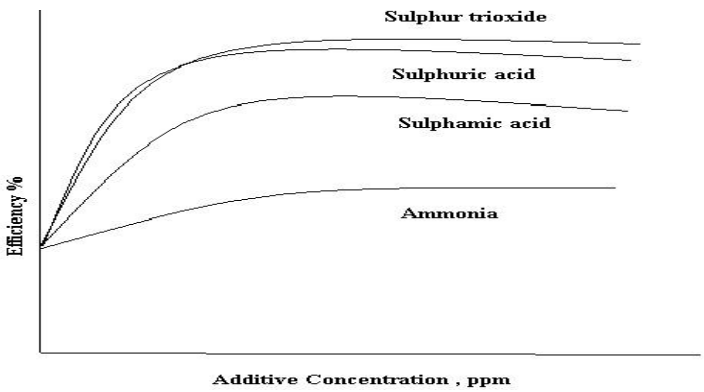

Figure 8: The effect of additives on ash precipitation efficiency.

The resistivity of coal is changed with many additives but they have some long term effect on metal. Especially the dosing of SO_3, Na_2SO_4, NaCl, etc is worth mentioning. The addition of carbonate (Na_2CO_3) is preferable to that of sulphate or chloride. The effect of Na_2CO_3 dosing on resistivity is shown in Fig.9.

The experience with additives to improve the performance of ESP can be summarized as follows:

i) Trace amount of acidic and alkaline additives when adsorbed on the surface of ash can reduce the resistivity by 2 – 3 orders of magnitude.
ii) The most commonly used additive for this purpose is sulphur trioxide (SO_3). The additive may be injected as neat SO_3 or generated from sulphuric acid or by catalytic oxidation of SO_2.

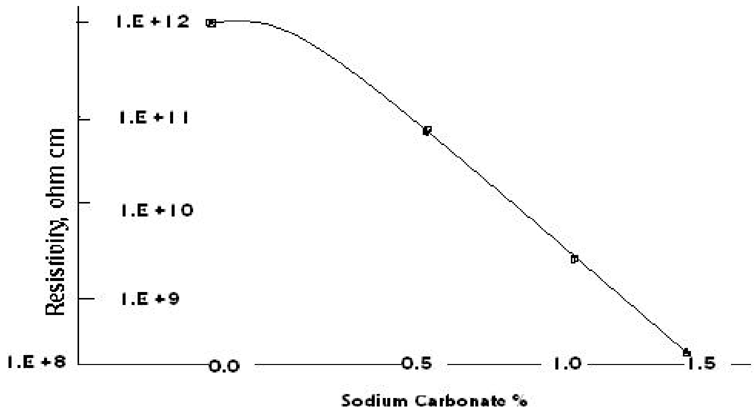

Figure 9: The effect of Na_2CO_3 on resistivity

iii) Solutions of ammonium sulphate and sulphamic acid are frequently used, which decompose to SO_3 and ammonia in the flue gas. Despite the higher cost, the solution additives are preferred because they are easily handled, but they may cause fouling by sticky deposits.

iv) The effective dose rate of SO_3 in the flue gas depends on the ash composition and the sulphur content of coal, but is usually between 5 and 30 ppm. At these levels, SO_3 is quantitatively adsorbed by the flue gas borne ash and there should be no significant increase in the SO_3 content of chimney emitted flue gas.

v) Ammonia may be injected directly into the flue gas or it can be generated from thermal decomposition of sulphamic acid and triethyamine. The effective dose rates were found to be between10 and 50 ppm NH_3.

vi) Solid additives are less extensively used as ash precipitation aids. The Experimental work has shown that alkali-metal compounds can be used with some low-sodium coals. Iron compounds may also have some impact, but calcium compounds do not enhance ash precipitation. There are doubts that magnesium compounds can increase the ESP performance with high resistivity ashes.

Changing of Coal Ash Characteristics by Blending

Detail survey on additive application reveals that there is no encouraging acceptance of additive(s) dosing by power station engineers, they place their trust in improving the engineering hardware rather than on chemical dosing. In this situation, it is better to use blended coals. The properties of coal required for better ESP performance can be changed by blending the poor grade coals with higher grade coal, sometimes by imported coal or by biomass rich in alkali or sulphur content. This will provide the basis to change the resistivity of feeding coal, in turn results in improvement of ESP performance. In India, coals from North – Easter region content low ash and high Sulphur and having high heat value. Biomass like horticulture wastes (mustered crop waste, cotton seeds, coffee husk, etc.) having high alkali content can be used. Some trial has been made using Coal-a and high sulphur coal from North Eastern region (S=6%) in different ratio. The resistivity value of Coal – a was reduced to less than 10^{12} ohm cm, in 90 :10 ratio(Coal-m) of Coal-a and north eastern coal of high S(6%), less than 10^{11} ohm cm in 75:25 ratio(Coal-n) and less than 10^{10} ohm cm in 55:45 ratio in blended coal(Coal-o). Blended coal with 55:45 ratio will be the most suitable coal in terms of good ESP performance is concern (Fig.10).

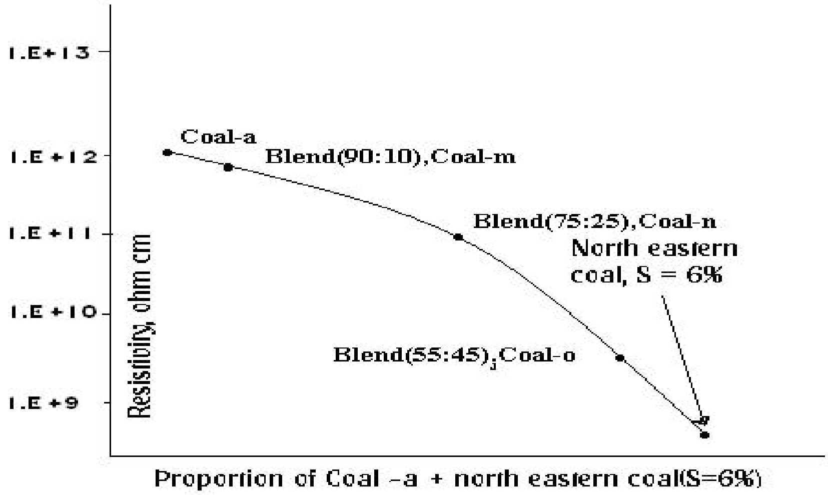

Figure 10: The effect of blended coal on resistivity

Some Comments on ESP Performance in India due to Use of Low Grade Nn-coking Coals in Pulverized Coal Based Stations

Based on the many years operating experiences in power stations in India it can be mentioned that for Indian power coals the performance of the ESP is influenced by many factors and in practical sense to achieve the 99.9 % efficiency is very difficult. It may achieve the target but the sustainability is very less. After overhauling the ESP system works very satisfactorily but it deteriorates its performance very rapidly. This is because of the high refractory nature of ash and poor heat value of Indian non-coking coal resulting in over loading on ESP system.

i) Clearing of electrodes: - The performance of ESP generally depends on the amount of electrical power consumed by the system. The highest collection efficiency is achieved when maximum possible electrical power for a given set of operating conditions is utilized in the precipitation process. During the operation of ESP, the applied is reduced by the potential drop across the deposited dust layer on the collecting electrodes due to current flowing through it. This results in the reduction of the effective voltage which consequently reduces the efficiency. A thick cover of dust layer on the collecting electrode also leads to unstable operating conditions. The ash deposit on the emitting wires results in non-uniform corona. So the efficiency decreases due to heavy deposits of ash on collecting and emitting electrodes which needs efficient rapping system for both the collecting and emitting electrodes.

ii) Gas temperatures: - The operation of precipitator at gas temperature below the
    a. acid due point (< 100°C) results in :
    b. Failure of emitting electrodes due to stress corrosion cracking.
    c. Corrosion of terminals.
    d. Collection of wet ash on the electrodes leads to formation of hard- to- rap layers of ash.
    e. Difficulty in removal of wet ash from the hoppers.

iii) Spark rate: - The operating voltage and current keep changing with operating conditions. This takes care by the electronic controller unit. Very high flash over rate results not only reduction of useful power and interruption of precipitation process but also cause snapping of emitting electrodes due to electrical erosion.

iv) Rapping frequency: - The frequency and sequence of rapping of collecting and emitting electrodes are programmed by the synchronous program master controller. The time interval between the raps of various fields have been optimally chosen to permit build- up of sufficiently thick layer so that when rapped , the ash is dislodged in the form of agglomerates resulting in re-entrainment and puffs through the stack.

v) Oil combustion: - The unburned oil has an important impact on ESP performance. Unburned oil, if pass through EP, can clot the collecting and emitting electrodes. This reduces the precipitator operating voltage due to high electrical resistivity and consequently the EP performances deteriorate. The precipitator performance remains poor until the oil vaporizes and the layer get rapped off., which is usually takes few weeks time.

vi) Hopper evacuation: - Improper / incomplete hopper evacuation is the major cause for the ESP malfunctioning. If the hoppers are emptied regularly the ash will build to the high tension emitting system causing shorts. In addition, the ash build up in the ESP chamber beyond the hopper will cause bulking of the collecting plates and dissociation of the emitting frames leading to misalignment of the electrodes.

CONCLUSION

Indian non-coking coals used in power stations are of poor grade having high ash (35 – 50%) and low heat value(2500 – 5000 kCal /kg). The ash contains mainly silica and alumina (total, > 90 %). Fly ashes are of low Sulphur (< 0.5%) and low alkalis(<0.8%).Due to presence of high SiO_2+ Al_2O_3 and low sulphur and alkalis the fly ash generated in Indian Thermal power stations have high resistivity (10^{12} – 10^{13} ohm cm). The high resistivity fly ashes are difficult to collect by ESP due to back corona making the ash collection difficult in sustainable basis.

The high resistivity fly ash can be collected by: i). Operating gas temperature control, ii) Intermittent energization, iii) wide – pitch electrodes, iv)pulsed power supply or semi pulsed operation, conditioning of flue gas (ammonia, ammonium sulphate, sodium carbonate, SO_3, sodium conditioning by sodium sulphate, etc) and v) changing coal properties by blending with high sulphur and high heat value coal. For example, north east coals in India(S, 5-6%) or biomass like horticultural waste having high alkalis (4 – 6 %) or mustered crops waste (high sulphur content) may be blended with coal in suitable proportion depending on the sulphur / alkali content.

In spite of adopting various methods, suitable for high resistivity ash the sustainable efficient collection of ash is very difficult. This is mainly because of difficulties in : i) Clearing of electrodes, ii) operation of precipitator at gas temperature below the acid due point (< 100°C), iii) high spark rate, iv) clotting on the collecting and emitting electrodes during oil combustion, and v) hopper evacuation due to heavy ash build up.

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