NO_x CONTROL TECHNOLOGIES FOR THERMAL POWER STATIONS

FACTSHEET

Centre for Science and Environment

India has substantial reserves of low-grade (high ash, low calorific value) coal, which provide a reliable and cheap base load power. However, coal-based thermal power industry is responsible for a significant share of emissions for the country's industrial sector. Combustion of coal converts the nitrogen bound in coal to form products such as nitric oxide (NO), nitrogen dioxide (NO_2) and nitrous oxide (N_2O). These products are collectively called oxides of nitrogen (NO_x)—a major pollutant. In general, 90–95 per cent of NO_x emitted from coal power plants is in the form of NO. NO_x is responsible for both smog and acid rain, and is a major contributor to the formation of secondary particulate matter (PM) and ground level ozone, both of which have adverse health impacts.

Thermal power plants are responsible for an estimated 30 per cent of annual NO_x emissions of India's industrial sector.[1] NO_x emissions from thermal power plants were unregulated till recently and increased dramatically by over 97 per cent—between 1996 and 2010—with an average annual growth of about 5 per cent.[2]

To combat the pollution load from coal power plants, in December 2015, the Ministry of Environment, Forest and Climate Change (MoEF&CC) notified emission standards for coal-fired power stations in India. Emission standards were applicable for PM, SO_2 NO_x, and mercury (see *Table 1: NO_x emission standards for Indian coal power plants*). Out of the current 197 GW installed coal capacity in the country, about 187 GW capacity has to meet the NO_x emission norm of either 600 mg/Nm^3 or 300 mg/Nm^3. Only 10 GW capacity, or 5 per cent of the total, has to meet the 100 mg/Nm^3 standard (see *Figure 1: Age-capacity profile of Indian coal power plants*).

It is estimated that the new norms will help reduce NO_x emissions by almost 70 per cent by 2026–27 against a business of usual scenario where no pollution control technologies are used. This is in line with the global trends observed, whereby NO_x control regulations led to a significant reduction in NO_x emissions. For e.g., in the United States, since the Clean Air Act Amendments were passed in 1990, NO_x

TABLE 1: NO_x EMISSION STANDARDS FOR PROFILE OF INDIAN COAL POWER PLANTS[3]

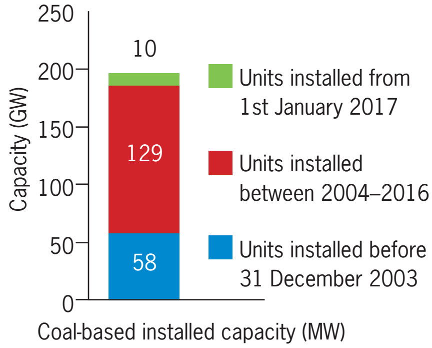
Norms are in line with global standards

Category	NO_x emission standards (mg/Nm^3)
Units installed after 1 January 2017	100
Units installed between 2004 and 2016	300
Units installed before 31 December 2003	600

Source: MoEF&CC, 2015

FIGURE 1: AGE-CAPACITY INDIAN COAL POWER PLANTS

Only 10 GW (5%) capacity has to meet the stringent NO_x norm of 100 mg/Nm^3



Source: CSE 2018

emissions from pulverized coal-fired power plants reduced by about 29 per cent in 2003 compared to the levels in 1990. Even coal usage has increased by almost 30 per cent over the same period.[4] Similar trends were observed in China, where NO_x emissions for power plants decreased by 56 per cent between 2011—when the norms were adopted—and 2015.[5]

NO_x formation during coal combustion

Formation of NO_x during coal combustion is influenced by the combustion conditions and nitrogen content in coal. The NO_x formation can be categorized into three mechanisms:[6]

- **Fuel NO_x:** Nitrogen intrinsically bound in the fuel gets converted to either N_2 or NO during combustion, depending on the intermediate reactions and availability of oxygen. The conversion of fuel nitrogen to NO is highly dependent on the local flame stoichiometry. Fuel NO_x contributes about 70–80 per cent of the total NO_x formed when coal combustion occurs in boiler at typical temperature ranges.
- **Thermal NO_x:** Nitrogen, which is also a major component of air used for coal combustion, gets converted to NO_x at high temperatures (>1,000°C). Thermal NO_x generally accounts for about 5–25 per cent of the NO_x formed during coal combustion.
- **Prompt NO_x:** This is formed due to the reaction between nitrogen in the air with hydrocarbon fuel fragments in front of the burner flame. Prompt NO_x accounts for less than 5 per cent of the total NO_x emissions.

Emissions data gathered by CSE through various surveys suggests that NO_x emissions from coal-based power plants in India are presently in the range of 250–650 mg/Nm^3, with a large majority having NO_x emissions near the 300 mg/Nm^3 limit.

Primary measures for NO_x control (in-combustion control)

Primary combustion measures control and limit the production of NO_x from the combustion zone by promoting its reduction to nitrogen. These are relatively low-cost NO_x control technologies and can be implemented quickly. Equipment manufacturers have informed CSE that plants commissioned after 2000 already have some form of in-combustion NO_x control.

Following are some of the most widely used in-combustion measures for NO_x control which have been identified by technology suppliers as suitable for high ash Indian coals:

Low NO_x burners (LNBs)

In LNBs the initial fuel combustion occurs in a fuel-rich, oxygen deficient zone. This is followed by a reducing atmosphere, where hydrocarbons created during coal combustion react with already formed NO_x to turn it into molecular nitrogen (N_2). After the primary combustion zone, the air required to complete combustion of coal is added (see *Figure 2: Layout of LNB, OFA and SNCR system in a pulverized coal power plant)*. This staging reduces peak flame temperatures resulting in lower NO_x formation.

LNBs typically achieve 30–50 per cent NO_x reduction on their own and are relatively easy to instal. LNBs are a well proven and mature technology that has been in use for over thirty years in countries with similar control standards. In India too, newer boilers are now equipped with LNBs. One concern about LNBs is their potential to reduce combustion efficiency, which leads to an increased level of unburnt carbon and emissions of carbon monoxide (CO). However, better design and operations can keep the levels of unburnt carbon and CO to a minimum.

Over fire air (OFA) system

OFA system controls the availability of oxygen near the burner area, minimizing the formation of fuel NO_x. About 70–90 per cent of the required total combustion air is provided near the burners, creating an oxygen-deficient, fuel-rich zone, leading to partial combustion of fuel. The balance of the combustion air is then injected above the burner elevation, through the OFA nozzles into the furnace, where combustion is completed (see *Figure 2: Layout of LNB, OFA and SNCR system in a pulverized coal power plant)*. The relatively low temperature of the secondary stage limits the production of thermal NO_x. Although, a majority of existing boilers in India have stand-alone OFA systems, they are not operated properly. OFA technology can reduce NO_x formation by 20–45 per cent.

There are different variations of OFA systems available, such as two-stage over fire air systems or secondary over fire air systems (SOFA), boosted over fire air (BOFA) system, rotating opposed fire air (ROFA), and bypass over fire air systems etc. All of these are aimed at promoting an improved mixing of the OFA and the furnace gases. These systems have a slightly higher NO_x reduction potential compared to the conventional OFA system.

LNB + OFA systems should be used together in-combination to achieve optimum NO_x reduction.

In-combustion controls are the most economical approach to reduce NO_x emissions for any coal-fired plant (see *Table 2: Key parameters for in-combustion NO_x control*). Careful design of combustion control system is essential but measures such as the measurement and control of combustion parameters and the appropriate O&M of downstream equipment is also necessary, otherwise the boiler operations will be adversely affected, leading to the formation of pollutants like carbon monoxide.

Combustion optimization

Boilers are subject to frequent load changes as well as changes in the quality of coal. Hence, there can be localized hotspots or temporary periods of incomplete combustion. This could increase NO_x, CO, unburnt carbon and exit furnace temperature, leading to other undesired effects such as slagging (molten ash and incombustible byproducts that can stick to furnace components following coal combustion). In India, a majority of boilers are tangentially fired, which are known to have lower NO_x emissions compared to wall-fired boilers. Moreover, the tangentially fired boilers incorporate devices which can tilt the burner through an arc range of minus 30 to plus 30 degrees from horizontal. This tilting of burners is used to control the steam temperature inside the boilers. Optimizing this burner tilt angle can have an appreciable effect in controlling NO_x emissions.[7] Thus, by controlling the existing boiler operating parameters (like burner tilt, excess air, coal mill operations etc.) plants can have a measurable impact on NO_x emissions.

In addition to this, plants which have installed OFA and LNBs are initially tuned to provide optimum NO_x reduction at a given load on a particular fuel. However, the unit's NO_x performance decreases whenever a variable changes (units operating profile, load, fuel quality, etc.). To assist in the maintenance of NO_x performance, combustion optimization systems which monitor key combustion parameters—NO_x, O_2, CO, unburnt carbon and boiler efficiency—should be integrated into the boiler control systems. All these measurements, if performed accurately, can be used to control both excess air and coal flow to the individual burners resulting in optimized combustion conditions.

Combustion optimization incurs minimal cost and requires very little time for implementation (about five months). Its NO_x reduction potential is around 15–35 per cent and is dependent on fuel type, boiler dimensions, existing burners, OFA technology and existing coal mill performance.

Several manufacturers have stressed on the fact that the majority of plants commissioned between 2003 and 2016 are already equipped with LNB and OFA. These units, whose NO_x emissions are likely around 300 mg/Nm^3, can achieve compliance by simply carrying out combustion optimization.

TABLE 2: KEY PARAMETERS FOR IN-COMBUSTION NO_X CONTROL

Parameters	LNB + OFA	Combustion optimization
NO_x reduction potential (%)	44–73[7,8]	15–35
Cost (Rs/MW)	Rs 8–10 lakh / MW	Consultancy fees
Unit down time for installation	1–2 months	Not applicable
Total project implementation time	8–10 months	4–5 months
Unburnt carbon in Fly Ash (%)	1.1–1.7	Not applicable
Increased CO in flue gas (mg/Nm^3)	2–7	Not applicable

Source: Based on information shared by various vendors/manufacturers

Post-combustion NO_x control

Post-combustion control methods can reduce NO_x emissions by neutralizing the NO_x in the flue gas into nitrogen via chemical reactions with or without the use of a catalyst. These technologies have higher NO_x reduction potential; however, they require higher capital and operating costs.

Following are the two most widely used post-combustion NO_x control technologies:

Selective non-catalytic reduction (SNCR)

SNCR is a method used to reduce NO_x to N_2 by injecting either ammonia or urea into the boiler furnace at locations where the flue gas temperature is between 900°C–1100°C (see *Figure 2: Layout of LNB, OFA and SNCR system in a pulverized coal power plant)*. SNCR is a simpler post-combustion control system, which can achieve reliable NO_x reductions ranging from 25–50 per cent, and can be installed within a regular plant outage schedule.

The main reactions are as follows:
Using urea:

$$4NO + 2CO(NH_2)_2 + O_2 \rightarrow 4N_2 + 2CO_2 + 4H_2O$$

(Urea)

$$2NO_2 + 2CO(NH_2)_2 + O_2 \rightarrow 3N_2 + 2CO_2 + 4H_2O$$

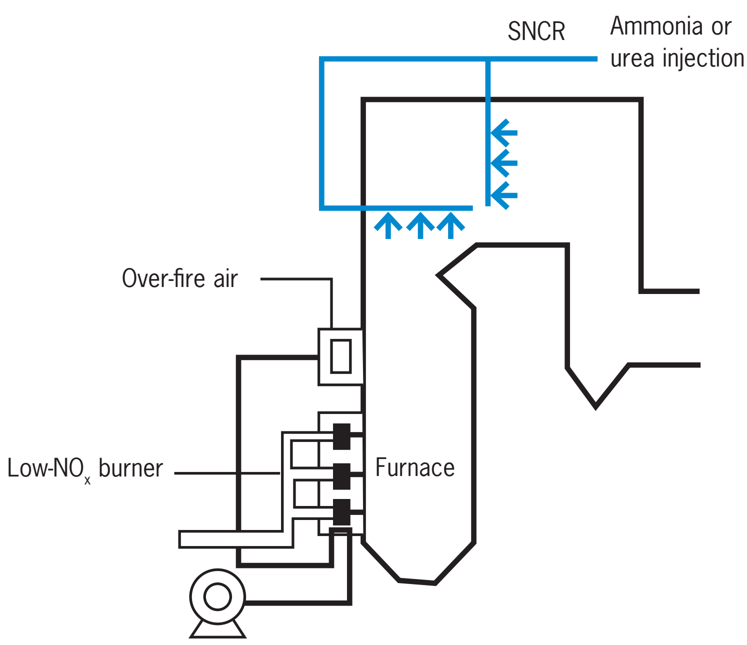
Using ammonia:

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$$

SNCR systems do not require a catalyst; however, their effectiveness is dependent upon sufficient reaction time within a narrow flue gas temperature window and adequate mixing of the reagent with the flue gas. The temperature window plays a critical role on the effective operation of SNCR system:

- If the temperature is too high, the ammonia or urea will decompose to produce additional NO_x.
- If the temperature is too low, the reaction will not occur, resulting in wasted ammonia. This wasted ammonia (called ammonia slip) reacts with sulfur from the fuel to form ammonium sulfate and ammonium bisulfate, which condenses on cooler surfaces of the air heater, causing significant loss of efficiency and mechanical damage.[8]

FIGURE 2: LAYOUT OF LNB, OFA AND SNCR SYSTEM IN A PULVERIZED COAL POWER PLANT[9]



For every tonne of NO reduction, around 0.8 tonne of ammonia or 1.4 tonnes of urea will be required (considering 70 per cent utilization factor). Plants thus will have to account for the cost and availability of urea/ammonia when using SNCR.

Selective Catalytic Reduction (SCR)

SCR is the most effective and well-established NO_x removal technology—in use since the early 1970s. It can be applied as a standalone control technology or in combination with other technologies, including SNCR, combustion optimization and in-combustion controls such as LNB and OFA.[10]

Typically, an SCR is installed on a power plant that requires a much higher level of NO_x reduction compared to the reduction achievable through primary measures and/or SNCR. Only those units which are required to meet the strictest NO_x emission standards of less than 100 mg/Nm^3 should consider opting for this technology.

SCR has a similar working principle to that of an SNCR system—NO_x is reduced to nitrogen and water via the chemical reactions of NO_x and a reagent (like ammonia). However, SCR carries out this reaction in a separate chamber in the presence of a catalyst which promotes the reduction reaction.

The main reactions are:

$$2\,NO + 2\,NH_3 + \tfrac{1}{2}\,O_2 \rightarrow 2N_2 + 3\,H_2O$$

$$2\,NO_2 + 4\,NH_3 + O_2 \rightarrow 2\,N_2 + 3\,H_2O$$

Use of catalysts gives the SCR system two main advantages over SNCR: First, a much higher NO_x removal efficiency (around 90 per cent) is achieved; and second, the NO_x reduction reaction can take place at a lower and broader temperature range. The optimum temperature range for SCR on a pulverized coal combustion unit is usually around 300–400°C. These advantages, however, are offset by a significantly higher capital costs as well as cost and disposal of the catalyst.

There are three different configurations in which an SCR system can be implemented in coal power plants.[11]

1) Hot-side, high-dust: SCR system is installed before the ESP where the temperature of the flue gas is ideal for SCR system; hence, it is the most widely used configuration globally. This configuration, however, may not be suitable in Indian context as it exposes the catalyst to high fly ash concentrations.

2) Hot-side, low-dust: SCR is installed after the ESP which reduces degradation of the catalyst by fly ash erosion, but may also need a flue gas heating system to maintain the optimal temperature required for the catalytic reaction of NO_x.

3) Cold-side, low-dust: SCR is installed after the ESP and FGD just before the stack where there is least amount of fly ash and thereby prolong catalyst life. This configuration is easier to retrofit compared to the other two configurations; however, it is capital intensive due to the requirement of additional equipments for re-heating the flue gas to required temperatures and heat recovery.

Suitability of technology options

In India, almost all of the presently operational plants have to meet the NO_x emission limit of 600 mg/Nm^3 or 300 mg/Nm^3. Given the applicable standard, these do not require the implementation of post-combustion control technologies. Compliance can be achieved only through primary measures. In fact, according to several technology suppliers, the latest third generation LNB + OFA technology is capable of reducing NO_x emissions well below the 300 mg/Nm^3 limit. Power stations across the country have now begun the process for Implementation of primary control technologies.

The plants that have to meet the NO_x emission limit of 100 mg/Nm^3 will be required to go for post combustion NO_x control. However, even these plants should first consider adopting primary NO_x control technologies as they can significantly reduce the operating costs associated with post combustion control technologies.

Managing the catalyst in SCR system is a serious concern that merits stringent storage and disposal regulations and close oversight by the PCBs. Majority of coal in India is of poor quality with high ash content (over 30 per cent) and low calorific value (3000–5000 kcal/kg). The thermal power industry has raised concerns about the suitability of SCR for NO_x control in Indian context and NTPC has run pilots to test SCR's suitability. Independent experts believe that SCR technology will work for Indian coal, however, the erosive ash components such as silica and alumina will have an impact on the SCR and its catalyst causing a faster deactivation of the catalyst.

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