

NOx Control Technologies: Focus SNCR

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Presentation Summary

Selective non-catalytic reduction (SNCR) has been successfully applied to a very wide range of fuels. During the past decade Fuel Tech has enabled clients in a various industries to meet permit requirements for NOx control in more than 250 commercial applications. Powder River Basin (PRB) coal is an environmentally attractive fuel by virtue of its characteristically low sulfur and fuel nitrogen content. When fired in advanced combustion systems very low emissions are achievable. Even from low baseline NOx emissions SNCR can generally achieve further reductions.

Temperature, residence time, and furnace CO conditions are the main determinants of SNCR performance. Fuel Tech's chemical kinetics model predicts performance from a reaction set comprising more than 31 species in 93 reactions. Figure 1 is a typical plot of results from the model for a NOx baseline condition of 200 ppm. The reaction "window" is shallow at high temperatures. However, more than 90% reduction can be achieved given ample residence time at optimal temperature. Such conditions are found in applications such as municipal waste combustors. Combustion conditions that cause elevated levels of CO in the upper furnace result in a shift in the temperature window. The chemistry that leads to high CO produce conditions similar to increased temperatures. Power boilers normally do not have ideal conditions. Nonetheless, substantial reductions are possible. Very good SNCR performance is possible in units with generously sized furnaces combusting fuels that burn well.

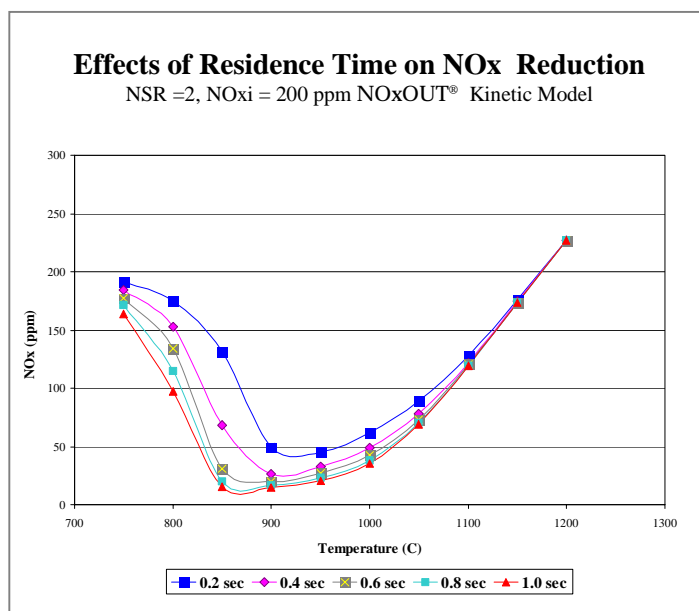


Figure 1

PRB coal can be difficult to use, particularly when switching fuel in a unit designed for another coal. PRB ash typically contains significant sodium levels and thus has low ash softening temperature. The fuel has high inherent moisture and oxygen contents, and lower heating values than for higher rank coals. As a result flue gas volumes per unit heat input are greater.

A furnace suitable for PRB will have features beneficial for SNCR. A generous surface to volume ratio is desirable to limit furnace exit temperatures and thereby reduce slagging problems in the high temperature convective sections. The adiabatic combustion temperature for the fuel is lower due to the higher gas volume per unit energy, when compared with bituminous coal for example. PRB tends to burn well, with low CO emissions. When compared with a unit designed for low volatile bituminous coal, for example, a PRB unit will have lower furnace exit temperature (Figure 2) and lower CO levels in the upper furnace.

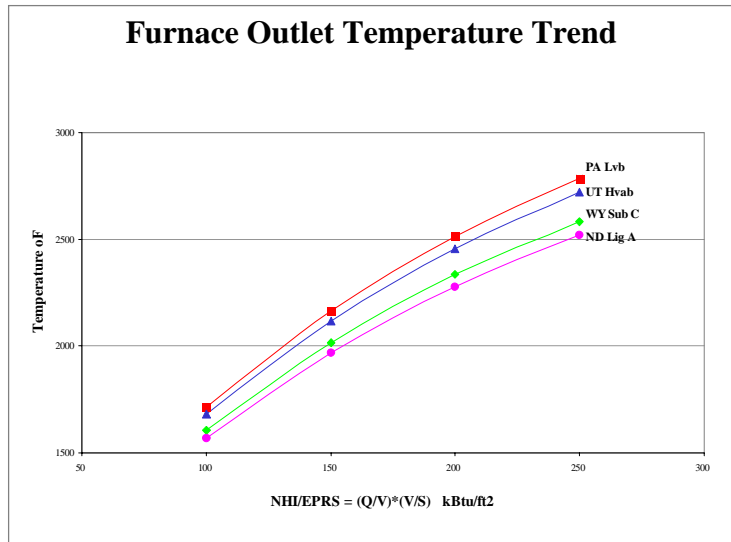


Figure 2

Post combustion reduction methods now offer a wide range of options to meet the needs of an individual situation. In 1985 Fuel Tech acquired the exclusive rights to two EPRI patents for urea based selective non-catalytic reduction. Fuel Tech has subsequently developed a full technology marketed as the product NOxOUT®. The technology comprises more than 40 patents, sophisticated computational design tools, specialized injection equipment, reliable chemical handling systems, and optimized control methods. SNCR offers NOx reduction at low capital cost and moderate operating cost. Relatively simple equipment is used to inject urea based reagent into the combustor. SNCR can be installed quickly with minimal impact on plant operations. Installed capital cost is typically in the 5-20 \$/kW range. NOxOUT® has been combined with other techniques, such as catalytic and reburning processes, to provide flexible options for meeting a wide range of NOx reduction needs.

NOxOUT CASCADE® is a combination of a redesigned SNCR and downstream selective catalytic reduction (SCR), hybridized to provide improvements in chemical utilization and overall NOx reduction. The two NOx reduction technologies each provide process strengths that make the hybrid combination more flexible and effective than the sum of its parts.

SNCR is typically limited to temperatures high enough to insure very low ammonia breakthrough. At very high furnace temperatures, however, performance can be lessened by competing reactions, which either consume effective chemical or lead to NOx formation. Modified SNCR takes advantage of a downstream “ammonia sink” by injecting chemical in cooler regions where NOx reduction and chemical utilization improve dramatically.

Selective Catalytic Reduction (SCR) is typically performed in much cooler flue gas passes where the oxidation potential of nitrogen species is minimized. The catalytic surface provides sites that permit the ammonia and NO_x to react at nearly complete utilization. The extent of NO_x reduction is limited by the local ammonia-to-NO_x ratio, flue gas temperature, and the size of the catalyst reactor. The catalyst size is limited by the available space and pressure drop constraints. PRB ash present problems for SCR catalyst. Alkali materials tend to poison the catalyst. High levels of calcium, while often injected to prevent arsenic poisoning with eastern bituminous coals, tend to foul catalyst with PRB.

Hybrid SNCR/SCR NO_x utilizes lower temperature SNCR injection to provide substantially improved NO_x reduction performance while generating somewhat higher ammonia slip. The ammonia slip feeds a small SCR reactor, which removes the slip and reduces NO_x while limiting the costs associated with a larger catalyst. For example, a CASCADE system which achieves 65% overall NO_x reduction (50% reduction with SNCR and an additional 30% SCR reduction) requires less than one third the catalyst required for 65% SCR reduction (Figure 3). The smaller catalyst decreases the pressure drop by the same fraction.

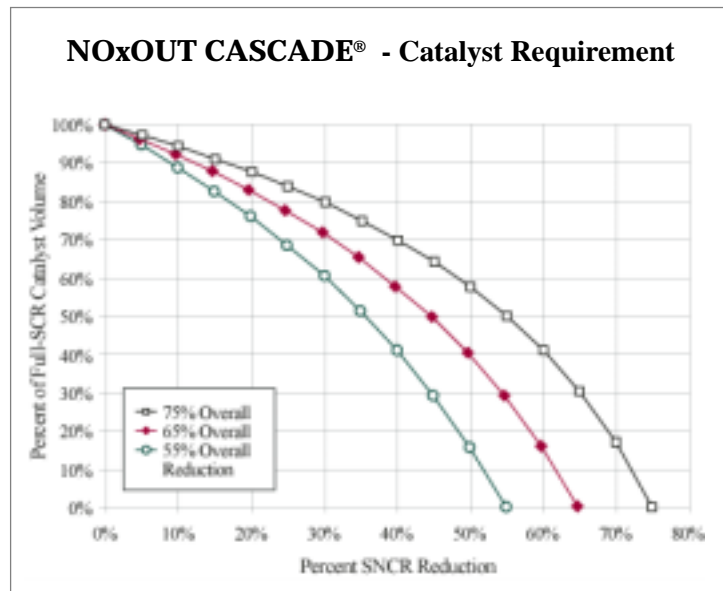


Figure 3

NO_xOUT CASCADE[®] achieves greater reduction while maintaining or even increasing chemical utilization at a modest increase in capital cost. The use of “in-duct” catalyst may allow installation with minimal plant modifications. Normally, existing induced draft fan capacity is adequate for the small increase in pressure drop with a small catalyst. A typical capital cost range is 15-25 \$/kW. With regard to chemical cost, achieving increased NO_x reduction at the same chemical utilization as for straight SNCR resists the law of diminishing returns. With a smaller catalyst than for full SCR catalyst replacement and disposal costs are minimized.

SNCR can be combined with reburning processes. Natural gas as a reburning fuel has recently become very expensive. However, Fuel Lean Gas Reburn (FLGR[™]) provides moderate levels of reduction with small amounts of reburn fuel. The amount of natural gas is controlled so as to maintain an overall fuel lean stoichiometry in the upper furnace. Natural gas injection is normally in the range of 7-10% of total heat input to the unit.

The chemical kinetic mechanisms of FLGR[™] and SNCR have similar selective reactions. The injection of natural gas in hot, low oxygen furnace gas results in the formation of hydrocarbon radicals (CH_i), and the injection of urea (NH₂-CO-NH₂) results in the formation of amine radicals (NH_i). Both of these radicals reduce NO to molecular nitrogen reactions.

The detailed chemistry is complex. The Gas Research Institute has developed GRI Mech 3.0¹. It computes the kinetics of 53 species in 325 steps to predict reburn performance. The temperature window is wide with a range of 1900°F to 2700°F under reducing conditions. With reburn sufficient fuel must be injected to produce reducing conditions. Oxygen is then reintroduced to complete burn-out. Computational fluid dynamics (CFD) tools provide information on the furnace conditions affecting the chemistry.

SNCR/FLGR achieves effective NO_x reduction under overall oxygen available, or fuel lean, conditions. Substantial cost savings are realized by avoiding the need for complex equipment and extensive boiler modifications for installing completion air. The injection of natural gas is limited to less than 10% of heat input in order to avoid the need for completion air. In many cases a NO_xOUT[®] system will already exist. It can readily be converted to provide the amine reagent.

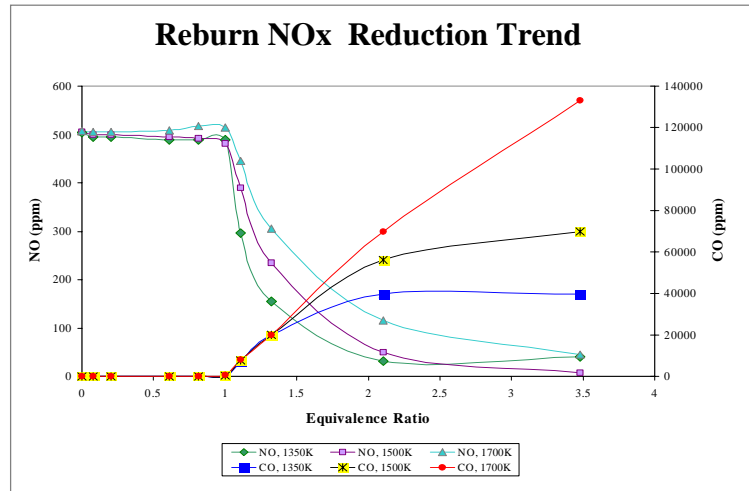


Figure 4

Empirical methods for capturing the chemistry can be effective. In Figure 4, the results of computations with GRI MECH 3.0 are shown. NO_x and CO emissions are plotted versus fuel-to-oxygen equivalence ratio, the inverse of the air-to-fuel molar ratio to stoichiometry, for three temperatures. The behavior is relatively simple to describe empirically when applied to the appropriate conditions. Separate calculation of detailed kinetics and experience from practice can be applied to calibrate the fundamental behavior.

Essentially nothing happens with regard to NO_x reduction when the equivalence ratio is less than stoichiometry. Heat release from natural gas raises the local temperature. This can result in NO_x formation even at stoichiometry when gas temperatures are already high. As conditions become locally fuel rich, NO_x reduction begins. CO also increases. When the equivalence ratio is between 1.1 and about 1.3 substantial NO_x reductions are achieved with modest increases in local CO. As the products with the local jets combine with the remainder of the flue gas much of the CO is eliminated. CO formation under fuel rich conditions tends to increase with increasing temperature.

SNCR/FLGR have been applied to several units. Specific to PRB, a demonstration program was conducted in 1999 at Wisconsin Electric's Pleasant Prairie Power Plant Unit #1². It is a nominal 600 MW Riley Reheat Type "ISR" Turbo Furnace steam generating unit fueled by Powder River Basis (PRB) coal. At full load, reductions of more than 50% were consistently attained. Baseline conditions were typically in the range of 0.42 to 0.46 lb/10⁶ Btu. As experience was gained, reductions improved. In the final testing NOx was reduced to 0.18 lb/10⁶ Btu. CFD modeling and temperature probing were performed to identify conditions within the unit. Data from the demonstration provides an additional basis for testing and validating advanced modeling techniques.

Computational fluid dynamics and chemical kinetics models provide a wealth of data for designing the system. The volume of data can be overwhelming. Fuel Tech has developed visualization tools that improve the speed and quality of decision making. Virtual Vantage™ software enables the designer to interact with the computational models in virtual reality. A design laboratory enables the designer to become immersed in the model. It is much like inspecting a boiler--but with the unit running. With conventional visualization techniques the view is determined by commands chosen by the user. The view is the result of an expectation. Often the user then sees what is expected. With Virtual Vantage™ the user "experiences" the working model. As with the field inspection, the user has the opportunity to notice the unexpected. Increased opportunities for problem solving result. Fuel Tech is now able to provide visualization services to outside clients.

References:

1. GRI MECH 3.0, Smith, G. P., Golden, D. M., Frenklach, M., Moriarty, N. W. , Goldenberg, M., Bowman, C. T., Hanson, R., Song, S. H., Gardiner, Jr., W. C., Lissanski, V., Qin Z. W., <http://www.me.berkeley.edu/gri-mech>.
2. Performance of Amine-Enhanced Fuel Lean Gas Reburn on a 600 MW Utility Boiler, Greco, R. A., Morris, E. L., Michels, W. F., Cardinal, T. A., and Houy, S., presented at Power-Gen 99, November 31- December 3, 1999, New Orleans, Louisiana.