Flue Gas Conditioning

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Abstract: Flue gas conditioning (FGC) systems offer an effective option for control of Particulate Matter (PM) emissions and enhances the performance of the Electrostatic Precipitators (EPs) when using coal of different properties. The increasing environmental awareness and the mandate of the Environmental Protection Agencies (EPA) in various countries to thermal power stations using coal-fired boilers for lowering Suspended Particulate Matter (SPM) emissions has increased the urgency for reviewing options and alternatives. As compared to ESP retrofits or bag filters, the FGC systems in conjunction with existing EP offer cost effective and flexible alternatives for controlling SPM emission levels. The paper describes recent advances in FGC technologies. Chemithon's FGC technologies are in use at more than 170 thermal power plants world wide. The presentation reviews the flue gas conditioning technology as well as few case studies for high ash and low sulfur coal and highlights the economic advantages of a cost effective technology option.

Keywords: Flue Gas Conditioning, Suspended Particulate Matter, Ammonia Injection, Sulfur Trioxide Injection Ammonia & Sulfur Trioxide Injection

1 HISTORICAL PERSPECTIVE

The history of flue gas conditioning dates back almost as far as the first electrostatic precipitator (ESP). As early as 1912 it was discovered that increasing levels of SO_3 in smelter converter gases increased the collection efficiency of the ESP. Experimental work demonstrated that many non-conductive dusts and fumes could be made collectable by adding SO_3 and/or moisture to the gas stream ahead of the ESP. Since that time, many other substances have been used to condition flue gases. These include: ammonia, triethyl amine, and various proprietary chemicals. SO_3 dosing is still the predominate treatment for containing high resistivity ash and ammonia for agglomerating dusts from high ash.

2 THEORY AND APPLICATION

The term Flue Gas Conditioning involves modification of the flue gas particulate properties. These are ash resistivity, ash cohesivity and to some degree ash particle size.

Electrostatic Precipitator particulate removal efficiency is in large part dependent upon the ability of the collected particulate matter to accept and release an electric charge. This characteristic of the particulate is generally referred to as the 'ash resistivity'. Fly ash resistivity is a function of the composition of the ash, the gas temperature, and of the flue gas composition. Optimum particulate resistivity is generally in the range of 5×10^9 to 5×10^{10} ohm-cm. Ash resistivity below the optimum range results in good charging of the ash and field current densities but since the charged particles easily release the charge on the precipitator collecting plates the ash has a low holding force. This causes excessive entrainment of the collected ash and makes it difficult to get the collected ash into the hoppers. This can be a major problem if the precipitator is small with high gas velocities.

High resistivity ash is difficult to charge and when charged may not release the charge at the collecting plate. This inability to release the charge can cause difficulty in removing the ash from the collecting plate resulting in an insulating layer of material on the collecting plate and leading to a situation referred to as back corona. In back corona the material on the collecting plate releases the charge into the gas passage instead of the collecting plate which dramatically lowers the field voltage and reduces further charging of the inter electrode particles.

3 SULFUR TRIOXIDE FGC

Sulfur trioxide is by far the most common type of flue gas conditioning with over 600 installations world wide. The earliest systems which were installed in the early 70's were liquid sulfur trioxide or sulfuric acid vaporizing systems. Subsequent systems employed sulfur dioxide feedstocks with catalytic conversion to sulfur trioxide. Nearly all of the modern systems burn elemental sulfur and convert the sulfur dioxide catalytically to sulfur trioxide. These systems are safer, use inexpensive feedstocks, and have low energy consumption.

Fig. 1 below illustrates a typical sulfur burning FGC system. The basic process is as follows: Molten sulfur is stored in an insulated steam heated tank or pit maintained at about 148 ℃. From the tank it is pumped to a sulfur burner where it is mixed with heated air and combusts to sulfur dioxide. The hot gas mixture then enters a catalytic converter where it is oxidized with the aid of a vanadium pentoxide catalyst to sulfur trioxide. The hot sulfur trioxide/air mixture exits the converter and is conveyed through insulated piping to the injectors located in the flue gas ducting. Typically, SO_3 is injected at rates to achieve 5 to 25 ppm in the flue gas.

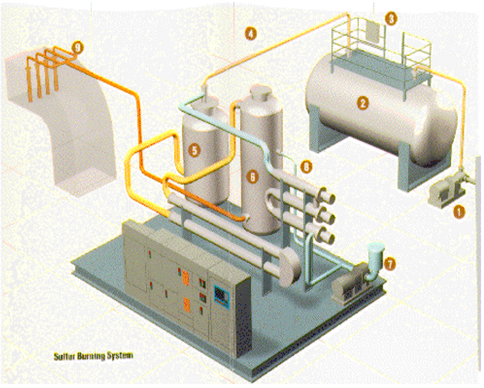

Fig. 1

1. Unloading Pump
2. Storage Tank
3. Metering Pump
4. Liquid Sulfur at 135 ℃
5. Sulfur Burner
6. Multi-Stage Converter
7. Air Blower
8. Air Heater
9. SO_3/Air at 475 ℃

To achieve a high conversion of the SO_2 to SO_3 within the catalytic converter, the temperatures entering and exiting the converter must be within a specific range. Typical catalysts convert SO_2 to SO_3 in the range of 400 to 595 ℃. The conversion of SO_2 to SO_3 within the converter is exothermic. As the temperature of the reaction approaches 595 ℃, the chemical equilibrium tends to favor a reverse reaction back to SO_2. Therefore, it is important to initiate the reaction at the lowest practical temperature for good conversion.

Many of the newer systems use much less energy by varying the process air flow with the sulfur rate so that the process air heater is off at most operating rates. Some of the other improvements are:

1. Positive displacement process air blowers.
2. In tank sulfur pumps.
3. Sulfur mass flow elements for accurate feed rate control.
4. SO_2 cooler between the burner and converter.
5. Two stage converters to achieve over 96% conversion.
6. Fully automated PLC control and remote supervisory systems.

The sulfur trioxide conditioning system has the following advantages:

1. Improves precipitator performance for low sulfur coals.
2. Lowers resistivity of fly ash.
3. Reduces precipitator electrode ash buildups.
4. Prevents back corona problems.5. Consistent and stable operation.
6. Efficiency maintained over time.
7. Elimination of opacity spikes due to soot blowing and other signs of precipitator upsets.

4 AMMONIA CONDITIONING

Ammonia gas conditioning has been used by the petroleum industry to treat catalyst dust since about 1940. In addition, ammonia alone has been used on boilers firing high sulfur coal for many years to improve precipitator performance, reduce the acid dew point and corrosion, and in some cases eliminate the 'blue plume' from high sulfur trioxide emissions.

Indian coal with less sulfur requires low quantities of ammonia for ash conditioning. The typical dosage of ammonia ranges between 50 ppm-60 ppm with an equilibrium slip stream of less than 1-5 ppm. This does not result in environmental issues with respect to ammonium hydroxide in the leachet liquor in an ash pond or in the uses of dry ash for cement manufacturing.

An anhydrous ammonia injection system is fairly simple. The equipment consists of anhydrous ammonia storage and vaporization equipment, ammonia metering, an ammonia/air mixer, and ammonia injectors. Generally to provide distribution the ammonia vapor is mixed with air to a concentration of less than 10%. Fig. 2 is a simplified P&ID of the process.

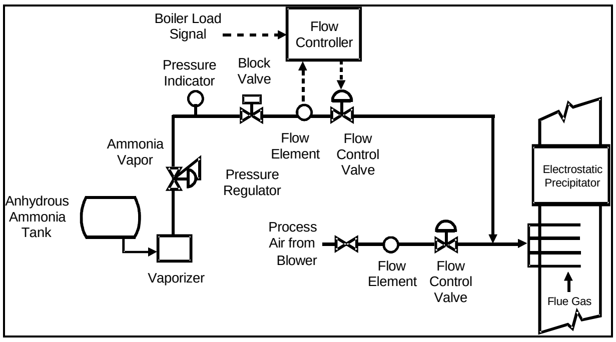

Fig. 2 Anhydrous Ammonia Flue Gas Conditioning System

5 DESIGN ASPECTS OF NH_3 CONDITIONING SYSTEM

The critical requirements required from power plants for ammonia FGC to perform are as follows:

1. The ash has to be acidic with a pH value less than 7.
2. The combined silica and alumina content in the ash should exceed 85%.
3. The leachet analysis has to be accurate and provided by the customer.
4. ESP should be in sound electrical and mechanical condition.
5. Minimum secondary voltage of 25kV and current 200 mA in each field, with minimum 95% of the corona power specified by the ESP supplier and all fields in service.
6. Ash handling system functioning properly and evacuating ash continuously from all the hoppers.
7. Treatment time as per ESP Design parameter specified by ESP supplier.

The ammonia flue gas conditioning system has the following advantages:

1. Agglomerates fine particulate in the gas stream, which produces an attendant reduction in opacity.

2. More adhesive fly ash layers collected on the precipitator plates reducing rapping losses.
3. Increases space charge.
4. Eliminates "blue" plume (SO_3 slip).
5. Lowers acid dew point.
6. Reduces rapper re-entrainment and emissions

6 DUAL CONDITIONING

In some cases of high ash resistivity, sulfur trioxide flue gas conditioning alone is not effective. Some of these are:

1. The fly ash does not absorb the sulfur trioxide. This is generally true of fly ash that has a combined silica-alumina content of more than 90% and a low concentration of alkali metals. These ashes are frequently referred to as acidic ashes.
2. Flue gas temperatures are too high for the sulfur trioxide to attach to the ash. This can be as low as 320 ℉ (160℃) and depends on ash composition and gas moisture.
3. High precipitator gas velocities. The performance improvement from lowering ash resistivity is offset by increased re-entrainment due to lower 'holding forces.'
4. High unburned carbon carryover in the ash. The carbon particles do not hold a charge. In addition they are extremely fine and will increase the stack opacity without a proportional increase in mass loading. When the carbon carryover exceeds about 10%, re-entrainment becomes a severe problem.
5. ESP designs with a minimum SCA of 100 m^2/m^3/sec and aspect ratios less than 1.

The simultaneous and independent injection of both ammonia and sulfur trioxide referred to as dual gas conditioning can be an effective solution to these problems.

Ammonia injected into flue gas in the presence of sulfur trioxide and flue gas moisture reacts to form ammonia compounds, principally ammonium sulfate and bisulfate compounds. These particles nucleate on sub micron particulate in the gas stream and help to agglomerate and increase ash particle size. The ammonia also reacts with 'acidic' ash to facilitate absorption of sulfur trioxide. The resulting ammonium bisulfate is a sticky compound and is believed to help agglomerate the ash and improve the ash cohesivity. Another observed effect is an increase in the flow of ions, electrons and charged particulate in the inter-electrode space, or space charge.

The lower ash resistivity enables the ash to more readily release its charge to the collecting plate, reducing the electrostatic holding force. The reduced holding force allows more ash to re-entrain into the gas stream when the collecting plates are rapped. The improvement in ash cohesivity from dual conditioning reduces rapper re-entrainment by agglomerating ash on the collecting plates. The lower resistivity particulate readily re-entrains into the gas stream. In addition, the low resistivity particulate tends to reduce the maximum field strength and prevents charging of the high resistivity ash. Injecting sulfur trioxide alone improves the capability to charge the high resistivity ash but the benefit is often offset by increased re-entrainment of the carbon particles.

Dual injection overcomes this problem by reacting the carbon particles to form various ammonia-sulfate based compounds, which agglomerate the carbon particles and increase ash cohesivity. This reduces re-entrainment, and allows an increase in the sulfur trioxide which in turn reduces ash resistivity.

The ratio of ammonia to sulfur trioxide is important. Too much ammonia may cause the following problems.

1. Higher ash resistivity and increased particulate emissions.
2. Unreacted ammonia can escape up the stack (NH_3 slip).
3. Excessive precipitator ash buildup.

Excessive sulfur trioxide concentrations could cause excessive sulfur trioxide slip, possible acid dew point problems, and excessive rapper re-entrainment. As a general rule the ammonia treat rate is one half to two thirds of the sulfur trioxide treat rate. The ammonia flow is measured with a mass flow element using a boiler load signal indicative of the precipitator gas volume to control to a desired injection rate in ppm.

7 CASE STUDIES OF OPERATING FLUE GAS CONDITIONING SYSTEMS IN INDIA

Chemithon Engineers Pvt. Ltd. (CEPL), India, in the past five years has successfully tested and implemented Flue Gas Conditioning (FGC) systems at twenty three (23) units at eleven (11) thermal power stations in the five states of the country. The FGC systems were tested and installed at the following thermal power stations in the country.

1. Gujarat State Electricity Corporation Ltd., Ukai (Unit 4 - 200 MW) Dual FGC
2. Punjab State Electricity Board, Bathinda (Units 3 & 4 - 110 MW) Ammonia FGC
3. West Bengal Power Development Corpn. Ltd., Kolaghat (Units 1, 2 & 3 – 210 MW), Bandel (Unit No. 5 – 210 MW) Ammonia FGC
4. Durgapur Projects Ltd., Captive Power Plant (Unit No.3, 4, 5 77 MW each & 6 - 110 MW) Ammonia FGC
5. Maharashtra State Power Generation Company Ltd. Khaperkheda (Unit No. 1 - 210 MW) ; Bhuswawal (Unit No. 3 - 210 MW); Chandrapur (Unit No.3 - 210 MW) and Parli (Unit No.5 - 210 MW)Ammonia FGC
6. Chhattisgarh State Electricity Board, Hasdeo (Unit No. 1, 2, 3 & 4 - 210 MW) Dual FGC
7. Chhattishgarh State Electricity Board, Korba (East) (Unit No.1, 2, 3 & 4 – 50 MW each) DFGC.

The parameters based on which the dosing system is designed are the coal & ash analysis provided by the TPS and the ESP design & operating data that are important factors for arriving at the dosing rate. CEPL does the resistivity analysis and draws the resistivity graph. Different parameters like load of the power plant, temperature of the flue gas at the ESP inlet, dust load before and after ESP is taken into consideration for arriving at the dosing rate of the chemical. The change in SPM levels before and after SO_3/NH_3/Dual injection are measured during the trial and performance runs. The Tables (1 & 2) gives in detail the design parameters and the SPM reduction achieved by the quantity of chemical dosed.

8 COST COMPARISON

The SO_3/NH_3 and Dual FGC systems are a cost effective as compared to the conventional methods as well as are proven technology to control the emissions of particulate matter from the stacks of thermal power stations. The application of the FGC systems can also be extended to that of cement, sugar, petroleum, and copper and aluminum industries.

The comparative capital and operating cost between various options available for reducing the SPM emission for a 210 MW plant is given in Table 3.

9 CONCLUSIONS

To summarize:

1. Flue gas conditioning using SO_3/NH_3 offers cost effective options.
2. Enables TPS to comply with environmental emission standards.
3. Improves ambient air quality at the power plant.
4. Improves availability of the power plant.
5. Technology commercially available in India
6. Provides design flexibility for ESP sizing.
7. The system is lowest in capital cost and the DFGC is lowest in operating cost.

The Flue Gas Conditioning system is a proven and tested method for reducing fly ash emissions from thermal power plants. Its application can be extended beyond the tested realm of utility companies to the cement, sugar, petroleum and copper and aluminum industries.

Table 1 FGC Plants In Northern, Central & Eastern India

	Durgapur Projects Ltd, Durgapur (DPL)		West Bengal Power Development Corporation Ltd (WBPDCL)		Punjab State Electricity Board (PSEB)	Chattishgarh State Electricity Board (CSEB)
	CPP	CPP	Bandel TPS	Kolaghat TPS	GND TPS	Hasdeo TPS
Unit No.	3, 4, 5	6	5	1, 2 & 3	3 & 4	1 & 2
Load (MW)	77	110	210	210	110	210
Coal Analysis (% Wt)						
Carbon	40.0	40.0	54.7	34.5	32.11	27.8
Moisture	10.0	10.0	4.90	6.7 to 6.8	0.99	21.1
Sulphur	0.5	0.5	0.38	0.4	N/A	N/A
Ash	40.0	40.0	29.8	51.4	52.94	42
GCV (Kcal/Kg)	3800	3800	4927	N/A	N/A	N/A
Ash Anaylsis (% Wt)						
$Na_2O + K_2O$	1.10	1.10	N/A	0.18 to 0.25	0.34 to 1.35	0.38
MgO	0.5	0.5	1.0	0.07	1.45	0.75
SiO_2	59.3	59.3	60.0	61.0	54.7	64.2
Al_2O_3	20.0	20.0	21.70	27.85	29.56	24.50
SO_3	N/A	N/A	N/A	N/A	N/A	N/A
Resistivity (Ohm cm)	3E – 9	3E – 9	5E – 11	5E – 10	6E – 11	4E – 12
Temperature at ESP outlet (^oC)	148	150	145	142	150	137
Injection of SO_3(Kg/hr)	0	0	0	0	0	18
Injection of NH_3(Kg/hr)	22	15	30	30	28	14
SPM level before injection (mg/Nm^3)	120.6	350	247	800	410	400
SPM level after injection (mg/Nm^3)	80	120	49	82	74	130

Annual Operating Cost (US $) (7200 hrs/annum)	110880	75600	151200	151200	141120	90000

Note : Sulphur - US $ 150 / Ton
Ammonia - US $ 700 / Ton

Table 2 FGC plants in western India

	Gujarat State Electricity Corporation Ltd (GSECL), Ukai TPS	Maharashtra State Power Generation Company Ltd (MSPGCL)			
		Khaperkheda TPS	Bhusaval TPS	Chandrapur Super TPS	Parli TPS
Unit No	4	1	3	3	5
Load (MW)	200	210	210	210	210
Coal Analysis (% Wt)					
Carbon	43.53	32	70-75	43.81	38.86
Moisture	12.40	16	6-9	14.40	8.19
Sulphur	0.63	0.4	0.5-0.9	N.A	0.7
Ash	42.1	37.5	27-35	34.03	38.14
GCV (Kcal/Kg)	4306	3225	4190-4870	4404	3894
Ash Anaylsis (% Wt)					
$Na_2O + K_2O$	1.25 to 2.05	1.25	1-2.8	0.79	0.7
MgO	Traces	0.50	0.30	0.68	0.5
SiO_2	60.48	68.40	50-60	61.92	63.50
Al_2O_3	31.80	20.57	22-30	24.65	25.50
SO_3	NIL	NIL	0.3-1	N/A	NIL
Resistivity](Ohm cm)	1.0E+12	4E -10	8E -11	5E -12	1.0E+11
Temperature at ESP (^{O}C)	160	130-135	140	131	172
Injection of SO_2 (Kg/hr)	18	0	0	0	0
Injection of NH_3 (Kg/hr)	14	24	24	15	15
SPM level before injection (mg/Nm^3)	358	310.5	231	187	620
SPM level after injection (mg/Nm^3)	61	91	124	92	128
Annual Operating cost US $ (7200 hrs/annum)	90000	120960	120960	75600	75600

Note : Sulphur - US $ 150 / Ton
Ammonia - US $ 700 / Ton

Table 3 Cost and performance of various control systems

	(Thousand US Dollars)			
TYPE OF CONTROL SYSTEM	RETROFIT EP	BAG FILTER	AFGC (*)	DFGC (#)
CAPITAL COST				
Equipment Cost (approx.) (A)	4020	6660	400	1200
Downtime for installation (Days), typical	90	60	1	1
Revenue Loss due to Downtime For Installation (B)	20160	13440	220	220
Total Cost (A+B)	24180	20100	620	1420
OPERATING COST				
Auxiliary Power Required (Kw), typical	150.00	450.00	35.00	40.00
Auxiliary Power Cost (P.A) (a)	48	144	11	13
Estimated Maintenance Cost per year of Capital Cost (b)	133	111	11	22.00
Annual Cost Of Consumables / Chemicals (c)	0.00	110	151	72
Annual Operation Cost (a+b+c)	181	365	173	107
PROJECTED OPERATING COST (20 Years) (C)	3620	7300	3475	2140
Guaranteed SPM emission levels mg/Nm3	50.00	50.00	150.00	50.00
ASSUMPTIONS				
TPS Operation Time Hrs/Year	7200			
TYPICAL DOSAGE RATE FOR				
(*) AFGC :Ammonia – 30 kg/hr	Price : Ammonia - US $ 700 / Ton Sulfur - US $ 150 / Ton Power - US $ 45/1000 Units			
(#) DFGC:Ammonia - 10 kg/hr Sulfur - 20 kg/hr				