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# High-efficiency SNCR injection systems

Within the last decade the de-nitrification of flue-gas has become an essential topic for all cement, power and waste incineration plant owners. Here Lechler GmbH's global division leader, Ullrich Speer, describes options for $NO_x$ removal within the cement industry.

To comply with current and future emissions requirements, it is important that equipment suppliers remain 'in-the-know,' so that they can offer the most appropriate solutions. Even within the EU, the differences in $NO_x$ emissions limits from cement plants are significant and Germany will introduce a new 200mg/Nm³ limit in 2019. However, the government is keen for all plants to meet the new limits within a much shorter time-frame.

A cement plant offers multiple possibilities for flue gas conditioning systems at the raw mill, the cooling tower, the duct, the pre-heater, the alkali-bypass and at the clinker cooler. Within long kilns there are additional applications relating to burner lances. Dedicated $NO_x$ reduction equipment can be applied to calciners and dry and wet long kilns. In both locations, selective non-catalytic reduction (SNCR) technology is a fundamental technique to reduce $NO_x$ emissions.

## $NO_x$ reduction and ammonia slip

When fuel is burned pollutants are emitted in the flue gas. One of the main pollutants is $NO_x$. Once emitted, $NO_x$ reacts with other atmospheric components to produce ozone ($O_3$). Other products generated during combustion, such as nitric acid ($HNO_3$), react in the atmosphere and fall as acid rain, which negatively affects people, plants and animals.

SNCR technology currently involves the injection of ammonia ($NH_3$) or urea ($CH_4N_2O$) solutions. The reaction of ammonia or urea with gaseous nitrous oxide ($NO_x$) is transformed by thermal decomposition into steam ($H_2O$) and nitrogen ($N_2$).

When ammonia is used, a solution is injected directly into the duct in several positions/levels, at approximately 900-1000°C. The ammonia reacts with nitrogen monoxide (NO) to produce nitrogen ($N_2$) and steam:

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

Adding urea solution is simpler and safer and you don't need explosion protection. In the SNCR application, urea reacts like ammonia but with carbon dioxide ($CO_2$) as a by-product:

$$NH_2CONH_2 + H_2O \rightarrow 2NH_3 + CO_2$$

During the injection of ammonia or urea, ammonia slip will appear in the exhaust gas. The amount can be reduced via process adjustments, but it cannot be eliminated. At high temperatures, ammonia creates $\bullet NH_2$ radicals. These are a result of the reaction between ammonia with hydroxyl radicals and oxygen radicals, which are usually created in hot gas streams by other reactions. The $\bullet NH_2$ radicals reduce nitrogen monoxide to dinitrogen:

$$\bullet NH_2 + NO \rightarrow N_2 + H_2O$$

In the overall reaction, the radical formation reactions appear twice and the reduction reaction four times. This results in the following overall equation:

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

When urea is used it forms $\bullet NH_2$ and the resulting carbon monoxide (CO) is oxidised by oxygen.

The reduction of $NO_x$ by ammonia or urea is based on many partial reactions, the balance of which is determined by the temperature and concentration of the reagents. Therefore, with a theoretical over-stoichiometric injection relationship between ammonia and $NO_x$, the NO cannot be completely removed. Additionally, some of the reducing agent is regenerated as $NH_3$ from the reaction.

For a maximum reduction rate of nitrogen monoxide leading to low ammonia and $NO_x$ emissions, a temperature window must be complied with (Figure 1). In addition, nozzles are often installed at several levels throughout the whole duct. Based on temperature measurements and calculations, those nozzles closest to the injection point with the optimum reaction temperature will be activated.

Sophisticated single-nozzle control systems that offer independent injection-level sprays already exist. If they could be combined with a local and timely highly-resolving temperature calculation (like an online computational fluid dynamics - CFD), the best $NO_x$ removal results could be achieved. Furthermore, minimum ammonia slip will be achieved.

## Challenges to be managed by the plant

There must be a clear strategy to meet changing $NO_x$ and ammonia emissions limits, with different requirements for different plants. Some plants can proceed step-by-step with multiple small investments, but others find it better to invest in a full package. How are such decisions made?

1. Emissions limits are different in different jurisdictions. Could production costs be optimised even with tighter values?
2. Plants must determine (and understand) the complexity of the influencing variables of NO production and $NO_x$ reduction, such as: Flue gas temperature in the injection area; Flue gas speed in the injection area; Flue gas speed in other parts of the system; Fuel properties; Raw $NO_x$ load from the sintering zone and possibly from the calciner.
3. The process choice will influence current and future investments. There are many options at different prices with varying future adaptability. Some of Lechler's solutions will be discussed later.

Unfortunately the parameters listed under point 2 must be controlled as well as known. Each of the influencing factors must be controlled separately and considered in the final calculation that will decide on the type of control system. Within the plant there are three different influencing groups:

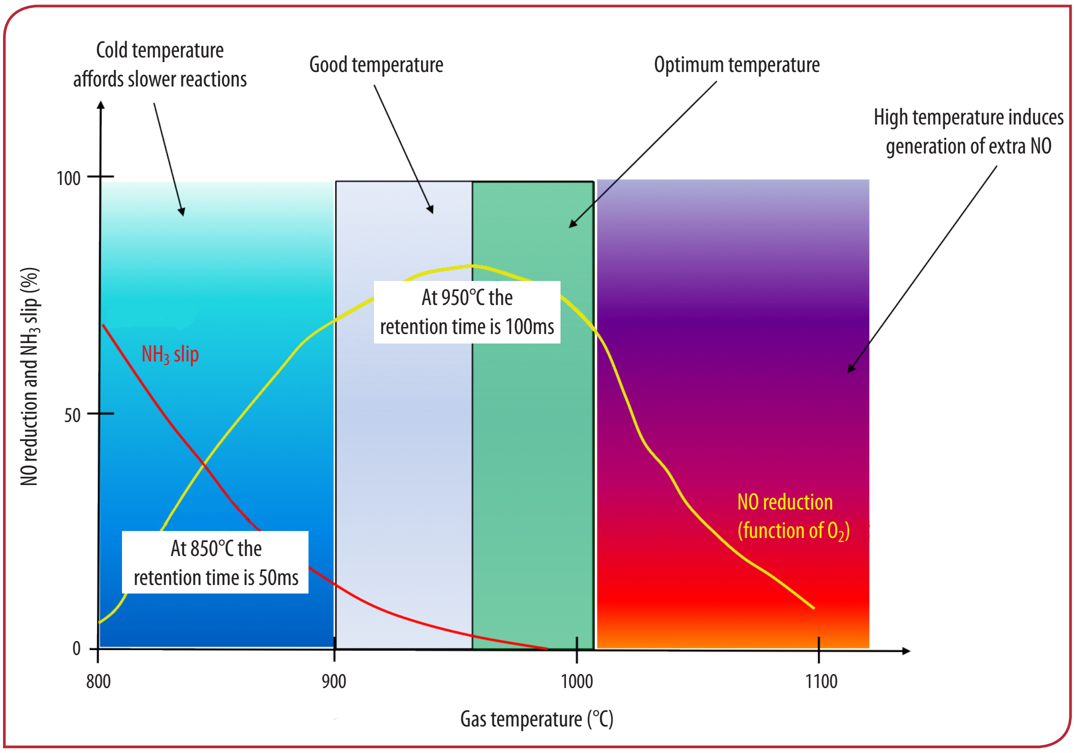
- **Unknown variables**: These include the raw $NO_x$ value, temperature, gas speed and gas composition in the injection area and must be measured to be known.
- **Difficulty factors:** These include temperature fluctuations in the injection area, high dust loads within the system, up to five minute delays between the measurement point(s) and stack, the riser duct refractory, the gas flow and speed, fouling at the tip of the nozzles and the residence time of the gas.
- **Permanent process changes:** Most European cement plants (any many elsewhere) use alternative fuels and each of these changes the gas composition. Ongoing modifications to the kiln line, or even existing changes within the process while the kiln is running, will also permanently affect the process.

One factor that will affect $NO_x$ production is build-up in the calciner. This is because the whole process of the production line is based on theoretical calculations of an optimised new plant. With increasing build-ups in the tower, the internal diameter of the tower reduces. Assuming the same volume of gas, but travelling through a smaller diameter, we will see a higher gas velocity. A specific residence time at the optimum temperature is required to achieve the best possible $NO_x$ reduction. However, increased velocity will shorten the residence time, resulting in an incomplete reaction and higher $NO_x$ levels.

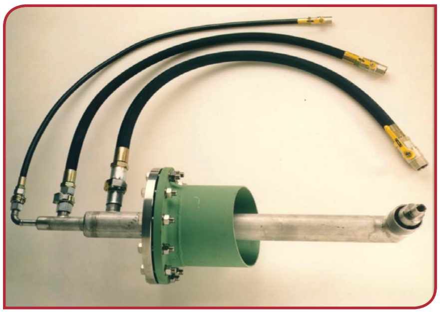
To prevent this, it is necessary to have online control of the build-ups and to be able to predict the next occurrence ahead of time.

## 3D-temperature simulation and online CFD

STEAG Powitec GmbH (Powitec) from Essen, Germany has developed a high-efficiency SNCR (heSNCR) software system for $NO_x$ reduction in cement plants in cooperation with Lechler GmbH, due to the fact that primary measures like staged combustion will not be able to meet the 200mg/Nm$^3$ $NO_x$ limit. It is available as a stand-alone solution or as an upgrade to an existing SNCR plant.




**Left - Figure 1:** The temperature window for the injection of the ammonia solution is vital for good operations of the SNCR system.



**Above- Figure 2:** The Lechler SNCR lances and twin fluid Laval nozzles are included in the basic SNCR, the eSNCR and the heSNCR systems.

The heSNCR technology enables low $NO_x$ emissions while maintaining tight limits for the ammonia slip and reduced reagent consumption. Upgrading to heSNCR from standard SNCR is attractive because this approach almost always makes investment in an SCR system obsolete. The total costs of the heSNCR system are also lower than those of SCR technology. The system can also be supported by the advanced sintering process control system to reduce primary $NO_x$. The system software comprises: **1.** Online CFD for continuous generation of a highly-resolved time and spatial model of the flue gas in the rising duct between kiln and pre-heater (or calciner); **2.** Estimation of the build-up thickness in relevant duct walls that dominate airstream issues; **3.** Online calculation of the ideal spray amount (considering current and future levels of $NO_x$, $O_2$, temperature, deposition rate and slip); **4.** Permanent adaptation of control to process changes.

An additional special characteristic of the process is that the $NO_x$ reduction efficiency and slip depend strongly on temperature and $O_2$ distribution. To achieve the targets, the temperature window must be determined for spraying the right amount of reducing agent at the right time to the right area. However, this poses another challenge as the optimal temperature window permanently changes, influenced by: **1.** Current cement production volumes; **2**. Local fuel loads, fuel types and qualities; **3.** Build-ups; **4.** Local gas flow and velocity.

To meet these challenges, Steag Powitec follows the sense, analyse, predict, control (SAPC) approach:

**Sense:** Additional temperature sensors are used to gain detailed knowledge of the conditions in the area where reagent is injected. The sensors are installed in the refractory material of influential ducts, in positions where build-ups tend to occur. At each position two temperature sensors are used to improve the understanding of the current build-up of the deposits at this specific point.

Because the sensors are of different lengths, they can measure a specific temperature difference. In the case of build-ups or a reduction of refractory wall thickness due to wear, the changes in temperature difference give information about gas flow velocity.

**Below - Figure 3:** The Lechler heSNCR system installed in the German cement plant.

**Analyse:** The current build-up deposit situation in the rising duct is estimated using the data from the temperature sensors together with the process control system data. Data is continuously analysed and noise removed.

**Predict:** The temperature distribution in the rising duct is calculated by dividing the duct into many small segments. For each segment, the physical parameters of the flue gas (mass, density, velocity and temperature) are modelled. Mutual interactions are described by mathematical equations as used in CFD analysis.

The calculated values are calibrated online with the values from the process control system. The temperature distribution is continuously calculated online with update rates of 10-30s. The permanent online CFD allows the calculation (prediction) of the load- and fuel-dependent change of temperature. This enables efficient and intelligent system control.

**Control:** As clinker production is a non-linear process with significant reaction times and constantly-changing correlations, controlling an heSNCR system is a complex task. Different operating conditions generate different emission loads and different temperatures.

The PiT Navigator SNCR technology, part of the heSNCR system, continuously uses conventional process data, the additional temperature sensor data and the results of the online CFD calculations to find and evolve process models automatically over time. The technique is a system of neural networks, which are used to estimate important process results. Thus, the PiT Navigator automatically evaluates the presently-valid model to determine the effect of certain activities. For example, it simulates slight modifications to the amount of reagent injected through the nozzles to determine the effect on $NO_x$ reduction and the ammonia slip at the stack. The best result derived from these simulations is used for the control of the lances in the actual plant.

Unlike standard control systems, the PiT Navigator SNCR system is self-calibrating and auto-optimising closed-loop control software. Consequentially, extensive and permanent manual reconfigurations are not necessary. Additionally, statistical models do not rely on subjective expert knowledge; they learn from existing process data automatically and select the best control strategy. The system is also fault-tolerant: If a single measurement fails, it will rely on others.

The heSNCR technology is equipped with a self-learning adaptive process controller that adjusts itself automatically to process changes and thus injects the optimal quantity of reagent, at the right time, in the right area. This has the effect of continuously achieving significantly lower $NO_x$ levels with the lowest possible reducing agent consumption at the lowest possible slip. In places where $NO_x$ limits are not yet low, the system still offers significantly lower reagent consumption rates and protects against further investment costs when $NO_x$ limits are lowered.

## SNCR solutions

Lechler GmbH and Powitec provide a variety of $NO_x$ reduction systems. The differences between each system and the anticipated $NO_x$ and ammonia reagent reductions are outlined.

**SmartNO$_x$®:** The Lechler SmartNO$_x$ system is a standard valve skid for de-$NO_x$ using ammonia. Customisation options are limited and the lances (Figure 2) are not individually controllable. The system was designed for those that want to gain experience with de-$NO_x$ and is also useful for meeting more relaxed $NO_x$ emissions limits.

**Basic level SNCR:** Basic SNCR is recommended for customers seeking long-term equipment that are willing to upgrade later on. It includes a twin fluid valve skid with a conventional control system and four Laval nozzles and lances on one injection level. It is possible to individually adjust the volume and droplet size delivered by each lance. Typical reductions in $NO_x$ emission levels are from 700mg/Nm$^3$ to 500mg/Nm$^3$.

**Efficient SNCR (eSNCR):** This includes two additional lances with Laval nozzles, giving six lances on two levels, as well as a second small control rack. Beside the existing control system, the eSNCR system offers a special $NO_x$ prediction. The system can reduce $NO_x$ emissions from 1000mg/Nm$^3$ to 500mg/Nm$^3$, using 15% less ammonia than the basic SNCR.

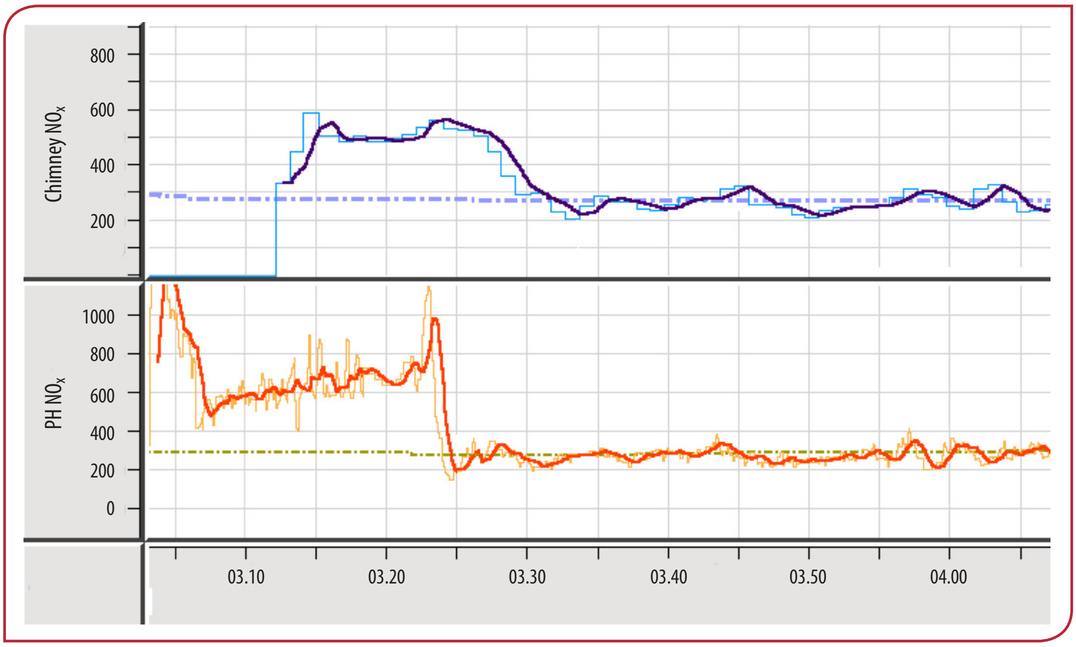
**High-efficiency SNCR (heSNCR):** The heSNCR consists of the eSNCR system, the build-up detection and the online CFD. Two additional Lechler twin fluid Laval nozzles are included and the injection takes place on three levels in the calciner. All outstanding and currently available technologies are included, like the $NO_x$ prediction, the PiT deposit detectors and the PiT online CFD tool. A reduction from 1000mg/Nm$^3$ to 200mg/Nm$^3$ $NO_x$ is typically achieved, as well as a saving of approximately 30% of ammonia reagent.

## Case study

A case study at a German cement plant in Rhineland-Palatinate, Germany, illustrates the excellent results achieved with the heSNCR technology (Figure 3). The $NO_x$ emissions were measured at the chimney, which is the measuring point for the Federal Environment Agency, as well as directly behind the injection system at the calciner.

The cement plant has a kiln without a calciner, which requires $NO_x$ limits of 1200mg/Nm$^3$ when the main fuel is coal and 600-800mg/Nm$^3$ when a significant quantity of RDF is used, (which is the normal case). Using the heSNCR system it was possible to reduce emissions to 300mg/Nm$^3$ on a constant basis (Figure 4) within six minutes of start-up.

The customer was pleased with the reduced $NO_x$ emissions, as well as the lower volume of ammonia required. "By using the heSNCR system on kiln 1 in our Göllheim plant, it was possible to reduce ammonia consumption at the $NO_x$ limit of 500mg/Nm$^3$ by about 35%," said plant personnel. "During a trial period, it was possible to maintain the $NO_x$ limit value of 200mg/Nm$^3$ at an ammonia slip <30mg/Nm$^3$."




**Right - Figure 4:** The $NO_x$ emissions volumes (mg/Nm$^3$) during a one hour trial on 3 May 2014 at a German cement plant.