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PERFORMANCE IMPROVEMENT OF ELECTROSTATIC PRECIPITATOR: SOME EXPERIMENTAL STUDIES

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ABSTRACT

Emissions standards are becoming more stringer, as a result new retrofit/technique are being applied in the existing power plant in India. Electrostatic Precipitators (ESP) are used to control fly ash emitting from the boilers of the power plants. The coal burned in power plants in India to generate the power are characterized by low calorific value (3500-4500) Kcal/Kg., and high ash content (35-45) %. Thus compared to U.S. and European coals, Indian coal generate about 6 to 7 times more ash for collection for similar electricity generation. Besides, low sulfur content (<0.5), results in the resistivity of fly ash being 100-1000 times higher than that generated elsewhere. Thus ESPs in India, despite being much larger, have lower collection efficiencies than the ESPs in U.S/Europe. In this paper we discuss some methods which are being applied in different power plants in India to improve the collection efficiencies of ESP.

The methods, which have met with success, are (a) Pulse charging of ESP unit, (b) Flue gas conditioning by water fogging and ammonia, and (c) coal ash conditioning with sodium salt before feeding to boiler. In some case additional ESP was put in series with the existing one thereby, increasing the total collection area. The paper describes the experiments and analyses the results obtained.

1. INTRODUCTION:

Coal fired power plants provided 45% of electricity needs in developing countries in 2002, which in likely to increase to 47% in 2030. In fact coal reserves are significantly more abundant and more wide widely and evenly dispersed, as compared to other fossil fuels. Oil and gas reserves are more lightly concentrated in Middle East and the Former Soviet Union. As shown in Table A. Coal is well positioned to make a valuable contribution to global energy security [1].

For meeting the rising demand of electricity to meet the industrial production needs, India, too is making massive investment in Power Sector. The total installed capacity, which was slightly more than 100,000 MW in March 2001, is expelled to reach around 215,000MW in the year 2011-12 [2], as shown in Table B.

Table A: Location and Availability of the World's Main Fossil Fuel Reserves (Gigatons of coal equivalent)

S.No.	Location	Coal	Oil	Gas
1.	North America	258	16	11
2.	South America	22	25	11
3.	Western and South Europe	97	07	08
4.	Central and Eastern Europe	33	01	01
5.	Former Soviet Union	225	21	86
6.	Middle East	02	179	110
7.	India	84	01	01
8.	China	115	06	03
9.	Africa	55	25	21
10.	Asia & Oceania	94	06	17

Table B: India's perspective plan for power for zero deficit power by 2011 /12 (In MW)

S. No.	Capacity Details	Thermal (Coal)	Gas/LNG Diesel	Nuclear	Hydro	Total
1.	Installed Capacity as on March 2002	61,157	Gas 10,153	2720	25116	100,10
2.	Addition Capacity (2001-2012)	53,333	Diesel 854 Gas 20,408	9380	32,673	115,794
3.	**Total**	**114,490**	**31,425**	**12,100**	**37,789**	**215,804**

The contribution of coal based thermal plants, which is 58% today (2003) is likely to remain significant (53%) in 2011-12 as well, when coal based installed power capacities will reach around 115,000 MW. In order to maintain clean environment in and around the power plants, stringent emission standards are enforced by the Pollution Control Boards for the power plants. In India, there are 83 coals based thermal power plants out of which 4 plants are closed. 55 plants comply with emission standards and 23 plants are yet to comply with the emission stands Electrostatic Precipitators (ESPs) are used to control the fly ash emission from the boilers of the plant. The percentage of utility boilers equipped with ESPs in India is 99.5% (320 out of 325). The present emission standards for particule emission for a 210 MW or more utility boiler are 150mg/nm^3, which is likely to revise to 100 mg/nm^3 soon. It is estimated that a sum of Rs 1740 Crore (USD 400 Million) will be require to meet the new emission standards for the existing plant [2].

The design, operation and performance of ESP largely depend on the properties of coal burnt and fly ash generated. The properties of the coal used in different plants across the country vary widely. In many of the power plants in India the ash contents of coal are as high as 45% and coal have low calorific value. Thus, compared to US and Australia coals, Indian coal generated about 6 to 7 times more ash for collection for generating a unit kWh of electricity. Besides, low sulfur contents ($\leq$ 0.5%) result in resistivity of fly ash being 2 to 3 order of magnitude higher than that generated elsewhere. The higher value of electrical resistivity results in development of back corona even at much lower current densities and generation of sparks at much lower voltages. As a result the ESPs in India, despite being much larger, have lower collection efficiencies than that used in US/ Europe. The reduction in size (lower capital cost) and improvement in collection efficiencies of ESPs are major challenge for power industries in India. The performance of old ESPs can be improved by taking number of retrofit measures for which systematic studies are required.

The major technologies are:

(i) Intermittent charging to suppress back corona discharges.
(ii) Modification of fly ash resistivity by sodium conditioning.
(iii) Flue gas conditioning by using ammonia /SO_3 / water fogging.

These technologies may be applied in either in isolation or combination. In the present investigations the applications of these technologies have been reported to reduce the emissions from the power plant.

2. INVESTIGATIONS:

The results reported in the paper are based on the investigation carried out of at different power plant run by National Thermal Power Plant Corporation (NTPC) India. Some investigations were carried out at BTPS, Delhi. The emissions levels were brought down by using intermittent charging units to power the ESP units. Some results based on the investigation are used here, while more details have been provided else where [3]. Another investigation [4] were carried out on sodium conditioning, water fogging and coal washing for environmental performance improvement of ESPs at power plant No.2 by a teams consisting of the experts from SRI, Birmingham, USA and CenPEEP, NTPC. Some results have been used to analysis the ESP performance in the present paper Flue gas conditioning using ammonia was applied to reduce the emission at a power plant at power plant No.3 during July/ August 2005 by the researchers from CenPEEP, NTPC and Research Centre NTPC, some of the data generated there is used to analyze the ESP performance. Simultaneous dust loadings were carried out at the inlet and outlet of ESP unit in all the investigations, which were used to determine the collection efficiency of the ESP units. Fly ash samples were collected from the different power plants for various conditions of operations (e.g. before and after flue gas conditioning with ammonia etc). The fly ash resistivity measurements for different samples were carried out at ash resistivity measurement laboratory at Centre for Energy studies, IIT Delhi India as per IEEE standard (548-1984 norms). A laser based size particle analyzer was used to determine the particle size distribution in various ranges. In the following sections we briefly describe these investigations.

(i) Particulate Reduction using Intermittent Charging

Intermittent charging/energizing systems are normally used to suppress back corona discharges in the ESP collecting fly ashes having high electrical resistivity 10^{11}-10^{13} Ohm-cm. The system simply energizes ESP unit for a specified number of cycles and suppresses the ESP energization for specified number of cycles not by gating thyristors. The system works because of time dependence of the formation of back corona in a resistive dust layer, which can be considered equivalent to an electrical circuit having capacitor and resistor in parallel. The capacitors must be charged a voltage across the dust layer just before back corona can form. With normal continuous operation with high resistivity fly ash this condition is met continuously. However, with intermittent charging the voltage is never allowed to reach like critical break-down level. The time it takes the voltage to break-down level depends on number of factors such as resistivity, dielectric constant, break down strength, current density etc. Intermittent charging is the periodic gating (on) and suppression of gating (off) of the thyristor. The duty cycle or the charge ratio is defined as the ratio of the number of on cycle to the sum of the on and off cycle. Advanced precipitator controllers (BAPCON) developed by Bharat Heavy Electricals Limited, India (BHEL), have been used for intermittent charging and controlling the current to ESP in the present investigations. The charge ratio can be varies in the range 1:1 to 1:159, which is necessitated to tackle the high resistivity of fly ash encountered in precipitators in India. At higher charge ratios the base voltage reduces to very low values. The provision of base charging is made during some of the skipped half cycles there by avoiding the effect of low voltage. A facility is provided for the measurement of peak and valley voltages of the charging signal. A high peak voltage increases the effective migration velocity and thus increases the collection efficiencies.

To release the ash from the collecting electrodes in to the hopper a rapping system (RAPCON) is provided by BHEL, India. The RAPCON is a dedicated microprocessor based device for controlling the rapping motors. There are 16 rapping motors associated with 16 fields. The starting time, run time and repeat time for all the motors can be set either in local or remote mode. The controller has error check provisions. It has a time factor feature, which adjusts the repeat time of rapping motors.

Investigations were carried out to choose the optimum operating conditions namely, input current, charge ratio, rapping rate, voltage developed in all 16 fields of the unit just before the break down with the help of BAPCON and RAPCON units. The magnitude of the charging current to different fields is decided by the maximum allowable spark rate of 5 rates per minutes, (which was the beginning of the back corona). Thus the conditions were established for getting maximum peak voltage just before high spark rate conditions (high back corona), which depends on charge ratio, current supplied to the field, rapping rates at a given temperature, pressure and volume of flue gases passing through ESP units. The charge ratios were optimized on the basis of maximum peak voltages obtained in different fields. These values were (15, 19, 25 and 31) in first, second, third and fourth field respectively.

Dust loading tests were carried out simultaneously at the inlet as well as the outlet of the ESP units. The other parameters measured at the inlet and out let of the ESP units are flue gas emission rate, stack velocity and temperatures. The inlet and out let dust loadings were used to calculate the dust collection efficiencies of ESP units under various conditions of operation. These values of collection efficiencies were used to calculate average migration velocities of the charged dust particles using standard Deutch-Anderson relations. These migration velocities were used as indices of the performance of ESP under various conditions of operation. The experimental results obtained in these studies are used to investigate the fractional changes in migration velocities under different conditions of charging the ESP units. Table1 shows the variations in the values of migration velocities. It is seen that it is possible to enhance the migration velocities over the designed one by in corporating the pulsed / intermittent charging system. The migration velocity may be optimize by choosing charging current, charge ratio and rapping rate of collecting electrodes. Enhancement in migration velocities up to 25% may be achieved there by reducing the emission level drastically from the power plants.

(ii) Experiments Related with Sodium Conditioning

Sodium conditioning was carried out at power plant No.2. Depending on the chemical composition of the fly ash generated in the plant and appropriate sodium salt was chosen as to enhance the sodium ash contents of fly ash by 0.5%. The ash resistivity was measured before and after the conditioning of coal fed in to the boiler. The experimental results are summarized in table 2. Simultaneous dust loading test were performed at the inlet and out let of the paths A and B of the unit 1 and unit 2 of the power plant. First base line conditions were established and there after sodium injection were applied in both the paths of the two units. For comparing the migration velocities in different condition the following expressions were used based on Anderson- Deutch relations.

$$\frac{\omega}{\omega_0} = \frac{(SCA)_0}{(SCA)} \frac{\ln(1-\eta)}{\ln(1-\eta_0)}$$

and $$\Delta\omega = (\frac{\omega}{\omega_0} - 1)$$

While

ω = Migration velocity

SCA= Specific collection area

η = Collection Efficiency

= Change in migration velocities from base line conditions

Base line condition are denoted by (0)

The results of the experiments have been shown in table no.2 [4] the changes in migration velocities have been calculated by assuming SCA same during the while expand. The following observations can be made based on the results:

(a) There is drastic reduction in outlet dust concentration when the sodium salt is mixed with coal in boiler in all cases. The emission levels are reduced to a level of (25-16) % of base line levels.

(b) The collection efficiencies of the units are enhanced in the range (0.5-1.27) %, there by leading to drastic reduction in out let dust concentrations.

(c) The effective migration velocities are enhanced by (27- 44.6%), of base line conditions.

(d) The electrical resistivity reduced to ($9x10^{11}$) ohm-cm from ($2x10^{12}$) of base line conditions at operating temperatures of ESP.

(e) Since the amount of fly ash collected in last fields is very little (<1.0%), it may be removed all together thereby reducing the size of ESP and meeting the emission norms at the same line.

The enhancement of collection effectives and migration velocities may be attributed to drastic reduction in electrical resistivies of fly ash due to sodium conditioning.

(iii) Water Fogging Experiments

An increase in moisture contents in flue gases reduces the electrical resistivity of fly ash and the system. This results in increase of spark over voltage and enhancement of collection efficiency. The moisture resistivity conditioning reduces the actual volume flow of the gas and thus increases the specific collection area (SCA). However large quantities of water mass are required to reduce the temperature of flue gas by tens of degrees calsius. It may affect the life of emitting and collecting electrodes adversely.

Moisture conditioning of flue gas by water fogging does not inject enough water to reduce the temperature of water significantly and as a results the resistivity of fly ash remains the same. However, operating voltage increases at the allowable current density. During water fogging water is injected through a special nozzle in to flue gas. The water droplets should be evaporated prior to impingement on any surface with the dust. The success of the process depends critically on the complete evaporation of the water droplets injected in to the flue gas. Experimental results carried out at power plant No.2 have been shown in table3. As one can see there is a reduction of emission levels at the out let due to water fogging.

(iv) Efficiency Improvement using Ammonia Dosing:

Ammonia dosing was introduced to the flue gases entering in to the ESP units of power plant No.3. Inlet and outlet dust loadings were measured at various stages of ammonia dosing. Table 3 describes the various parameters measured under different conditions of experiments. The parameters like collection efficiency (η) migration velocity (ω), deviations in migration velocities ($\Delta\omega$) have been calculated based on Anderson-Deutch relation for the experimental conditions described in table 3. Based on table 4 some inferences may be drawn as follows:

(i) There is a significant drop in the out let concentration because of injection of ammonia, although there seems to have some optimum value of ammonia dosing at around 15 Kg/hr (˜ 0.142 ppm).

(ii) The ESP collection efficiency is enhanced due to ammonia dosing and so is the migration velocity. The migration velocity rises in the range (16.60 – 22.82) % as different doses of ammonia conditioning compared to no dosing.

(iii) It is possible to achieve new emission standards (˘ 100 mg/ Nm^3) using the same ESP units by appropriate amount of dosing of ammonia in to flue gases.

4. CONCLUSION:

It is possible to reduce the emission from the existing ESP by adopting either or any one of the following methods (i) water fogging (ii) intermittent charging (iii) ammonia dosing of flue gases and (iv) sodium conditioning of flue before feeding to boiler. While there is limited reduction in emission level due to water fogging, quite appreciable reduction in observed in emission levels due to intermitted charging of the fields in ESP. Other methods e.g. Ammonia dosing and Sodium conditioning of fuel hold great promise to reduce the emission levels in significant way. It is possible to achieve emission levels less than 100 mg/ Nm^3 in existing power plants in Indian by adopting these methods. SO_3 conditioning of flue gases is another promising process but results based on such method are not available in India.

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Table 1. Changes in collection efficiencies and migration velocities due to intermittent charging

S.No.	Exp no.	η	ω	$\Delta\omega$%
1.	Designed	99.61	3.51	0
2.	Exp 1.	98.84	3.83	9.1
3.	Exp 2.	98.92	3.96	12.0
4.	Exp 3.	99.27	4.23	20.05
5.	Exp 4.	99.40	4.39	25.07
6.	Exp 5.	99.08	4.07	15.95
7.	Exp 6.	99.85	3.98	13.39

Table 2: Improvements in ESP performance due to Sodium conditioning at power plant NO. 2

Unit-1

S.No.		ESP Inlet loading mg/Nm3	Outlet loading	Measure (η)	$\Delta\omega$%
1.	Baseline Side A	45305	634.27	98.50	44.6%
2.	Sodium inject A	45305	104.20	99.77	
3.	Baseline Side B	64855	778.26	98.80	38.3%
4.	Sodium inject B	64855	142.7	99.78	

Unit-2

1.	Baseline Side A	69870	572.90	99.18	27.38%
2.	Sodium inject A	69870	153.70	99.78	
3.	Baseline Side B	67830	454.40	99.33	27.39%
4.	Sodium inject B	67830	115.30	99.83	

Table3. Water Fogging at power plant No 2

S.No.		ESP Inlet loading mg/Nm3	Outlet loading	Measure (η)	Δ ω%
1.	Baseline Side A	69870	670.80	99.04	4.73%
2.	Sodium inject A	69870	496.00	99.23	

Table4. Improvements in emission levels due to Ammonia dosing at power plant No. 2

Unit load (MW)	NH_3 injection (Kg/hr)	Sp. Coal kg/KWH	Output Con. mg/Nm^3	Input Con. (mg/Nm3)	Area, A m2	Volume flow rate Q (m3/s)	SCA = A/Q	η	ω
200	0	0.9	166.2	58750	59684.4	245.2352	243.38	99.717	2.41
200	15	0.84	48	52350	59684.4	252.3072	236.55	99.908	2.96
200	25	0.86	48.3	48110	59684.4	253.8304	235.13	99.900	2.94
200	40	0.96	52	41915	59684.4	253.3408	235.59	99.876	2.84
175	15	0.71	34	45345	59684.4	233.0496	256.10	99.925	2.81
150	15	1.03	76.5	61350	59684.4	251.0016	237.78	99.875	2.81

Table 5. Changes in collection efficiencies and migration velocities due to Ammonia Dosing

S. No.	η	ω	Δ ω%
1.	99.717	2.41	-
2.	99.908	2.96	22.82
3.	99.900	2.94	21.99
4.	99.876	2.84	17.84
5.	99.925	2.81	16.60
6.	99.875	2.81	16.60