Emission Control Technologies for Thermal Power Plants

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Abstract. Coal thermal power plants are one of the primary sources of artificial air emissions, particularly in a country like India. Ministry of Environment and Forests has proposed draft regulation for emissions standards in coal-fired power plants. This includes significant reduction in sulphur-dioxide, oxides of nitrogen, particulate matter and mercury emissions. The first step is to evaluate the technologies which represent the best selection for each power plant based on its configuration, fuel properties, performance requirements, and other site-specific factors. This paper will describe various technology options including: Flue Gas Desulfurization System, Spray Dryer Absorber (SDA), Circulating Dry Scrubber (CDS), Limestone-based Wet FGD, Low NOX burners, Selective Non Catalytic Reduction, Electrostatic Precipitator, Bag House Dust Collector, all of which have been evaluated and installed extensively to reduce SO2, NOx, PM and other emissions. Each control technology has its advantages and disadvantages. For each of the technologies considered, major features, potential operating and maintenance cost impacts, as well as key factors that contribute to the selection of one technology over another are discussed here.

1. Introduction

Being the third largest economy and fourth largest consumer of electricity with around 125 crores population, and thrust on development of infrastructure and manufacturing industry, power supply in our country certainly cannot keep up with high demand. Setting up large thermal power plants is most probable solution to meet growing electricity demand. Thermal power plants result in emissions of sulfur-dioxides (SO2), nitrogen oxides (NOX), particulate matter (PM) and metals like mercury (Hg). Ministry of Environment and Forest has issued a draft notification in April 2015 that proposes to regulate SO2, NOx and Hg in coal-fired thermal power plants.

Various emission control technologies are available to control SO2, NOx, PM, Hg, SO3 and other trace metals. This paper explores several emission control systems that are available to regulate emissions from coal-based thermal power plants. Emission control technologies include electrostatic precipitators, fabric filters, wet and dry flue gas desulfurization, catalytic reduction, dry sorbent injection, etc.

2. Pollutants From Thermal Power Plants

Crude coal includes carbon, nitrogen, sulfur, ash, trace mercury, etc. When these elements undergo combustion, emissions such as NOx, SO2 and SO3 are released in the atmosphere- Table 1.
### Table 1 Pollutants from coal combustion and Control

| Constituent | Pollutant | Control method |
|-------------|-----------|----------------|
| Carbon      | Heat, CO2 | Boilers        |
| Nitrogen    | NO\textsubscript{X} | Burner and selective catalytic reduction system |
|             | SO\textsubscript{2} | Wet and Dry flue gas desulfurization |
| Sulfur      | SO\textsubscript{3} | Wet Electrostatic Precipitators |
| Ash         | Ash       | Electrostatic Precipitator, Fabric Filter, Ash Handling system |
| Mercury     | Hg\textsuperscript{++}, Hg\textsuperscript{0} | Powdered activated Carbon Injection, Wet flue gas desulfurization |

Nitrogen and oxygen react at high temperature forming various oxides of nitrogen. These oxides are together termed as NO\textsubscript{X}. NO\textsubscript{X} denotes collective emissions of nitric oxide, nitrogen dioxide and trace quantities of other nitrogen species. Thermal power plants are considered to be one of the largest contributors of nitrogen oxides. Nitrogen oxides combine with water to form various secondary pollutants like acid rain, smog, and ground ozone. Ignition of fossil fuel generates NO\textsubscript{X} comprising of NO and NO\textsubscript{2} at high temperatures. NO\textsubscript{X} quantity depends on various factors like nitrogen quantity, oxygen availability, temperature, mixing intensity and reaction time.

Sulphur content in coal may range from 0.1 % - 3.5%. Whenever sulphur-containing fuel is burnt, sulfur in fuel reacts using oxygen and results in formation of SO\textsubscript{2}. Thermal power plants are principal sources of Sulphur-dioxide. Some amount of generated SO\textsubscript{2} is oxidized to SO\textsubscript{3}. SO\textsubscript{2} reacts with additional gases forming Sulphuric acid. Sulphuric acid precipitates in form of acid rain. This may lead to damage of ecosystem and various other harmful effects to environment.

Particulates are very small particles of soot, dust, or other matter, including tiny droplets of liquids. Particulates often exist in suspended form in flue gas and are released in atmosphere in absence of collection device. Particulates comprise of ash that is not combustible or partly combustible smut. Mercury, present in coal in trace quantity, is discharged after combustion process. This mercury in chimney gas can exist in various forms. It is termed as particulate mercury in solid phase and vapour-phase mercury in gaseous phase. Mercury concentration in coal is mainly dependent on type of coal.

Carbon dioxide is assumed to be result of fuel burning and never a contaminant. Kyoto protocol, Green House gases and global warming have transformed the manner in which we contemplate carbon-dioxide. It has evolved to be one of foremost greenhouse gases. Thermal power plants are looked upon as chief contributors of CO\textsubscript{2}. Ash is residue after combustion. Cement plants utilize some amount of ash during production. However, disposal of large volume of ash can cause various environmental pollution problems. Ash comprises of toxic components which may infiltrate in drinking water or ground water system.

### 3. Emission Norms

Emissions norms as per World Bank and Indian Context are shown in Tables 2 and 3 below.
Table-2 Indian norms

| Pollutant | Thermal power plants installed before Dec 31 2003 | Thermal power plants installed after Dec 31 2003 | Thermal power plants installed after Jan 1, 2017 |
|-----------|---------------------------------------------------|--------------------------------------------------|-----------------------------------------------|
| PM mg/Nm³ | 100                                               | 50                                               | 30                                            |
| SO₂ mg/Nm³ | 600 (for units <500 MW)                          | 200                                               | 100                                          |
| NOₓ mg/Nm³ | 600                                               | 300                                               | 100                                          |
| Hg mg/Nm³  | 0.03                                               | 0.03                                               | 0.03                                          |

Table-3 World Bank Norms

| Pollutant | 24 hour average | Annual average |
|-----------|-----------------|----------------|
| PM10 mg/m³ | 150             | 50             |
| TSP mg/m³  | 230             | 80             |
| NO₂ mg/m³  | 150             | 100            |
| SO₂ mg/m³  | 150             | 80             |

4. SO₂ Control
SO₂ is colourless, non-flammable and non-explosive gas. Long term exposure to high levels of SO₂ causes respiratory problems and heart diseases. It also causes asthma, bronchitis, eye irritation, throat troubles etc. SO₂ is one of chief components causing acid rain. There are two elementary methods to control SO₂ discharge. These include 1) using technology to remove SO₂ from flue gas and 2) reducing sulfur in fuel by fuel blending. A number of technologies exist for removal of SO₂. These include Wet Flue Gas Desulphurization, Dry Flue Gas Desulphurization utilizing a dry scrubber of circulating type, spray dry absorber, and dry absorbent injection.

Wet flue gas desulphurization (WFGD) is dominant technology used for SO₂ control. For WFGD limestone is generally consumed as reagent. For high SO₂ control, WFGD using limestone is low cost option than other SO₂ removal processes. However, WFGD is designed using number of reagents like lime, magnesium-supplemented lime and soda-ash. Conventional WFGD systems use wet limestone along with forced oxidation to remove SO₂ which produces gypsum as a by-product.

In SO₂ removal process, hot flue gas goes into absorber tower. In this tower, it gets cool and saturated with slurry. Flue gas then moves upward through the spray zone of absorber. Here, slurry is scattered in opposite direction to flue gas flow. This completes removal process of SO₂. Normally, SO₂ removal method comprises of in-situ oxidation method that is forced. It transforms calcium sulphite generated in SO₂ removal process to calcium sulphate or gypsum. SO₂ removal efficiencies as high as approximately 98% can be achieved using Limestone forced oxidation systems.

For SO₂ control in utility boilers, dry FGD is a preferred substitute to wet FGD. Dry FGD is also termed as semi-dryto distinguish it as dry reagent which is injected into flue gas. In spray dryer absorber (SDA), lime slurry is gushed into warm flue gas in atomized form for SO₂ absorption. Theresidue comprises offly ash and remainder of reaction. This residue is accumulated in particulate controller device like fabric filter or electrostatic precipitator. In SDA system, fabric filter, that is an effective dust collector, is located as final emission control device before the chimney in flue gas cleansing train. SDA technology gives upto 96% of SO₂ removal and is preferred for lower sulfur fuels (<2%). Advantages of dry flue gas desulphurization include less erection cost, less process tasks, easiness to handle and operate, low water intake, less ancillary power intake, reduction in SO₃ discharge and generation of dry dense by-products.
Circulating dry scrubber (CDS) is an alternative type of dry flue gas desulphurization system. CDS technology is used in thermal power plants using average to higher sulfur coals. This method uses a fluidized bed which adheres SO\textsubscript{2} in flue gas to reagent. Hydrated lime is used as reagent in CDS technology. Rigorous mixing of gas and solid happens in vessel which stimulates SO\textsubscript{x} reaction with particles of dry lime in flue gas. The combinations of reaction products from gas stream are calcium sulfate or calcium sulfite, lime that is unreacted and fly ash. This mixture is carried to particulate control device located downstream. Part of dry waste is removed and disposed of. Major part of discarded product is blended with new calcium hydroxide and used in vessel. Waterjet is sprayed on fluidized bed discretely from parched substance. This improves operation for maximum SO\textsubscript{2} removal with least lime utilization. Removal efficiencies as high as 98\% can be achieved using circulating dry scrubbers.

Dry sorbent injection (DSI) involves infusion of dry absorbent like lime or sodium bicarbonate induct following boiler vessel. SO\textsubscript{x} reacts quickly with dry absorbent and residue is accumulated in particulate collector device located downstream. Capital cost is reduced as separate absorber vessel is not required. DSI systems are used when lower removal efficiency is needed or in small plants. DSI systems may have removal efficiencies between 50 to 70\%.

5. NO\textsubscript{x} Control
NO\textsubscript{x} group contains NO, NO\textsubscript{2}, N\textsubscript{2}O. The most harmful effect is of NO\textsubscript{2}. When in atmosphere NO\textsubscript{2} undergoes chain reaction that forms secondary contaminants. NO\textsubscript{2} is produced when nitric oxide combines with oxygen in atmosphere. It absorbs light and reduces visibility. NO\textsubscript{2} is more toxic than NO, it affects lungs, causes bronchitis and increases chance of respiratory failure.

NO\textsubscript{x} emissions can be controlled by proper fuel selection. After fuel is selected; next phase is to reduce NO\textsubscript{x} emissions by using low NO\textsubscript{x} combustion method. NO\textsubscript{x} combustion control method is low cost methodology to decrease NO\textsubscript{x} but it does not give necessary emissions values as per standards. Final phase are to use NO\textsubscript{x} control device after combustion. This may include selective non-catalytic reduction system (SNCR) or selective catalytic reduction (SCR) system. In either technology, NO\textsubscript{x} is reduced to nitrogen gas and water by series of reactions.

For SNCR system most common chemical used is ammonia and urea. For SCR systems, common reagents used are anhydrous and aqueous ammonia and urea. In SCR system, when urea is used, it is reduced to ammonia, carbon dioxide and water. Once ammonia is in vapour form, it is diluted with air for conveyance, flow control and instillation functions. Anhydrous ammonia is used as reducing agent in various systems. Various systems use ammonia in aqueous form to reduce dangers associated with ammonia storage and handling. Urea can be stored as solid or in solution form by mixing with water.

SNCR system adds reagent in a definite temperature range. It is required to blend reagent appropriately with flue gas to start reaction. Also contents should have sufficient retention time at necessary temperature. NO\textsubscript{x} reduction using SNCR can be between 15 to 35\% and can be increased to 50\% but with high ammonia slip.

If higher NO\textsubscript{x} removal is needed, SCR technology must be used. SCR system converts flue gas NO\textsubscript{x} to N\textsubscript{2} and H\textsubscript{2}O catalytically. It is most effective technology to reduce NO\textsubscript{x} emissions particularly when removal efficiencies as high as 70 to 90\% are required. As flue gas moves through catalyst chamber, reduction in NO\textsubscript{x} is achieved. Ammonia is introduced in flue gas before entering catalyst, where it is blended. As contents enter reaction takes place. SCR reactions occur in a specific temperature range. NO\textsubscript{x} removal efficiency using SCR varies from 50 to 90\%. However, NO\textsubscript{x} removal up to 93\% can also be achieved but it necessitates fitted and precise inlet ammonia to NO\textsubscript{x} distribution.
6. PM Control
Particulates are finely divided air borne solid or liquid particles which remain in suspension in air for very long time. Their size ranges from 0.02 µ to 500 µ and are designated as SPM, PSPM, PM10, and PM2.5. Particulates from combustion sources are in size range of 1 to 100 microns. Particulates less than 1 micron result from condensation process. Particulate control devices intended to eliminate these tiny particles from flue gas and prevent particulates from re-entering flue gas stream. There are different types of particulate matter control equipments like electrostatic precipitator, fabric filter, and ventuere scrubber etc. Each device works on distinct principle which affects collection efficiency.

ESP uses electrical charge to collect and remove ash particles from flue gas stream. ESP comprises of number of parallel plates. Flue gas is passed through these plates between which electrodes are placed. These electrodes provide electric field. Removal efficiencies to tune of 99.9% can be obtained using ESP. Advantages of ESP are better removal efficiencies, better consistency, less pressure loss in flue gas stream, resistance to dampness, and less maintenance. In a fabric filter when flue gas stream moves along filter material dry particulate matter gets collected. It comprises of a multiple compartment enclosures. Each compartment contains thousands of long and vertically supported filter bags. Flue gas moves along bag material and separates particulates from flue gas stream. Properly designed fabric filter achieve particulate removal efficiencies up to 99.9%.

There are two types of fabric filters namely reverse air filter and pulse-jet filter. Pulse-jet fabric filter is normally preferred than reverse air filter because it is small in size and less costly. In pulse-jet type filter, particulate cake is formed on outer side of filter bags and removed using high pressure air. Cleaning process is done with compartment online. In reverse air filter, compartment is taken out of service for cleaning. Advantages of fabric filter are better collection efficiency, more reliability, resistance to flow change, and good dust cake characteristics.

7. HG Control
In coal-fired boilers, mercury is reduced to elemental vapour form on combustion of coal. When flue gas cools, chain reactions start to change mercury vapour to ionic mercury compounds. This segregation of Hg into Hg0, Hg 2+, and Hg is known as speciation of mercury. In coal-fired boilers, majority of gaseous mercury is Hg2+ and in lignite-fired boilers, majority of gaseous mercury is Hg0. The two technologies used for mercury control are Co-benefit technologies like ESP, Fabric filter, FGD, SCR, SDA which are used to remove particulate matter, SO2 and NOx in addition to mercury and Non Co-benefit technologies like Activated carbon or Novel solvents.

Powdered activated carbon introduced in flue gas stream is one of most recognized technologies to control mercury. By adsorbing on PAC surface, mercury in elemental, oxidized and particulate form is removed in particulate matter collection device. It can provide up to 95% mercury removal. PAC is powdered carbon treated with high temperature steam to create a large surface area. Each PAC element contains carbon element with several branching pores. This carbon skeleton provides high surface area to volume ratio. Contaminants, like mercury, are adsorbed in minute pores of PAC particles, and efficiently eliminated from flue gas. Additional methods to improve mercury removal can be using a halogen-based fuel before combustion, which forms more mercury in oxidized form. A wet scrubber slurry additive is used to obstruct removal of arrested oxidized mercury to elemental form. Wet FGD is more efficient to remove oxidized mercury.

8. CO2 Control Technologies
Numerous methods are used to eliminate CO2 from a flue gas. This includes absorption technique using amine or adsorption using membrane. CO2 may be arrested by using dense chemicals which react with flue gas in solid phase. Such chemicals may be eliminated easily from flue gas stream using
less energy than general scrubbing methods. The solids can be regenerated which produces a clean stream of CO₂ for application or sequestration.

Once CO₂ is arrested, it is utilized or sequestered. Consumption of CO₂ for chemical production may use only small portion of CO₂ that can be arrested. CO₂ storage may be done in various ways like underground storing or sequestration in ocean. CO₂ may be collected in leak proof underground tank that is empty or contains water. When CO₂ is infused underground, some amount of CO₂ dissolves in water and some amount of CO₂ forms gaseous phase. Accumulation of CO₂ in deep ocean has a great potential capacity.

9. Conclusion

Environmental guidelines are getting more stern and elaborate, incorporating more air emissions. Pollution control equipments used in flue gas cleaning are related with control of any one particular contaminant at a time. However, as emission regulations get severe, correlated effect of one pollutant over others must be predicted. With new emission legislations, it is essential for technology providers to understand various options for SO₂, NOₓ reduction to 90% or more. While selecting, pollution control technologies, it is important to evaluate all available options. Subsequent to that economic analysis shall be required to define a system that leads to overall economic choice over lifetime of plant. A technology selection study must be performed by personnel who have experience in all types of emission control technologies to ensure that conceptual arrangements, design inputs, and costs are reflective of the conditions that exist at each unique power plant.

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