

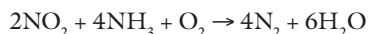
By Brad Buecker, Contributing Editor

Increasingly stringent nitrogen oxide (NO_x) control regulations are propelling the installation of selective catalytic reduction (SCR) systems on coal-fired power boilers, simple-cycle combustion turbines and combined-cycle units. Many lessons have been learned from existing SCR design and operation, including issues related to catalyst selection, fly ash fouling of catalyst beds, techniques to clean beds and other operational factors. This article examines a number of these topics and will be helpful to utility personnel who deal with SCR selection and who operate new and existing equipment.

Fundamental NO_x Chemistry

Approximately 75 percent of the nitrogen oxides from coal combustion come from reaction of nitrogen in the fuel with oxygen in the combustion air. This is known as fuel NO_x. Virtually all of the remainder is due to high-temperature reaction of combustion air nitrogen and oxygen and is known as thermal NO_x. In natural-gas fired combustion turbines, thermal NO_x is the primary reaction method.

Typically, 90 percent or so of the NO_x produced by combustion starts off as nitrogen monoxide (NO). Nitrogen dioxide (NO₂) makes up most of the remainder. Both compounds are removed from flue gas by reaction with ammonia (NH₃).



These reactions will not proceed without an energy input to drive the process. This impulse is known as the activation energy. For the process of selective non-catalytic reduction (SNCR), the reaction takes place in the upper portion of the furnace where temperature generates the activation energy. At most, SNCR may achieve 50 to 70 percent NO_x removal. Often, however, higher efficiencies are required. This is where SCR comes in, where the reaction takes place much further downstream in the boiler backpass (at temperatures of 550 F to 800 F) with the aid of a catalyst. As Figure 1 shows, catalyst lowers the activation energy (E_a).

Catalyst Design Features

What are the catalyst properties, both

physical and chemical, that provide this boost?

The primary base material of catalyst is titanium dioxide (TiO₂), with smaller amounts of other metal oxides including tungsten oxide (WO₂) for thermal support and vanadium pentoxide (V₂O₅), which is the primary active material.

Two predominant styles of catalyst are used in SCRs. These are the honeycomb and plate types.

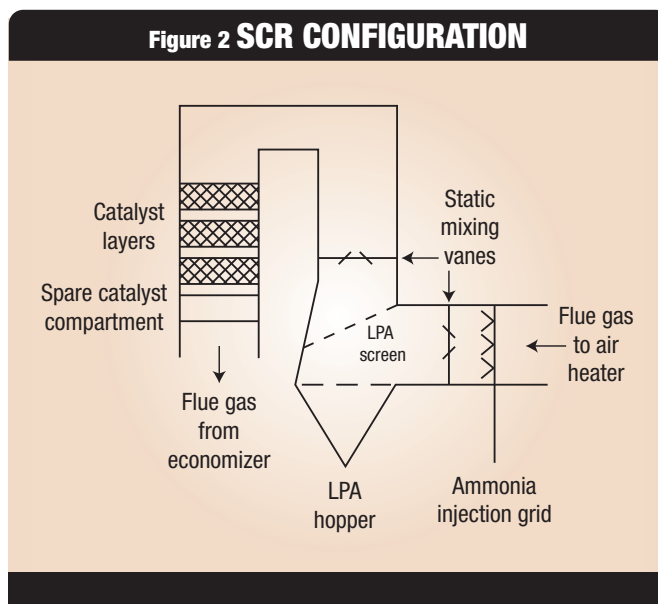
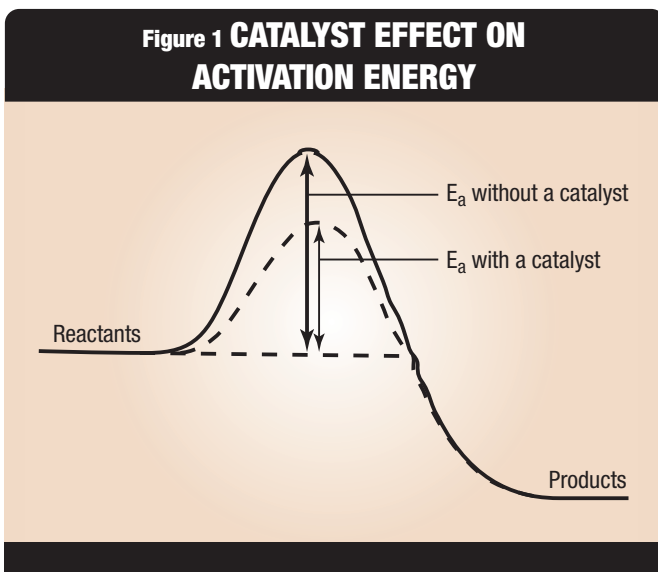
A critical aspect of any catalyst installation is to supply sufficient area for the required NO_x removal, as the NO_x-ammonia reaction takes place upon the catalyst surface. Honeycomb catalyst provides the greater surface area of the two designs, but can be susceptible to fly ash fouling. Catalyst opening size is referred to as "pitch." In the past, common pitch sizes have been in the 7.0 to 7.5 mm range, but the acceptable pitch size is largely a function of fly ash loading and the ability to remove the ash. In some cases, honeycomb catalyst has been replaced by plate catalyst due to severe ash fouling issues. One factor that often causes localized ash buildups on catalyst is insufficient flue gas flow modeling in the design stage. The use of computational fluid dynamics (CFD) is becoming common for analysis of flue gas flow characteristics, ash deposition patterns and turning vane/

flow straightener design.

SCR Design

Figure 2 illustrates the schematic of an actual SCR. It is not meant to outline a perfect system, but rather to illustrate the major equipment components. The diagram is a side view; in this case the complete system consists of two identical sets of ductwork and catalyst beds.

The multi-layer catalyst bed arrangement in this design is typical for SCR systems. Over time, catalyst performance will decline due to poisoning by impurities introduced from the coal (arsenic, phosphorous and al-



kali metals are common poisons) and by fly ash degradation. The top catalyst layer often degrades more rapidly than other beds and is usually the first to be replaced, with a new bed installed in the spare compartment. This process is repeated as conditions dictate. Later we will examine techniques to monitor catalyst performance.

Several aspects of the schematic illustrate common design features that are used to optimize SCR operation and efficiency. First is the ammonia injection grid (AIG). Different styles of AIG grids are used for various SCR systems, but all have the same purpose: to distribute the chemical feed evenly within the flue gas stream. AIG systems must be tuned during SCR commissioning and then periodically afterwards. The outcome of tuning is to provide correct distribution of ammonia from all nozzles. To further enhance ammonia-flue gas mixing, many systems are equipped with static vanes. Each duct in the configuration shown in Figure 2 has two sets of static vanes. Vane design is, or should be, determined by CFD analyses.

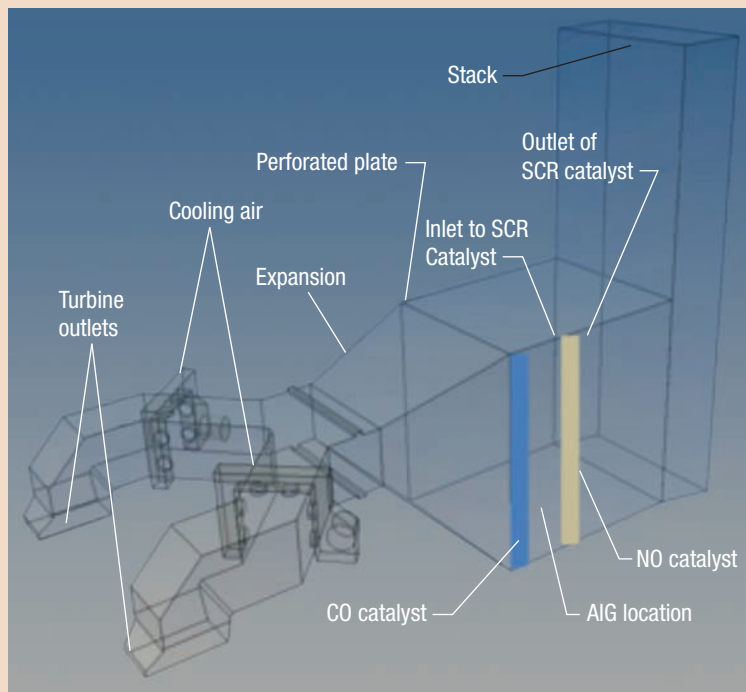
Most systems also include large particle ash (LPA) screens upstream of the SCR. In many but not all coal-fired boilers, large particulate ash (commonly known as “popcorn ash”) exits with the flue gas. This ash will quickly foul the top catalyst layer and choke flow. Because the possibility of popcorn ash is impossible to predict, incorporating LPA screens in the design is a recommended proactive decision. However, selecting and installing LPA screens should not be taken lightly. Screens can fail within a short period of time due to mechanical destruction from fast moving flue gas. A rule of thumb is to keep the linear flue gas flow rate below 70 feet per second at the screens.¹

The two most popular choices for on-line catalyst bed cleaning of fly ash are sootblowers and sonic horns. Sootblowers may be air or steam driven. Sonic horns are activated by plant air and, as their name implies, produce sonic waves to dislodge ash. Both systems have enjoyed success and failure, depending upon circumstances. Sonic horns must be well insulated to prevent the horn diaphragms from freezing in winter and also to minimize the possibility of acid dew point excursions in cool areas. In situations with poor flue gas flow characteristics to the catalyst beds, excessive localized ash buildups may defeat the actions of sootblowers or sonic horns.

Monitoring SCR Performance

No chemical reaction is ever 100 percent complete and this is true of SCR. A properly operating system will remove 90-plus percent NO_x , but the remainder escapes.

Figure 3 CO AND SCR CATALYST ARRANGEMENT FOR COMBUSTION TURBINE EXHAUST TREATMENT



Source: Fuel Tech

Similarly, a small amount of ammonia will pass un-reacted through the catalyst beds. Typically, systems with new catalyst beds are guaranteed to have an ammonia slip of less than 2 parts-per-million (ppm). As the catalyst becomes poisoned with metals and fouled with fly ash, ammonia slip will increase. Periodic flue gas testing by a reliable firm will reveal any increase in ammonia slip. Likewise, increased ammonia feed to obtain required NO_x reduction indicates a loss of catalyst efficiency.

Fly ash fouling will manifest itself by an increase of differential pressure (DP) through the catalyst beds. For the system outlined in Figure 2, DP monitors were placed between each catalyst bed so that operators and technical staff could evaluate the cleanliness and sonic horn cleaning efficiency of each bed. In this case, the top bed fouled much more quickly than the two lower beds. In fact, fouling reached an extent that utility personnel replaced the top layer of honeycomb catalyst with material of a larger pitch and are looking at retrofit installation of gas flow straightening vanes.¹

Common in SCR design is a small removable catalyst block installed in each layer. This can be extracted during outages and shipped to the catalyst manufacturer for analysis. A reputable vendor will be able to determine loss of catalyst efficiency, the causes behind degradation and if the catalyst can be regenerated. If the catalyst is not severely fouled,

regeneration is possible with savings to the owner. Regeneration may restore up to 90 percent of the catalyst’s original capacity.

SCR for Combustion Turbines

NO_x emissions requirements for simple and combined-cycle plants are in the single-digit parts per million range. Water injection into the combustion turbine to lower combustion temperature is one method to reduce NO_x , but SCR is often required. In simple-cycle applications, the SCR must be located at the furthest downstream location, where air injection may be used for cooling or where a high-temperature catalyst is employed. The choice involves tradeoffs between catalyst efficiency, cost and catalyst life. Often, the SCR catalyst is placed downstream of a catalyst layer designed to oxidize carbon monoxide (CO) to carbon dioxide (CO_2). For combined-cycle units, the SCR is placed within the heat recovery steam generator (HRSG) flow path, where temperature has been reduced by heat transfer through some of the HRSG superheater and reheater circuits. As with simple-cycle design, a CO catalyst bed is often located upstream of the SCR catalyst.

One industry expert pointed out important aspects of SCR design in these applications.

SCR catalyst downstream of simple or combined-cycle units [does not have to] deal with catalyst poisons in the fuel. The cata-

lyst deactivation is very low and the catalyst lifetime long. The challenge [for] this type of SCR system [is] the low emission limits. New air permits call for 3 ppm NO_x and NH₃ concentrations. The flow distribution, ammonia injection grid design and catalyst seals must be flawless to achieve this. CFD is becoming extremely important to design [for duct] expansion from the turbine outlet, where the gas velocity is greater than 700 feet-per-second to the cross-sectional area of the catalyst [inlet, with a common linear flow rate of] 20 feet-per-second.²

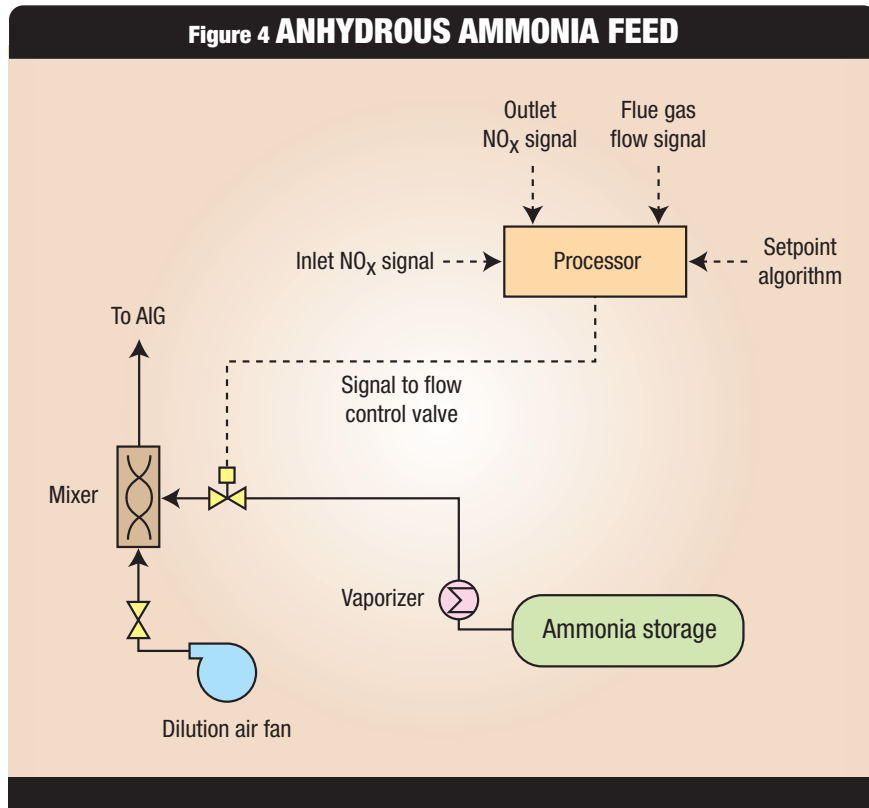
Ammonia Handling, Production and Storage

The least expensive form of ammonia is the anhydrous product. However, stringent safety and monitoring guidelines must be followed. Preparing the required documents and securing approval from regulatory agencies requires considerable effort on the part of plant personnel. The process may take up to a year or more. Most common is for anhydrous ammonia to be stored in long, horizontal tanks known as “bullets” up to 60,000 gallons in size. Before the ammonia enters the SCR it is warmed in vaporizers to prepare it for transport to the AIG. Figure 4 illustrates a common control schematic for ammonia feed control. The three primary feedback control points are inlet NO_x, outlet NO_x and flue gas flow. A computer algorithm monitors and balances all data feeds and adjusts the ammonia injection accordingly.

At plants in urban areas, community regulations often ban the use of anhydrous ammonia. A popular alternative is 19 percent aqueous ammonia. This material is safer to handle than the anhydrous version, but the primary drawback is that the plant is paying to ship 81 percent water. In some cases, even aqueous ammonia is considered too hazardous and ammonia is produced on-site by a urea (H₂N-CO-NH₂) thermal or hydrolysis decomposition procedure. This process, which is more expensive than anhydrous or aqueous ammonia feed, has the advantage of not requiring on-site ammonia storage.

Alternatives to Stand-Alone SCR

Alternative scenarios to stand-alone SCR may be cost effective at some sites, particularly when considering the potentially high operations and maintenance costs of using



ammonia or urea. One logical consideration for plants not already so equipped is installation of low-NO_x or ultra-low-NO_x burners to lower nitrogen oxide levels at combustion. Of course, any change in the combustion and firing pattern could influence fire-side waterwall tube corrosion and this issue must be considered. Another possibility is selective non-catalytic reduction (SNCR), where urea is injected into the upper furnace. While not as effective as SCR, the combination of low-NO_x burners and SNCR can reduce a significant amount of NO_x. Carrying this scenario farther is the potential combination of low-NO_x burners, SNCR and SCR with a single catalyst layer.¹ Any ammonia not consumed in the SNCR process will be used by SCR, thus providing efficient NO_x removal without a full-blown SCR unit.

SCR and the other techniques have become proven techniques to remove NO_x from steam generator and combustion turbine flue gas streams. Like other industrial processes, care must be taken in the design, construction and operational phases of these technologies to ensure that they perform properly. **pe**

References

1. Dale Pfaff and Volker Rummenhohl, *Fuel Tech. On-site meeting, June 2011.*
2. Personal correspondence with Volker Rummenhohl, *Fuel Tech, July 2011.*

Author: Brad Buecker is a contributing editor for Power Engineering and also serves as a process specialist with Kiewit Power Engineers in Lenexa, Kan. He has over 30 years of experience in, or affiliated with, the power industry, much of it in chemistry, water treatment, air quality control and results engineering positions with City Water, Light & Power in Springfield, Ill., and Kansas City Power & Light Co.'s La Cygne, Kan., station. He has an A.A. in pre-engineering from Springfield College in Illinois and a B.S. in chemistry from Iowa State University. He has written many articles and three books for PennWell on steam generation topics. He is a member of the ACS, AIChE, ASME, and NACE. He is also a member of the ASME Research Committee on Power Plant & Environmental Chemistry, the program planning committee for the Electric Utility Chemistry Workshop and the program planning committee for Coal-Gen.

Reprinted with revisions to format, from the November 2011 edition of *Power Engineering*
Copyright 2012 by PennWell Corporation

Get the best of both worlds



Increase your efficiency and reduce your emissions

Fuel Tech designs programs and systems to meet our customer's specific needs. Our TIFI® Targeted In-Furnace Injection™ programs have been proven to improve boiler efficiency, provide greater fuel flexibility and reduce emissions while providing a positive economic return. Our NO_x reduction systems provide flexible solutions by combining combustion and SNCR technologies with our ASCR™ Advanced SCR systems to rival traditional SCRs at a fraction of the cost.

We understand your needs and the challenges of the world today. With over 20 years of experience, we're ready to provide you with the customized approach that's best for you. Contact us today or visit our website for more information.



www.ftek.com • (US) 800.666.9688

(China) 86.10.8487.1742 • (Italy) 39.0331.701110

27601 Bella Vista Parkway • Warrenville, IL 60555

© Fuel Tech, Inc. TIFI® Targeted In-Furnace Injection™ and ASCR™ are registered trademarks of Fuel Tech, Inc.