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Short Note

Reduction in Particulate Matter Concentration by Ammonia Injection in Flue Gas—A Case Study

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Abstract: In India coal-fired power plants are equipped with electrostatic precipitators (ESP) to combat the suspended particulate matter emission from the stack. The efficiency of electro precipitator in removal of particulate matter is dependent upon the ability of the particulate matter to accept and release of electric charge. This characteristic of the particulate matter is generally referred to as ash resistivity. An exhaustive literature survey was undertaken to understand the resistivity problem. The resistivity is an electrochemical property and this paper describes the other aspect of ammonia that helps in agglomeration of the particles and enhances the collection efficiency of the electrostatic precipitators.

Key words: Flue gas conditioning, particulate matter, fly ash, electrostatic precipitator.

Introduction

Coal is one of the most important resources in our country and about 70% of power generation in India is coal-fired. The particulate matter emission from Thermal Power Station (TPS) poses serious health hazard and has substantial impact on the environment. Indian coals, which have low sulphur, limits the performance of the ESP. The main cause for the poor performance of ESP was attributed to the resistivity of the ash particle. It was decided to condition the flue gas in order to improve the efficiency of the ESP. As indicated by Schmidt, it led to the theory of conditioning the flue gas by principally altering the moisture-adsorption properties of dust surfaces. Essentially, in the theory developed so far for flue gas humidification, it was proposed that moisture would reduce the electrical resistivity of most of the dust (Ashworth et al., 1992). The choice of ammonia as a flue gas conditioner at Heavy Water Plant, Manuguru (A.P.) India is based on the ash characterization. The study advocates that ammonia would be an ideal choice for maintaining the right resistivity i.e.10^8-10^{10} ohm-cm. This study indicates that ammonia helps in agglomeration of the particles and enhances the collection efficiency.

This paper discusses and presents the data obtained during the short term trial study of the flue gas conditioning with ammonia conducted at Units 1 and 2 (210 MW) of Khaperkheda Thermal Power Station (Mahagenco), Khaperkheda. In addition it discusses the trials and other aspects of ammonia conditioning.

Theory and Application

The composition of typical coal and fly ash quality of Indian coal and composition of coal and ash quality at Khaperkheda is shown in Table 1 and Table 2 respectively. Basically Indian coal is known to be the low sulphur coal (< 1%) and high ash content (average 40%). Typically sulphur less than 1% corresponds to fly ash of high resistivity.

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Table 1: Analysis of average Indian coal and that of coal at Khaperkheda TPS

Parameters	*Indian coal (% WT)*	*Khaperkheda coal (% WT)*
Moisture	7-20%	11.14%
Carbon	21-50%	34.5%
Hydrogen	2.3-3.5%	2.98%
Nitrogen	0.7-1.3%	0.27%
Sulphur	0.3 - 0.9%	0.5%
Ash	30-50%	40.88%
Oxygen	1.7-11%	9.56%
Volatile matter	15-26%	20.96%
Calorific value	3000-5000 Kcal/Kg	3346 Kcal/Kg

Table 2: Typical ash analysis of average Indian coal and that of Khaperkheda TPS

Parameters	*Indian ash average*	*Ash of Khaperkheda*
SiO_2	35-65%	55.53%
Al_2O_3	13-30%	26.72%
Fe_2O_3	2.4-20%	2.93%
TiO_2	0.9-3 %	0.99%
CaO	0.46-3 %	0.74%
MgO	0.2-2.5 %	0.13%
SO_3	0.1-2.0 %	——-
P_2O_5	0.22-3 %	——
K_2O	0.64-0.96 %	0.60%
Na_2O	0.05-1%	0.15%
Resistivity	10^8-10^{13} ohm . cm	10^{11} ohm .cm

Within the range of the operating temperature the inherent bulk density of the fly ash is high due to primary constituents of silicates and metallic oxides. As a result of a study, Bickelhaupt showed that bulk density of fly ash was inversely proportional to sodium, lithium and iron content of ash.

In this temperature range where surface conduction is predominant, the moisture content in gas is low. To provide adequate surface conduction in absence of additional conditioning agent, sulphur contributes to the surface conduction property of fly ash. The fraction of sulphur in coal which is converted in sulphur trioxide (1% to 3 % of sulphur dioxide formed) is apparently the single most important factor in determining the fly ash resistivity (Bickelhaupt).

Research in combustion engineering has demonstrated that a very small amount of sulphur dioxide is converted to sulphur trioxide in the furnace, more across the high temperature superheater. Most of the sulphur trioxide is categorically generated in low temperature zone of boiler, where gas temperature is in the range of 600 to 752 $^{\circ}$C. This happens to be the ideal temperature for vanadium oxides in ash deposits and iron oxides on the metal surface to act as catalyst in the presence of sufficient oxygen for conversion of sulphur dioxide to sulphur trioxide (Bhatt and Vora).

The chemistry of ammonia reaction at ambient temperature is generally well characterised and must be understood before determining the behaviour of ammonia in flue gas of coal-based power plant. The first step in the production of ammonium salt is the reaction between sulphur trioxide and moisture in air heater as shown in equation (1)

$$SO_3\,(g) + H_2O\,(g) \longrightarrow H_2SO_4\,(aq) \qquad (1)$$

The second step in the process is the acid base reaction of ammonia gas with Sulphuric Acid aerosol via the following reaction of ammonia gas. The reaction is as follows

$$NH_3\,(g) + H_2SO_4\,(aq) \longrightarrow \underset{\text{Ammonium bisulphate}}{NH_4\,HSO_4\,(L)} \qquad (2)$$

Both these reactions have negative Gibbs free energy changes G^0 at standard state and are considered to be thermodynamically favourable. These values were calculated at similar temperature as flue gas and showed that even at higher temperature region of the system, these reactions were favourable. Ammonia can also react with SO_3 directly to form sulphuric acid as shown in equation (3). However it is thermally unstable and in presence of water hydrolyses immediately to become ammonium bisulphate.

$$SO_3\,(g) + NH_3\,(g) \rightarrow \underset{\text{Sulphamic acid}}{NH_2SO_3\,H\,(s)} \rightarrow \underset{\text{Ammonium bisulphate}}{NH_4\,HSO_4} \quad (3)$$

On the molar basis ammonium bisulphate is formed with 1 mg/m^{3}ammonia to every 4.7 mg/m^3 of SO_3. However, molar ratios less than one have much less driving force for the reaction to complete.

Physical properties of ammonium bisulphate are shown below in Table 3.

Table 3: Physical properties of ammonium bisulphate

Sr.No.	*Physical properties*	
1	Melting point	139°C
2	Boiling point	491°C
3	Density	1.78 gm/ml at 154°C

Observation

Ammoniated ash and ash samples of Khaperkheda TPS are analysed for surface resistivity and bulk resistivity from CPRI Laboratory, Bangalore. The test results are shown in Table 4.

Table 4: Resistivity of fly ash sample of Khaperkheda TPS

Sr. No.	*Particulars*	*Surface resistivity Ohms*	*Bulk resistivity Ohms-cm*
1	Unit 1	7.9×10^{11}	9×10^{10}
2	Unit 2	8×10^{11}	4.1×10^{10}
3	Unit 3	3×10^{11}	4.0×10^{10}
4	Unit 4	5.1×10^{11}	9.9×10^{10}

Observations of other thermal power stations of Mahagenco are noted:

1. It has been observed that FGC with ammonia is successful in reducing the emission levels well below the permissible limits i.e. 150 mg/m^3.
2. At Kahaperkheda TPS ammonia dosing was started on trial basis in October 2003 in Unit I. The dosing rate of ammonia was kept @ 20 kg/hr. The emission level was brought down from 298 mg/m^3 to 100 mg/m^3.
3. At Chandrapur TPS the ammonia dosing was done initially in November 2003 in Unit No. 3. The dosing rate was 35 kg/hr. The emission level was initially 400 mg/m^3. It was reduced to below 70 mg/m^3 in less than five hours.
4. At Koradi TPS, FGC trials were carried out in April 2004. The effect was seen after five hours. 15 ESP fields were available out of 20. The emission level was reduced drastically from 376 mg/m^3 to 110 mg/m^3.

The details of the parameters observed are shown in Table 5.

Discussion

1. From the fly ash analysis at CFRI Laboratory it was observed that there is no change in the ash resistivity of fly ash and ammoniated fly ash.
2. Some authors reported about the reduction in ash resistivity but from our observation agglomeration also plays a greater role in particulate matter reduction.
3. The mechanism of agglomeration can be explained as follows.

Ammonium bisulphate which is mainly formed is a sticky compound as its melting point is 139 °C. It is believed to help in the agglomeration process of ash. The carbon particles do not hold a charge but it is trapped by agglomerated particles. Agglomeration is due to capillary attraction and effect of moisture and subsequently dipole effect (Wilburn and Wright, 2004).

The trapping of carbon particles and agglomeration by sticky compound is proved in Koradi Thermal Power Station. It is an old unit which is designed for 25% ash. ESP hopper was overloaded due to excessive ash deposition. During ammonia dosing oil support was taken which also ensures trapping of blackish material i.e. carbon. Trapping of carbon particles was also reported

Table 5: Comparative parameters in three thermal power stations

Sr. No.	*Khaperkheda*	*Koradi*	*Chandrapur*
1	Drastic changes in vain emission levels observed within 2-3 hours	Change in the emission levels observed after eight hrs	Appreciable changes in the emission levels were observed within 5-6 hours
2	Dosing rate of ammonia 20 kg/hr	Dosing rate of ammonia 35-40 kg/hr	Dosing rate of ammonia 35 kg/hr
3	Colour of ash – No appreciable change	Colour of ash – Changed to yellowish mud colour	Not available
4	Change in colour of plume observed—Prudent white	Change in colour of plume observed	Change in colour of plume observed
5	ESP outlet temperature 145°C	ESP outlet temperature 150°C	ESP outlet temperature 145°C
6	Height of chimney 220 mt	Height of chimney 80 mt	Height of chimney 120 mt

by William G. Hankins (1996). Moreover M/s Chemithon and IIT Mumbai use ammonia in FGC in mechanical collector too. This observation shows that agglomeration plays major role rather than ash resistivity.

Conclusion and Recommendations

1. It is concluded that Flue Gas Conditioning (FGC) by injection of ammonia gas is cost effective and means for regaining ESP collection efficiency.
2. It reduces the particle load on the induced draft fans, resulting in saving in terms of maintenance.
3. The flue gas temperature is very important and should be maintained around 140°C to 15°C for better performance of ESP.
4. Less quantity of ammonia is required as compared to Koradi and Chandrapur due to variation seen in the design aspect. Design aspect of Koradi TPS and Chandrapur TPS is same. Height of chimney also plays an important role.
5. Finer tuning is needed in old ESPs to reduce stack emission level in short time. Frequent ash evacuation is needed to prevent cake formation and it proves that flue gas conditioning is an additional tool and not an only tool for reduction of particulate matter.

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