Enhancement of Collection Efficiencies of Electrostatic Precipitators: Indian Experiments

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Abstract: With the rising oil price, coal is well positioned to make a valuable contribution to global energy security. The market share of coal in electricity generation in developing countries is around 45% at present and is expected to rise up to 47% in 2030. A significant amount of power generation in countries like China, India, USA, Russia, East Europe, South Africa and Australia is based on coal. At present India has got 61175 MW (58% of total installed power capacities) installed coal based power capacity which is expected to rise 115500 MW (53%) by the year 2012. Fly ash emitted by the coal based power plants is serious air pollutants in and around the power plant compared to SO_x and NO_x air pollutants in India. Electrostatic Precipitators are used to control fly ash emitting from the boilers of most the power plants in India. The coal burnt in most of the power plants in India are perhaps are among the most difficult ones in the world, which are characterized by low calorific value 3500 kcal/kg-4500 kcal/kg, and high ash contents 35%-45%. Besides, ashes have got large electrical resitivities because of low alkali and sulfur. As a result the size of ESPs in India is much larger compared to other places for similar electric out put. In order to meet the more stringent emissions standards several methods have been adopted in many old power plants with aged ESPs. These methods include: (i) enhancement of collection area of ESPs; (ii) Pulse and intermittent charging of ESP units; (iii) Flue gas conditioning by water fogging, ammonia conditioning; (iv) Dual conditioning with NH_3 and SO_3, and; (v) Coal ash conditioning with sodium salt. These methods have got their respective advantages and disadvantages and have met partial success. The present paper discusses some of the points for some of the selected plants.

Keywords: ESP, India, power plant, collection efficiency

1 INTRODUCTION

Fossil fuels meet 80% energy demand of the world at present, which is likely increase to 81% in the year 2030. Coal meets around 28% energy needs of the world, but coal fired power plants generate around 40% of global electricity. In developing countries coal is still more important providing 45% of electricity needs, today, which is likely to increase to 47% by 2030[1]. The oil prices are increasing at tremendous pace and there is uncertainty in getting the gas supplies. It is only the coal which ensures a shamble of energy security because of its wide spread availability and stable prices, which are far cheaper compared to either of gas or oil for getting equivalent energy. Some of the major countries of the world like USA, China, India, South Africa, Australia and East Europe have more than 50% of their electricity generation based on coal. China's primary energy is dominated by coal The share of coal in primary energy consumption was 69%, oil 21%, and remainder divided between natural gas, hydropower, nuclear, wind and solar energy in the year 2005[2]. The share of coal in electricity production was still higher. The importance of coal production in China and its role as energy source is not set to substantially change in the near future. Coal is the dominant commercial fuel in India, meeting half of the commercial primary energy demand and a third of total energy needs. According to International Energy Agency (IEA) projections, coal will remain the dominant fuel in India's energy mix through to 2030. Demand is projected to grow from 391 Mt in 2002 to 758 Mt in 2030. Only china's demand for coal is expected to outstrip India's. The power sector will be the main driver of India's coal consumption–currently around 68% of India's Electricity is generated from, although this share is expected to decline slightly to 64% by 2030.

India is the sixth largest electricity generating country in the world accounting for around 4% of global electricity generation. It is also sixth largest electricity consumer worldwide. Annual electricity generation and consumption have increased by about 64% in the past decade and the projected rate of increase in electricity consumption is estimated at around 8%-10% annually through to 2020 to meet the electricity demand by that time. The present (May, 2008) installed capacity in India is around 144564 MW, which include 92216 MW (64.6%), thermal [76298MW (53.3%) coal, 14716 MW (10.5%) gas and 1201 MW (0.9%) oil], 36033 MW (24.7%) hydro, 4120 MW (2.9%) nuclear and rest 12194 (7.7%) by renewable. However, India is still facing a power shortage in terms of over all around 8% and peak demand of 12%. This capacity is expected to reach around 215000 MW in the year 2011-2012 to meet the power shortage. It will require around 70,000 MW of base capacity addition by 2012. The energy and power demand of India are shown in Table 1 [3].

One can observe from the Table 1 (a) ,(b), the coal fired power plants contribute the majority of electricity in India and will continue to be a major source of electricity generation into the future. The pollution control and improving the efficiency of coal fired power plants will be essential in helping to meet some of the demands. The introduction of supercritical technology will also be important with the addition of 36800 MW supercritical units to be commissioned during the 11^{th} (2007–2011) and 12^{th} (2012–2016) five year plans.

Table 1 (a) Commercial Energy Mix in India (Power Sector)

S No.	INSTALLED CAPACITY	YEAR 2005 MW	YEAR 2030 MW
01	COAL	67388 (55%)	200000 (44%)
02	HYDRO	31190 (26%)	100000 (22%)
03	NATURAL GAS	12172 (10%)	100000 (22%)
04	OIL	1202 (1%)	100000 (22%)
05	NUCLEAR	3000 (3%)	30000 (7%)
06	RENEWABLE (NON–SOLAR)	5684 (5%)	70000 (15%)
07	SOLAR	294	56000 (12%)
08	Total Installed Capacity	120000 (100%)	456000 (100%)

Table 1 (b) Primary Energy Requirments

S No.	Resources	YEAR 2003–2004	YEAR 2030
01	COAL	167 (51%)	816 (50%)
02	HYDRO	7 (2.3%)	43 (2.6%)
04	OIL	119 (36.4%)	435 (26.6%)
05	NUCLEAR	5 (1.5%)	115 (7.0%)
07	GAS	29(8.8 %)	224 (13.7%)
Total		327(100%)	1633 (100%)

(Million Tons of Oil Equivalent)

Coal reserves in India are plentiful but of low quality; high ash up to 45%, low calorific value and low sulfur. India has 10% of world's coal, at over 92 billion tones, third only to the USA and China in total reserves. At current rates of production, India has enough coal to last more than 200years. Less than 5% of India's coal reserves are coking coal, needed for steel industry. As a result, India imports coking coal to meet about 25% of its annual [4].

2 THERMAL POWER PLANTS AND POLLUTION CONTROLS IN INDIA

There are 98 steam power stations, out of which 91 are coal fired steam turbine power station. Twenty nine power stations having aggregate installed capacity of 9424 MW reported an overall efficiency less than 25% during 2003–2004. These power stations produce 34071 GWh i.e. 8.36% of total electrical energy. Twenty power stations with an aggregate installed capacity of 11616 MW reported an overall thermal efficiency ranging between 25%-30% and generated 64113 GWh i.e. 15.74% of total electricity generated. Forty nine power stations with an aggregate installed capacity of 43915 MW had an over all thermal efficiency above 30% and produced 309099 GWh representing 75.89% of total electrical energy produced. All India plant load Factor (PLF) of coal based steam power station in the country is around 74.3% [5].

In order to maintain clean environment in around the power station, stringent emission standards are enforced by the Central Pollution Control Board, Ministry of Environment and forests, India for the power plants. As the ash contents with Indian coals are high , the board has recommended the use of beneficiated / blended coal containing ash not more than 34% w.e.f. June 2002 for the following power plants: (a) Power plants located beyond 1000 kms from pit head; (b) Power plants located in critically polluted areas, urban areas and in ecologically sensitive areas. Beneficiated / blended coal having ash contents 34% or less is being used by 24 thermal power plants (85 units) at present.

Assessment of heavy metals emissions was carried out from some of the coal fired thermal power plants. The concentrations of Hg, Pb, As, Cr, Cd, Ni, Cu, & Zn were found significant in both forms i.e. as particulate and gaseous in the stack emissions. The concentration of Hg in particulate and gaseous emissions after ESP was recorded to be in the range of 4.98 $\mu g/Nm^3$–25 $\mu g/Nm^3$ & 5.5 $\mu g/Nm^3$–87.1 $\mu g/Nm^3$. Coal cleaning is suggested as one of the methods to remove mercury by 21% [6].

The concentration of sulfur is rather low (0.5% or less) for the coals used in the power plants; the ground level concentrations of sulfur dioxide coming out from the power plants are regulated by raising the height of smoke stack. Only in 1 unit out of 325 units of power utilities, Flue Gas Desulphurization or Scrubbers are being planed.

3 STATUS OF ELECTROSTATIC PRECIPITATORS IN INDIA

The emissions of fly ash from the Indian Power plants for equivalent power produced is quite high compared to else where, because of low calorific value and high ash contents of the coals fed into the boilers. Electrostatic Precipitators (ESPs) are used to control fly ash emissions in most of the power plants. Out of 325 units operating in India 320 are equipped with ESPs. 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 (≤ 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. In order to obtain relevant technical and financial information about the status of existing ESPs in all the operating coal based power stations of the country, a questionnaire was circulated to 76 power stations of the country by CPCB[7].Based on the information the power plants have been divided into three categories:

Table 3 contains those power plants having capacities less than 200 MW capacities; these are aging plants. In all data is based on 15 power plants. Many of the plants are having minor to major problems associated with ESPs .The total number of fields vary between 8-14. Most of them are energized in normal mode, while some of them have semi pulse or multi pulse energisation. The designed collection efficiencies are 99.5% or more. The flue gas velocities are in the range 0.8 cm/s-1.0 cm/s. The gas treatment time is quite large in the range 20 s-30 s. The inlet dust loading varies in the range 40 g/Nm^3-g/Nm^{3}120, which is quite high and so is the Specific Collection Area (SCA) in the range 130 m^2/m^3/s - 218 m^2/m^3/s. Migration velocities vary in the range 2.8 cm/s-4.7 cm/s, which are again very low and indicate a very high value of Resistivity of fly ash generated in excess of 1×10^{11} ohm/cm.

Table 4 presents the technical data of ESPs associated with power plants in the range of 200 MW–500 MW. These are largest in number and comparatively new. The data of ESPs from 29 power stations has been presented. The ESP fields associated are larger in the range12 to up to 24 fields. Semi pulse is the preferred mode of energisation of the ESP fields, followed by multi pulse mode, some are being still charged in normal mode. The inlet dust loading to the fields is comparatively small in the range 20 g/Nm^3-75 g/Nm^3. All other parameters are having similar values as for smaller plants.

Table 5 compares the technical parameters of ESPs attached to 500 MW thermal power plants boilers. Such power plants are small in numbers, although few higher capacity plants are in the process of being set up. The numbers of ESP fields is quite large in the range 24-32. The mode of energisation is either semi pulse or multi pulse mode. The designed collection efficiency is more than 99.5% in order to keep the emission levels less than 150 mg/Nm^3. The inlet dust loadings are in the range 30 g/Nm^3-75 g/Nm^3. The migration velocities attained are low in the range 3 cm/s-3.5 cm/s.

Table 3 Comparison of Technical Parameters of ESP's (< 200 MW)

S NO	Name of unit	ESP Fields / Energisation	Design Efficiency (%)	SCA m^2/m^3/s	Gas Velocity (m/s)	Treatment Time seconds	Inlet dust loading (g/Nm^3)	ESP Emsission (mg/Nm^3)	Migration Velocity (cm/s)	Reported problems in ESP
1	RAJGHAT TPS 1&2:67.5 MW	10 Multi pulse	99.77	206.4	0.56	31	50	150	2.81	None
2	INDRAPRASHT TPS –5 60 MW	10+6 Semi pulse	99.9	190.89	0.98	19.85	150	150	3.61	None
3	INDRAPRASHT TPS 2 – 4:62.5MW	10 Semi pulse	99.81	132.32	0.81	19.85	75	150	4.73	None
4	BADARPUR TPS 1,2&3 95 MW	8 Normal	99.6	151.87	0.80	28.8	125	500	3.63	None
5	TALCHER TPS 1to4: 60 MW	20 Normal	99.5	146.8	0.76	22.39	80	400	3.6	Major
6	BHUSAWAL TPS 1, 58 MW	8 Multi pulse	99.77	142.85	0.54	28.5	50	150	4.25	Major
7	ENNORE TPS 1,2&3: 60MW	12 Multi pulse	99.8	180	1.00	27	50	100	3.45	Major
8	BANDEL TPS 1,2&3 : 80 MW	08 Normal	99.4	132.97	0.90	19.95	83.33	500	3.84	Major
9	BANDEL TPS 4: 80 MW	12 Normal	99.4	125.97	0.78	16.72	50	300	4.08	Major
10	AMARKANTAK TPS 3&4: 120 MW	8 Normal	99.83	167.7	0.72	25.2	75	150	3.80	Major
11	ENNORE TPS 4&5: 120 MW	12 Multi pulse	99.86	275	1.00	27.00	50	100	2.38	Minor
12	SABARMATI TPS D,E&F 110 MW	14 Normal	99.77	154.22	0.83	23.00	50	100	3.93	Minor
13	SIKKA TPS 1 120 MW	14 Normal	99.36	159.1	0.94	23.87	21.42	150	3.17	Minor
14	TANDA TPS 1to 4 :110 MW	14 Normal	99.37	159.84		28.98	42.85	300	3.17	Minor

Table 4 Comparison of Technical Parameters of ESP Attached to Power Plants 200 MW–500 MW

S. NO	Name of unit	ESP Fields / Energisation	Design Efficiency (%)	SCA $m^2/m^3/s$	Gas Velocity (m/s)	Treatment Time seconds	Inlet dust loading (g/Nm^3)	ESP Emsission (mg/Nm^3)	Migration Velocity (cm/s)	Reported problems in ESP
1	RAICHUR TPS 1&2:210MW	12 Normal	99.4	147.32	0.87	22.1	21.66	130	3.47	None
2	RAICHUR TPS 3&6:210MW	12 Normal	99.78 99.83	227.53 209.37	0.79 0.86	34.1 31.40	50 75	150 150	2.68 3.04	None
3	RAICHUR TPS 5&6:	12 Normal	99.82	226.8	0.79	34.18	75	150	2.78	None
4	PANIPAT TPS 5:210MW	14 Multi pulse	99.82	166.22		26.07	50	100	3.80	None
5	KOLAGHAT TPS 1&3:210MW	16 Semi pulse	99.5	150	1.00	20.00	10	750	2.79	Major
6	KOLAGHAT TPS 4:210MW	12 Semi pulse	99.7	165	0.70	25.70	50	150	3.52	Major
7	KOLAGHAT TPS 5&6:210MW	10 Semi pulse	99.7	171.68	0.70	25.70	50	150	3.38	Major
8	BANDEL TPS 5:210MW	12 Semi pulse	98.0	81.32	1.06	10.19	25	500	4.81	Major
9	TUTICORIN TPS 1&3:210MW	20 Semi pulse	98.5	109.44	1.05	13.68	33.33	500	3.83	Major
10	METTUR TPS 1&4:210MW	24 Semi pulse	99.64	143.64	1.00	21.55	37.35	150	3.91	Major
11	WANAKBORI TPS 1&3:210MW	20 Semi pulse	99.23	140.4			31.25	250	3.46	Minor
12	WANAKBORI TPS 4–6210MW	24 Semi pulse	99.60	152.2	0.84	19.05	50	200	3.62	Minor
13	WANAKBORI TPS 7:210MW	28 Semi pulse	99.76	380.22	0.55	57.00	50	150	1.58	Minor
14	DAHANU TPS 1&2:210MW	28 Semi pulse	99.91	261.18	0.69	75.0		75	2.68	Minor
15	BHUSAWAL TPS 2 &3:210MW	20 Normal	99.0	111.85	1.03	13.98	30	300	4.117	None
16	TALCHER TPS 5 &6:210MW	14 Normal	99.78	175.6	1.15	—	68.18	150	3.48	None
17	RAMAGUNDAM TPS 1&3:200MW	20 Normal	99.85	147.68	0.81	22.15	46.66	70	4.40	None
18	DADRI TPS 5:210MW	28 Multi pulse	99.9	214.48	0.84	32.18	150	150	3.22	None
19	SINGRAULI TPS 1&5:210MW	12 Semi pulse	99.6	138.52	0.92	17.3	37.5	150	3.98	Major
20	BADARPUR TPS 4 &5 :210MW	20 Semi pulse	99.0	115.0	0.93	17.24	15	150	4.00	Major
21	BLUDGE TPS 1&2 :210MW	14 Semi pulse	99.86	……	…..	12	71.42	100	……	Major
22	CHANDERPUR TPS 1&2:210MW	06 Semi pulse	98.5	73.2	…..	—	50	750	2.737	Major
23	CHANDERPUR TPS 3&4:210MW	20 Semi pulse	98.24	142.22	0.75	21.33	46	350	3.43	Major
24	CHANDERPUR TPS 5&4:210MW	24 Semi pulse	98.87	167.96	0.90	25.20	23.0s	300	3.95	Major
25	KORADI TPS 5:210MW	20 Semi pulse	99.5	132.74	1.1	11.33	25.4	381	3.16	Minor
26	KORADI TPS 7:210MW	24 Semi pulse	99.0	132.74	1.1	16.59	24.83	248	3.46	Minor
27	NASIK TPS 3. 210MW	20 Semi pulse	98.5	106.48	……	….	12.53	188	3.94	Minor
28	PARLI TPS 3 &4:210MW	10 Semi pulse	99.5 98.9	109.6 114.3	……	……	28.06 25	421 275	3.83 3.94	Minor
29	PARLI TPS 4 :210MW	10 Semi pulse	93.5	133.33	……	……	40.76	265	2.05	

Table 5 Comparison of Technical Parameters of ESP Attached to Greater than 500 MW Power Plants

S.NO	Name of unit	ESP Fields/ Energisation	Design Efficiency (%)	SCA $m^2/m^3/s$	Gas Velocity (m/s)	Treatment Time seconds	Inlet dust loading (g/Nm^3)	E S P Emsission (mg/Nm^3)	Migration Velocity (cm/s)	Reported problems in ESP
1	SINGRAULI TPS 6&7:500MW	14 Multi pulse	99.6	164.57	1.0	25.2	37.5	150	3.35	None
2	RIHAND TPS 1&2:500MW	24 Semi pulse	99.5	160.00	1.25	26.00	30	150	3.31	None
3	RAMAGUNDTPS 5&6:	24 Semi pulse	99.6	221.9	0.81	33.33	75	70	3.11	None
4	KOLAGHAT TPS 4&6:500MW	14 Multi pulse	99.87	167.96	0.90	25.2	50	100	3.25	Major
5	CHANDRAPURTPS 7 500MW	14 Multi pulse	99.88	226.0	1.0	21.3	35	70	2.97	Major

Based on the analysis on the power plants; some of the common features of ESPs are: The inlet dust loading to the ESP units is invariably high in the range 40 g/Nm^3-120 g/Nm^3, the SCA is also very large 130 $m^2/m^3/s$ -218 $m^2/m^3/s$.The effective migration attained are in the range (2.8 cm/s-4.7 cm/s. Semi pulse / Multi pulse mode id the preferred mode of energisation of ESP fields. The low migration velocities indicate very high values of fly ashes generated and as a result development of back corona in Indian power plant. The size of ESP is, therefore quite large compared to ESPs elsewhere for similar electric power generation. 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.

4 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 [8]. Another investigation [9] 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 norms–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.

4.1 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} Ohm/cm-10^{13} Ohm/cm. The system simply energizes ESP unit for a specified number of cycles and suppresses the ESP energisation 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. The system is thus able to produce high peak voltages and currents for a short time, while maintains low average current through the dust layer below the onset of back corona. Advanced precipitator controllers (BAPCON) developed by Bharat Heavy Electrical 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. Table 6 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 incorporating 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.

Table 6 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

4.2 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 Table7. 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.

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

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

where:

ω = Migration velocity;

SCA= Specific collection area;

η = Collection Efficiency;

Δ= Change in migration velocities from base line conditions;

Base line condition are denoted by (0).

Table 7 Improvements in ESP performance due to Sodium conditioning at Power Plant No. 2

Unit–1

S.No.		ESP Inlet loading mg/Nm^3	Outlet loading	Measure (η)	Δ ω%
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

S.No.		ESP Inlet loading mg/Nm^3	Outlet loading	Measure (η)	Δ ω%
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	

Table 8 Water fogging at Power Plant No. 2

S.No.		ESP Inlet loading mg/ Nm^3	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	

The results of the experiments have been shown in Table 7 [9] 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:

(i) 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.

(ii) 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.

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

(iv) The electrical Resistivity reduced to 9×10^{11} ohm/cm from 2×10^{12} of base line conditions at operating temperatures of ESP.

(v) 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 resist ivies of fly ash due to sodium conditioning.

4.3 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 Celsius. 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 Table 8. As one can see there is a reduction of emission levels at the out let due to water fogging.

4.4 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 9 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 10. Based on Table 10 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.

Table 9 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/Nm^3)	Area, A m^2	Volume flow rate Q (m^3/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 10 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

5 CONCLUSIONS

Some of the common features of ESPs in India are: The inlet dust loading to the ESP units is invariably high in the range 40 g/Nm^3-120 g/Nm^3, the SCA is also very large (130 m^2/m^3/s-218 m^2/m^3/s.The effective migration attained are in the range 2.8 cm/s-4.7cm/s. Semi pulse/ Multi pulse mode id the preferred mode of energisation of ESP fields. The low migration velocities indicate very high values of fly ashes generated and as a result development of back corona in Indian power plant. The size of ESP is, therefore quite large compared to ESPs elsewhere for similar electric power generation. The reduction in size (lower capital cost) and improvement in collection efficiencies of ESPs are major challenge for power industries in India

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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