Injecting new life in NO_x control

The aqueous ammonia (NH_3) injection system for nitrogen oxide (NO_x) emission reductions at a cement plant in Florida, USA, provided limited ability for flow downturn and material usage efficiency. A new injection system, provided by Lechler, considerably lowered the use of NH_3 in its NO_x reduction system.

■ *by **Stewart McKenzie and Aly Gilbertsen,** Lechler Inc, USA, and **Daniel Ball**, Argos Cement, USA*

The goal of all nitrogen oxide (NO_x) control systems at cement plants is to produce the highest NO_x removal with minimal reagent use and cost while preventing ammonia slip. US-based Lechler Inc uses selective non-catalytic reduction (SNCR) systems injecting aqueous ammonia.

The SNCR systems are installed in high-temperature kilns and calciner ducts to scrub NO_x from the flue gas of coal-fired kilns which is formed as a combustion by-product. This SNCR-NO_x process works by injecting a finely-atomised aqueous ammonia (NH_3) solution into the flue gas that contains the acid gas precursors. The goal is to enable the complete reduction (ie, chemical reaction) needed within a short residence time to allow production to establish a reliable output.

Principles of SNCR and ammonia injection

In these SNCR systems NO_x is reduced with the use of aqueous ammonia to form molecular nitrogen and water by the following overall reaction:[1]

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

The efficiency of this reaction depends on a specific temperature range and residence time.

A new NH_3 injection system with the latest nozzle design by Lechler improved the performance of the SNCR system at a US cement plant

Temperature

The temperature window for the SNCR reaction is critical as the reaction is endothermic. At higher (>1000 ° C) temperatures, nitrogen may react with excess oxygen, potentially causing regeneration of NO_x species. At lower (<850 ° C) temperatures, the reaction rate in the NO_x reduction process becomes too slow, resulting in excessive NH_3 or excessive build-up of NH_3 in raw materials. The excess in the form of 'ammonia slip' presents a safety hazard and is shown by a distinct (usually yellow) colour in the stack exhaust.

Therefore, the optimum temperature range specified in recent publications is 800-950 ° C (1472-1742 ° F).[2] However, for each situation, specific constraints on the system must be considered, including available air, water flow and pressures and straight duct run for evaporation.

Figure 1: gas temperature vs NO_x reduction and NH_3 slip

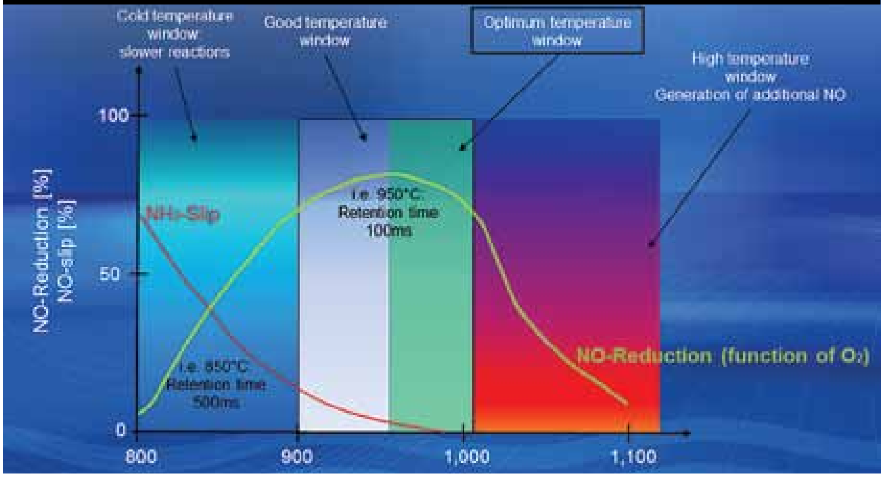


Figure 1 shows the injection gas temperature versus NO_x reduction efficiency with ammonia slip represented as the red solid line. The cement producer injected aqueous ammonia into the flue gas stream at a temperature of ~846 ° C.

Residence time

The residence time during which the reaction time takes place is also an important consideration. Lower temperature operation will require additional reaction time vs the higher temperature regime. This has obvious implications on operational strategies.

An injection system with a high liquid surface area allows for more reactions to take place, resulting in a shorter residence reaction time. The most efficient and cost-effective way to have more liquid surface area is to have smaller droplets formed from the aqueous ammonia. In general, the formation of smaller droplets lowers the consumption of aqueous ammonia in the system. Obviously, a manageable temperature/residence time balance is needed for this reaction depending on each project's constraints.

The determination of the ammonia injection is governed by the overall one-to-one stoichiometric reaction:

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

This reaction can become quite complex depending on a range of factors, such as the quality of the reducing environment including temperature, forced oxidation and residual contaminants. As a note, generally the amount of aqueous ammonia added is slightly higher than the theoretical amount due to the plant conditions.

Project background

A leading international cement producer with a 1.54Mta plant in Florida, USA, injects aqueous ammonia into the flue gas to reduce NO_x formation and therefore, NO_x emissions, at a minimum temperature of 800˚C. The plant's NH_3 costs were significantly higher than the stoichiometric amounts of aqueous NH_3 based on flue gas analysis. The stoichiometric amount of NO_x called for ~0.4gpm 19 per cent aqueous NH_3. The plant's system in use at the time had nozzles running, at their minimum flow rate, exceeding 1gpm 19 per cent aqueous NH_3.

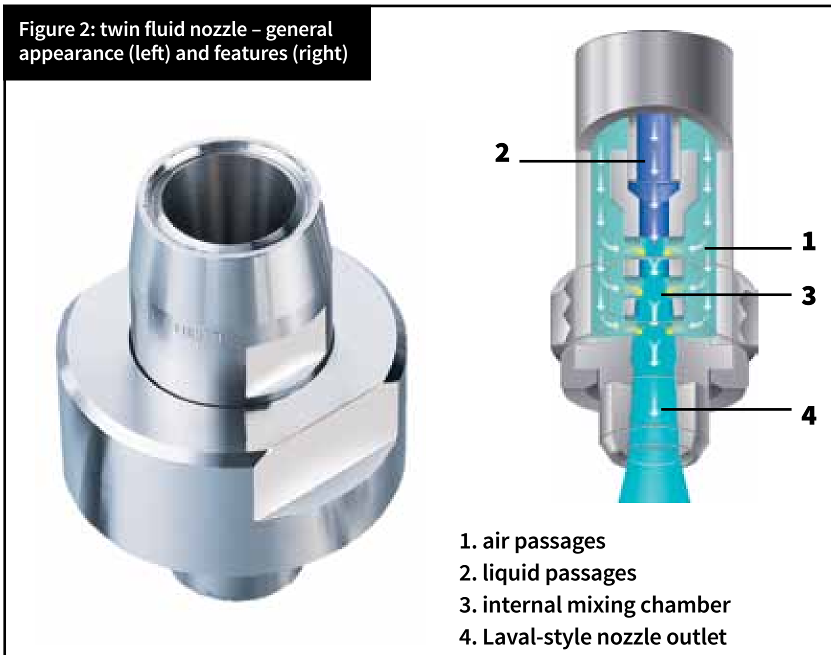
Therefore, the project aimed to gain more control over the SNCR system and reduce costs while maintaining the company's environmental permit for Kiln 1. This required a maximum of 1.95lb NO_x/t of clinker on a 30-day average.

Table 1: design outputs following SNCR-NO_x process analysis

Description	Minimum	Maximum
Total liquid injection flow rate (gpm)	0.32	3.2
Total atomising air consumption (scfm)	188	147
Liquid flow rate/nozzle (gpm)	0.11	0.8
Liquid pressure/nozzle (psi)	62.3	72.5
Atomising air flow rate/nozzle (scfm)	47	37
Atomising air pressure at nozzle (psi)	72.5	72.5

Note: for efficient performance, the maximum deviation of gas flow distribution will not exceed 20 per cent of the root mean square (RMS) value.

Figure 2: twin fluid nozzle – general appearance (left) and features (right)



1. air passages
2. liquid passages
3. internal mixing chamber
4. Laval-style nozzle outlet

Existing SNCR set-up

Reportedly over 10 years old, the existing spray system operated inefficiently, as evidenced by a lack of maintenance records. The hydraulic (ie, no air atomising) nozzles required barrier air for cooling at ~20-30scfm at 85-90psi. The legacy nozzles did not use compressed air. The 19 per cent aqueous NH_3 solution was injected into the inlet duct of the first stage of the precalciner via four hydraulic lances.

Nozzle architecture

The existing nozzles were mechanical atomisation (hydraulic) nozzles that incorporated a metal disk to shear the liquid, creating an atomised spray cone. These hydraulic nozzles were not capable of running below 1gpm without significant degradation of the spray cone and an increase in droplet size. The larger droplets have a lower surface area and therefore, result in lower reaction rates. Air atomised or 'twin fluid' nozzles use compressed air to atomise the aqueous NH_3. Typically, air atomising nozzles provide smaller droplet sizes than hydraulic nozzles.

Lechler performed a proprietary SNCR-NO_x process analysis and provided summary values, shown in Table 1.

Lechler proposed VarioClean® twin fluid Laval lance/nozzles with barrier air for this application, as shown in Figures 2-4.

Figure 2 shows the overall appearance and the features of the nozzle.

Figure 3 illustrates the typical small spray angle and barrier air/spray cone proximity in operations. The gap between the injection nozzle (centre) and the outer walls of the nozzle cap allows low-pressure

Figure 3: twin fluid nozzle operation

Figure 4: twin fluid lance with barrier air

Table 2: projected cost savings

Year	Clinker production (tpd)	Ammonia cost (US$)	Cost with 25% NH_3 reduction (US$)	Potential annual cost saving (US$)
2016F	900,000	318,387	238,790	79,596
2017B	933,000	330,061	247,546	82,515
2018B	993,000	351,287	263,465	87,821

B = budget. Capital investment: US$38,000 plus installation estimate (US$10,000) = US$48,000. Payback period <1 year.

air flow to maintain a concurrent flowing resistance in the nozzle area from dust and solids build-up. This barrier air also provides a degree of cooling along the length of the lance for protection of the lance from high-temperature duty.

Figure 4 shows the entire injection lance assembly with connections (for low-pressure air, atomising air and fluid flow) and a cut-away illustration of the barrier air concept. Proceeding from left to right are: fluid feed, atomising air feed and barrier air inlets connections.

The barrier air flow passes over the installed length of the lance. It is recommended to be left in an 'on' status if the lances are turned 'off'. This minimises lance overheating and potential NH_3 evaporation and scaling.

Economic benefits

Basic calculations with standard plant conversion factors were made to determine the amount of aqueous NH_3 consumed in this process with figures for actual use in six months as follows:

- 1,454,748l (320,000gal) of solution
- 0.92kg/l (7.66lb/gallon)
- 1,133,981kg (2.5Mgal) solution
- 217,724kg (480,000lb) NH_3
- US$177,227 (at US$0.81/kg or US$0.37/lb)
- 452,685t of clinker (499,000st)
- US$0.40/t of clinker (US$0.36/st).

The six-month figures were actual use confirmed by process logs and the plant's digital control system. The six-month aqueous NH_3 cost was derived from the standard physical property data which resulted in a cost of US$0.40/t of clinker.

Based on this data, a 25 per cent reduction in aqueous NH_3 use with the new Lechler VarioClean® system should provide approximately US$63,000 in annual savings in addition to reducing deliveries by ~20 truckloads of aqueous NH_3 annually.

The actual savings in aqueous NH_3 use with the Lechler VarioClean® SNCR-NO_x system was almost twice the conservative estimate shown in Table 2 (cost with 25 per cent NH_3 reduction). The cement producer was able to reduce the average aqueous NH_3 use from 1 to 0.3gpm (~70 per cent reduction and almost three times the estimate). This resulted in the company saving approximately US$180,000 per year.

Process impact and environmental emission limits

This plant has two kilns for full operation. Kiln 1 has an Environmental Protection Agency (EPA) permit limit of 0.88kg (1.95lb)/t of clinker. The plant was forced to use a setting of 0.73kg (1.6lb)/t of clinker as a way to ensure compliance due to the lack of control in the existing SNCR-NO_x system. This setting was needed to minimise the potential of overshooting the NO_x release and assure compliance.

Using the Lechler VarioClean® system, the plant was able to improve process control by adding efficiency and flexibility to the operating settings. The largest operational benefit allowed the plant to set a higher SNCR-NO_x operational target of 0.86kg (1.9lb) NO_x/t clinker. This new setting removed the artificial restrictions imposed before due to lack of control. The higher operational target also provided increased production.

Reducing the amount of aqueous NH_3 required not only reduced costs but also increased safety by scaling down the number of trucks delivered.

Multiple upgrade benefits

The upgrade in nozzles on the SNCR-NO_x system has enabled the cement producer to increase the reliability of the system, reduce costs and improve environmental compliance.

The existing hydraulic nozzle used for fluid atomisation was retrofitted by upgrading to Lechler VarioClean® twin fluid spray nozzles, which provided higher SNCR reliability and efficiency, lower maintenance cost, and ease of operation at both start-up and full load. The nozzles can operate reliably inside a kiln or duct which has been designed for a spray atomiser at widely fluctuating loads. Smaller ammonia droplet sizes support the more efficient use of aqueous ammonia and air consumption. The retrofit required little downtime and only minor changes to the vessel structure.


Figure 5: the new injection system in situ

The overall process to upgrade the existing SNCR-NO_x system was simple. A compatible process support system, including installed equipment (including pumps, compressors, gauges and hoses) was provided as part of the final solution. All of the existing consumption data was thoroughly confirmed along with efficiency capabilities to provide the best design for improvement before agreeing on the actions to be taken. This type of collaboration and review minimised overall costs for the project implementation and provided the baseline for ROI and the tremendous material savings on an ongoing basis.

While the initial economic justification for this upgrade was very attractive in a cost-conscious industry, the final result indicated less than a three-month payback and annual six-figure aqueous NH_3 savings. ■

REFERENCES

[1] DUO, W, DAM-JOHANSEN, K AND ØSTERGAARD, K (1992) 'Kinetics of the gas-phase reaction between nitric oxide, ammonia, and oxygen' in: Canadian Journal of Chemical Engineering, 70, p1014-1020.

[2] HELMREICH, C (1996) 'Improving SNCR performance' in: *ICR*, December, p70-71.