

# Lowering NO<sub>x</sub> in India

India's cement industry has grown steadily in recent years and production capacity has reached just under 380Mta. Alongside this expansion has been an increasing need to curtail emissions, including NO<sub>x</sub>, from cement plants. This article considers some of the challenges and solutions available.

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Under constant pressure to reduce costs and environmental impact, the Indian cement industry has adopted state-of-the-art technology to improve its energy efficiency and lower its carbon footprint. Particulate emissions have been curtailed by optimisation of raw materials and process conditions, as well as by installing efficient pollution control equipment. Specific energy consumption in the best-performing Indian plants is also in line with the best in the world.

Recently India's norms for gaseous emissions from cement plants have been revised and the Ministry of Environment and Forests (MOEF) has amended the Environment (Protection) Rules of 1986. The limit for NO<sub>x</sub> emissions for new plants is set at 600mg/Nm<sup>3</sup> at 10 per cent O<sub>2</sub> (800mg/Nm<sup>3</sup> for older plants) and for SO<sub>2</sub> emissions at 100mg/Nm<sup>3</sup> at 10 per cent O<sub>2</sub>, dry basis. This has led to the need for cement producers to assess to what extent their current operations meet these more stringent requirements and if necessary, carry out the appropriate modifications to their plant.

## NO<sub>x</sub> formation

NO<sub>x</sub> in kiln flames is generally generated by heat (thermal NO<sub>x</sub>) or fuel (coal, oil and petcoke).

Thermal NO<sub>x</sub> is formed by the combination of atmospheric nitrogen and oxygen at very high temperatures, typically 1800-2000 °C near the burner. The reaction takes place between oxygen radicals, nitrogen radicals and molecular nitrogen. Apart from temperature, the in-flame oxygen concentration and the residence time in the high-temperature zones influence the final thermal NO<sub>x</sub> emissions.

Fuel NO<sub>x</sub> is formed due to the presence of nitrogen bound as an organic compound in the structure of fuel (other than gas). During burning, this organic nitrogen becomes converted into a range

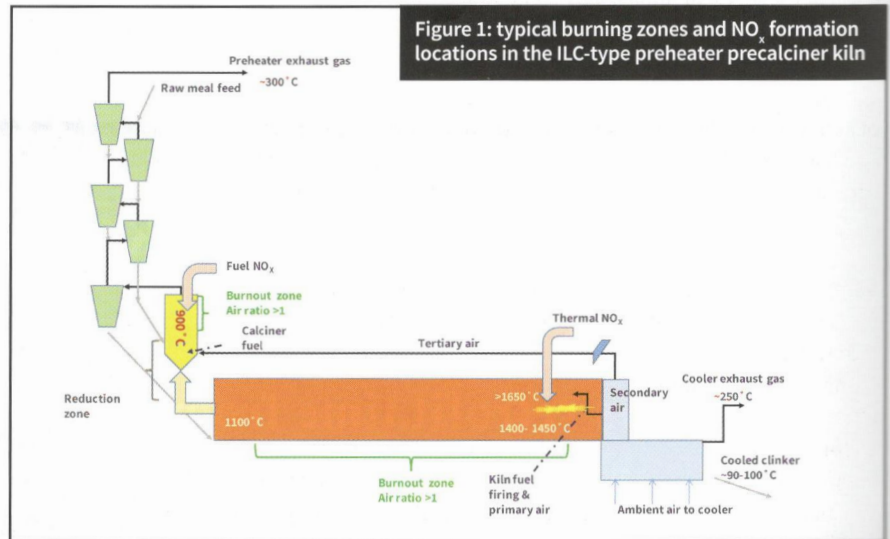


Figure 1: typical burning zones and NO<sub>x</sub> formation locations in the ILC-type preheater precalciner kiln

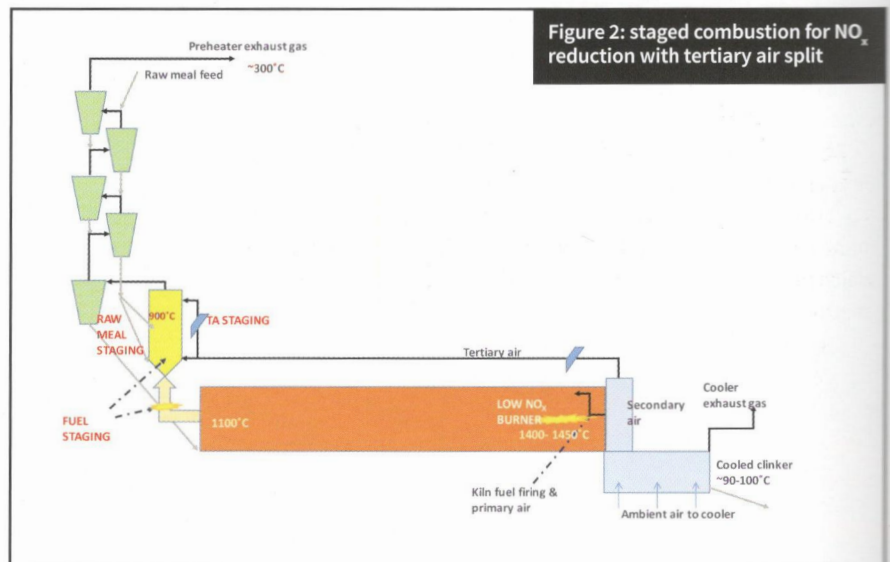


Figure 2: staged combustion for NO<sub>x</sub> reduction with tertiary air split

of cyanide and amine species, some of which are subsequently oxidised to NO<sub>x</sub>, depending on the local oxygen availability. This mechanism is less dependent on temperature.

Typical NO<sub>x</sub> emission values in older technologies can be as high as 1800-2000mg/Nm<sup>3</sup>, while average emission values are around 1200mg/Nm<sup>3</sup> (based on 10 per cent O<sub>2</sub>).

NO<sub>x</sub> emissions are dependent on certain

process-related factors such as feed mix composition, kiln fuel type, increased thermal efficiency, burner type and amount of excess air.

The burnout and reduction zones in a typical preheater precalciner (PH/PC) system are shown in Figure 1.

## NO<sub>x</sub> control mechanisms

To control NO<sub>x</sub> emissions the following retrofitting options can be incorporated in



existing PH/PC dry-process cement kilns.

### Installing low-NO<sub>x</sub> burners (LNB) in the kiln

Two distinct combustion zones are created using LNBs. Flame turbulence as well as air and fuel mixing are suppressed during the first stage of combustion. A fuel-rich, oxygen-lean, high-temperature combustion zone is first created by reducing the amount of primary air in the primary combustion zone and delaying the combustion of all of the fuel. Thermal NO<sub>x</sub> formation is suppressed in the primary combustion zone because less oxygen is available.

A secondary, oxygen-rich combustion zone follows, where fuel combustion is completed, but at lower temperatures to avoid NO<sub>x</sub> formation. This method can secure 10-15 per cent NO<sub>x</sub> reduction depending on the existing level of emissions.

### Combustion zone control

Continuous monitoring of CO and O<sub>2</sub> emissions in the exhaust gases of kilns provides an indication of the amount of excess air present.

Maintaining the combustion zone temperature at a minimum acceptable value for the given excess air level minimises process energy requirements and NO<sub>x</sub> emissions.

### Staged combustion in calciner with tertiary air split

Staged combustion in calciner (SCC) works by staging the introduction of fuel, combustion air and feed material in a manner to minimise NO<sub>x</sub> formation and reduce NO<sub>x</sub> to nitrogen. NO<sub>x</sub> formed in the kiln's combustion zone is chemically reduced by maintaining a reducing atmosphere at the kiln feed end by firing fuel in this region (see Figure 2). The reducing atmosphere is maintained in the calciner by controlling combustion air such that the calcining fuel is first burned under reducing conditions to reduce NO<sub>x</sub> and then under oxidising conditions to complete the combustion reaction. However, the overall process parameters during kiln operation under such reducing conditions must be carefully watched to limit CO emissions, especially where an ESP is being used instead of a baghouse.

Controlling raw meal introduction allows control of the calciner temperature. Through these mechanisms, both fuel NO<sub>x</sub> and thermal NO<sub>x</sub> are regulated. The combustion chamber allows for improved management of the introduction of tertiary air in the calciner region, which helps to promote the proper reducing environment for NO<sub>x</sub> control.

Engineered to the existing design of the kiln, this method can secure up to 25-30 per cent NO<sub>x</sub> reduction.

### Selective non-catalytic reduction

The selective non-catalytic reduction (SNCR) process is the injection of ammonia in the form of ammonia water or urea in the flue gas at a suitable temperature. An aqueous ammonia solution is the reagent that has been most often used for cement kilns and experience indicates that an ammonia solution is most effective for PH/PC cement kiln applications. Other reagent alternatives include anhydrous ammonia (injected as a gas), urea solutions and ammonium sulphate solutions. This reagent is called a reductant.

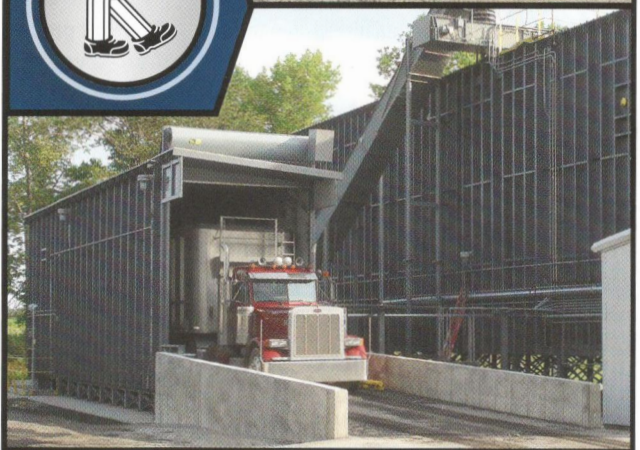
SNCR system performance depends on:

- residence time available in optimum temperature range
- degree of mixing between injected reagent and combustion gases
- uncontrolled NO<sub>x</sub> concentration level and oxygen level
- molar ratio of injected reagent to uncontrolled NO<sub>x</sub>.

The SNCR system can be easily installed as retrofit in an existing pyroprocessing system with the following main additions:

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**Table 1: typical aqueous ammonia consumption**

	Case 1	Case 2	Case 3	Case 4
Production (tpd)	2800	4200	9000	10,000
NO <sub>x</sub> at preheater outlet, 10% O <sub>2</sub> , dry (mg/Nm <sup>3</sup> )	2000	1200	1800	1347
NO <sub>x</sub> emission required at 10% O <sub>2</sub> , dry (mg/Nm <sup>3</sup> )	600	700	600	700
Gas volume at actual O <sub>2</sub> , wet (Nm <sup>3</sup> /h)	200,000	270,000	550,000	580,000
NO <sub>x</sub> reduction required (%)	70	42	67	48
Ammonia slip (mg/Nm <sup>3</sup> )	20	20	20	10
Ammonia slip (kg/h)	1600	522	2500	2230
Aq ammonia consumption (l/h)	1764	575	2756	2459
Aq ammonia consumption (m <sup>3</sup> /day)	42.3	14	66.2	59

- reductant receipt and storage section – adequate safety measures have to be taken for the handling of ammonia solution or ammonia.
- reductant pumping and delivery section
- reductant distribution system
- ammonia injection lances at calciner and/or kiln riser duct. The exact location and number of injection points is system dependent and optimised through testing.
- Measurement equipment is necessary to maintain the appropriate ammonia feed rate and additional monitoring equipment is required to record the amount of NO<sub>x</sub> and ammonia slip in the gases exiting the SNCR system to adjust the amount of ammonia entering the system.
- Temperature monitors are also required to ensure that the ammonia is delivered to the correct location in the riser duct and/or calciner.

It may be necessary to use multiple reduction techniques so that the emission standards can be met. It is essential to assess the existing emissions and identify the factors that influence NO<sub>x</sub> formation specific to each clinkerisation line.

### Practical considerations

The Indian cement industry is currently assessing its existing systems to formulate a practical and sustainable approach to reducing NO<sub>x</sub> emissions.

The typical requirements for ammonia reagent (25 per cent ammonia in water) for SNCR systems are given in Table 1. While the data presented is for different locations and different SNCR vendors, it provides an indication of aqueous ammonia volumes

required to be handled and consumed for the SNCR process.

However, in the implementation of SNCR projects to reduce NO<sub>x</sub>, three issues emerge:

- storage and handling of aqueous ammonia
- procurement of aqueous ammonia
- capital and operating expenditure.

### Storage and handling of aqueous ammonia

The storage and handling of aqueous ammonia, particularly in large volumes (eg in 100-200m<sup>3</sup> storage tanks) requires the training of staff to ensure safe unloading and pumping. The field operators also have to get used to ammonia odours which will emanate even if there are only small quantities of spills or vapours.

In addition, the industry has to develop its technical competence to understand the engineering of storage tanks, pumps and instrumentation which need to be installed. Fertiliser, paint and surfactant industries have experience in handling aqueous ammonia. Technical consultants and professionals from these sectors are now helping to transfer their knowledge and engineer such systems to the cement industry. Cement companies are also performing Hazard and Operability Studies Analysis (HAZOP) at the design stage to ensure that operational risks are minimised or even eliminated.

### Procurement of aqueous ammonia

As is evident from Table 1, a 5000tpd clinkerisation line may need between 15-25m<sup>3</sup> aqueous ammonia per day depending on the level of NO<sub>x</sub> emissions from the process. This requires a

movement of 1-2 ammonia tankers per day to replenish daily consumption.

In most cases, cement plants are situated away from the locations where ammonia is generated. As a result, the tankers have to travel over 1000km to reach the consumers, leading to substantial logistics costs. Moreover, there is also little merit in transporting 75 per cent water over such large distances.

In addition, the regular supply of aqueous ammonia may be disrupted during monsoon seasons.

One possible solution may be to generate aqueous ammonia at locations close to cement plant clusters. However, there are multiple complications in terms of obtaining resources such as water as well as regulatory permits for such aqueous ammonia plants.

### Capital and operating expenditure

The capital expenditure for the SNCR system is typically around €500,000-600,000. The landed cost of aqueous ammonia at site is estimated at about €200/year.

The operating cost, including the price of reductant, compressed air consumption, soft water for flushing, maintenance cost and power consumption, is about €770,000/year for a 4200tpd clinkerisation unit, based on current oil prices.

This is a huge cost and the industry is yet to decide how much of this cost will be borne by the producer and how much will be passed on to consumers.

### Conclusion

India's cement industry has carried out a critical analysis of the NO<sub>x</sub> emissions from its plants, taking into account the increasing use of alternative fuels. In all cases primary measures, such as staged combustion and burner improvements, are expected to be carried out to help minimise process-specific NO<sub>x</sub> emissions and meet limits set out in recent legislation. Only then should secondary measures such as SNCR be adopted to minimise the operational cost.

It is imperative that stakeholders of the cement industry, such as manufacturers, OEMs, technical consultants, industry associations and regulatory bodies, collaborate and share their experiences to work out a sustainable solution. Consultants and OEMs with global experience can also help to find the most suitable technology and address the issue of ammonia availability. ■