Introduction
Selective Non-Catalytic Reduction, or SNCR for short, has gone from being the subject of academic studies twenty years ago, and a rising technology a decade ago, to a technology which is increasingly found in the cement industry. Now a common feature in many kilns in Europe, the technology has been rapidly installed in a large number of existing kilns in North America and is currently gaining a foothold in systems in Asia and South America. Recent adoptions of regulations by the Chinese and Indian governments have seen a flurry of activity in the sale of SNCR systems in these countries, and the tightening of state regulations, as well as legal agreements put in place between cement producers and environmental authorities, has seen more than half of the kilns in the United States adopt the technology over the past ten years. While the technology has gained rapid adoption, to many smaller cement producers, as well as to production facilities that often see regulatory agencies ‘follow the lead’ of cement kilns in adopting technology (such as lime production), the steps to install SNCR can seem daunting. However, considering several key questions upfront can greatly assist in determining the proper course of installing an SNCR system.

Basics of SNCR processes
While the phrase ‘Selective Non-Catalytic Reduction’ can make SNCR seem to be an overly complicated process, the practice is fairly simple. SNCR reduces NOx emissions by injecting either ammonia or urea into a gas stream containing NOx, and the resultant reaction forms end-products of water vapor and nitrogen. There are three important items (the ‘Three T’s’) to ensure a complete reaction:

1. The injection of the reagent in the correct Temperature window.
2. The proper residence Time in this window.
3. Sufficient Turbulence to mix the reagent with NOx.

Injection in too high of a temperature window can result in the combustion of the reagent, generating additional NOx. Injection in too low of a temperature window can result in the reagent passing unreacted through the system, producing an emission of ammonia referred to as ‘ammonia slip.’ Insufficient time or turbulence for the reaction to take place after the injection location can also result in the occurrence of slip.

From a design standpoint, the installation of an SNCR system then begins with two questions:

1. Where in the process can I inject the reagent to ensure mixing with as much NOx as possible (i.e. after combustion is completed)?
2. Which reagent must I design the system for?

In reality, both of these questions may need to be answered simultaneously, depending on the location of the installation and the kiln process in use at the facility.

Ammonia vs. urea
The basic reaction in SNCR is between amino radical (NH₂) and NOx (typically as NO) to form nitrogen and water vapor. Whether urea [(NH₂)₂CO] or ammonia [NH₃] is chosen, the first step in the reaction is to activate the reagent to form ammonium. The chemical formula for urea shows that this is accomplished by breaking apart a pair of amino radical molecules and liberating a CO molecule, while for ammonia a single ammonium molecule is generated by releasing hydrogen ion. The step of activating the urea requires a slightly higher temperature than is required for ammonia – the reaction of ammonia can work effectively at temperatures in the range of approximately 850 – 950°C, while the use of urea generally requires temperatures closer to the 1050°C range. The temperature required for SNCR with ammonia therefore tends to correspond with the exit of a calciner vessel or a lower stage cyclone in a precalciner or preheater system, while urea requires a temperature that might be found at a kiln inlet, at the take-off of a kiln gas bypass, in a mid-kiln section of a wet or long-dry kiln, or in the transfer chute of a lime kiln preheater. As such, the design of the kiln can impact the reagent selected – ammonia reacts quite well in systems with calciners, as the injection of ammonia can be maintained at a controlled temperature zone within the reaction window. In kilns without calciners, the use of urea may be preferred depending on the normal kiln exit gas conditions.
The location of the plant may also factor into this decision of reagent. Due to increasingly stringent handling requirements in many locations, ammonia is not generally provided as an anhydrous (i.e. undiluted) product, and is typically supplied as an aqueous solution. Local regulations may limit the concentration of ammonia solutions to levels that are considered to be ‘safe’ for handling, whereas for higher concentrations strict handling guidelines must be adhered to. These types of regulations generally limit solution strengths ranging from the 19% solution that is common in the US market, through to the 25% solution prevalent in India and those of 29% and above commonly found in Europe. Therefore, SNCR systems utilising ammonia as a reagent will be supplied with an aqueous solution that may not be readily available in certain remote locations. Ammonia by itself is a pungent chemical, and can be detected by the human nose at levels as low as 5 ppm. This generally requires a closed storage vessel, which may require a pressure rating depending on the local ambient temperatures observed.

Urea, in contrast, can be received at a plant site either as a solution or as a granular solid that can be mixed with water for injection. The solution strength of urea is not nearly as stringently regulated, and can vary widely based on a variety of site specific requirements. In order to limit the cost of shipping, solutions received at plant site are generally in as high of solution strength as possible. Solutions mixed on site are limited in water content to minimise the introduction of water vapor to the process. However, urea solutions are prone to ‘salt-out’ – the precipitation of urea crystals at higher concentrations and at lower temperatures. This property generally limits urea concentrations between 30 and 50% urea and can also limit the usage of urea in very cold climates, as the storage tanks and piping may require heat tracing and/or insulation in order to prevent precipitation and plugging.

System design

Every SNCR system contains three essential components – a storage tank for the reagent, a pumping system to transfer reagent from the storage tank to the injection point, and a nozzle (or several nozzles) to atomise the reagent. The selection of this equipment depends on the injection rate required to meet the regulatory requirements at the plant. This is determined utilising an idea of the baseline NO\textsubscript{X} generally seen by the plant, as well as the limit being enforced, in order to calculate flow. It is important to know upfront whether the limit is a continuous limit to be enforced year-round, or whether the limit may apply only during certain conditions (i.e. gas vs. coal firing) or certain times of year (i.e. summer during ozone seasons). It should also be determined what the time-frame for the emissions control must be – is the limit placed on an hourly rolling average, a daily average, a monthly average, etc. A plant requiring continuous operation of the SNCR system with the operation of the kiln will require more redundancy than a system which may only run occasionally in order to trim a monthly emission level.

To calculate the pump size, the flow of ammonia should be calculated based on a targeted ratio of reagent to baseline NO\textsubscript{X}. For systems with in-line calciners, a typical expectation may be 50 to 60% reduction in NO\textsubscript{X} when injecting 1 molecule of ammonia for every molecule of baseline NO\textsubscript{X}. This reduction rate will vary with the design of the kiln system (e.g. long dry and wet kilns usually require much greater quantities) and by reagent in use.
can be accomplished more easily if several basic questions are answered at the outset of the process. A proper design begins with determining the reagent to be used (ammonia or urea), and the location of the reagent injection in the system. Following these decisions, the concentration of the reagent is used to size the key components of the system (pumps, storage tanks, piping, and injectors). While regulatory agencies may drive selection of some components in the system, a great degree of choice is available in design of system components, with implications in both capital and operational expenses. While the science behind the process is well developed and ‘standard’ for the industry the project needs are unique for each plant site and informed decisions in the process can greatly simplify project execution.

**Conclusions**

The implementation of an SNCR system for NOx control can be accomplished more easily if several basic questions are answered at the outset of the process. A proper design begins with determining the reagent to be used (ammonia or urea), and the location of the reagent injection in the system. Following these decisions, the concentration of the reagent is used to size the key components of the system (pumps, storage tanks, piping, and injectors). While regulatory agencies may drive selection of some components in the system, a great degree of choice is available in design of system components, with implications in both capital and operational expenses. While the science behind the process is well developed and ‘standard’ for the industry the project needs are unique for each plant site and informed decisions in the process can greatly simplify project execution.

**References**

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