NO$_x$ OUT CASCADE®
NO$_x$ Reduction Process

The NO$_x$OUT CASCADE® process is a multistage system, employing both urea-based Selective Non-Catalytic Reduction (SNCR) and a small Selective Catalytic Reduction (SCR) component.

TECHNICAL BENEFITS

- NO$_x$ reduction capability of 90%
- NO$_x$ OUT CASCADE® systems may be implemented in stages to achieve current and future compliance, delaying capital costs until required
- Process allows system operator to tailor operating costs to need
- System may be operated to provide varying NO$_x$ reduction to achieve peak reductions during ozone season and lower reductions for the balance of the year, or operated to achieve averaging goals with shorter time spans
- Low capital cost; usually employs existing ductwork and does not require a separate reaction chamber
- Same cost effectiveness range as NO$_x$OUT process
- No ammonia injection grid required or handling and storage issues

The NO$_x$OUT CASCADE® process integrates a special urea-based, in-furnace SNCR process with a compact back-end catalyst (SCR) module that is much smaller and less capital intensive than full SCR designs. NO$_x$ reduction can reach 90%, and efficiency of the chemical reagent usage is much improved over conventional SNCR processes.

The core of NO$_x$OUT CASCADE® is the widely used NO$_x$OUT® process that uses targeted in-furnace injection of stabilized urea reagent to react with NO$_x$ from the combustion process. At the back-end of the boiler, ammonia produced by an engineered excess of reagent reacts in a compact catalyst module with the remaining NO$_x$ for deeper reduction.

A NO$_x$OUT CASCADE® system may be installed complete or in stages to let the user keep pace with tightening regulations in the most cost effective way while both minimizing and avoiding capital investment until required.

Conventional Urea SNCR

It is well established that NO$_x$ reduction using the NO$_x$OUT® process occurs over a temperature range of ~1600 – 2200°F. In a conventional application of the process, the system would be designed to reduce NO$_x$ to the target levels and limit the production of ammonia (NH_3) to a relatively low range of 2-10 ppmv. As a stand-alone process, NO$_x$OUT® is designed to operate on the "Right Side of the Curve" shown in Figure 2. This scenario is not ideal for NO$_x$ reduction, but does minimize NH_3 slip, which is especially important for electric utility units using high sulfur or chloride fuels.

Figure 1: *The NO$_x$OUT CASCADE® Process*

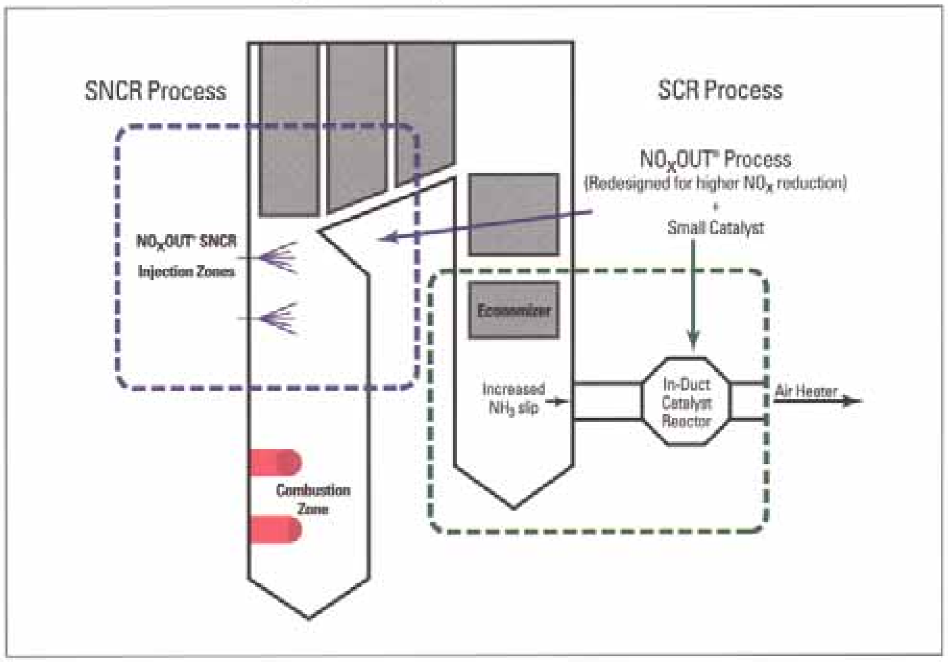

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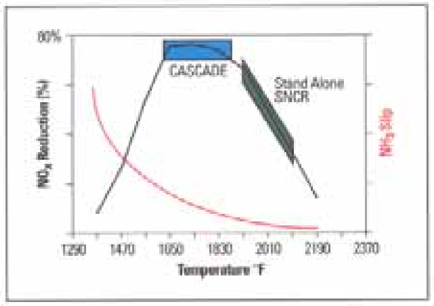
Figure 2: *NO_xOUT CASCADE® Process vs. Stand-alone SNCR*



There are many factors that must be considered in the design of a SNCR project. They include: boiler configuration, flue gas temperature and velocity, chemical distribution and residence time, presence and concentration of individual gas species (especially CO, NO_x, & O_2), pressure profiles, and possible reagent injection points and characteristics.

Fuel Tech uses two types of sophisticated and continuously improving computer models to ensure optimum real world performance of the finished design, and to provide for process guarantees. Computational Fluid Dynamics (CFD) uses the specific geometry and operating conditions in the unit to predict combustion and flue gas characteristics under different load and operating conditions. Examples of CFD results are the temperature profiles shown in Figures 3 & 4.

Chemical Kinetics Modeling (CKM) takes this information to the next level by combining reaction kinetics with the CFD information to predict the best temperature window for NO_x reduction with limited ammonia slip. Once this temperature window is identified, injection points and patterns are added and evaluated.

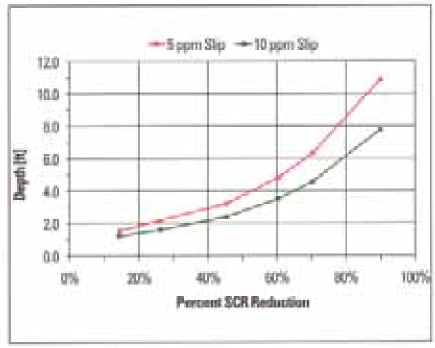
The optimized locations at two different loads can be seen in Figures 3 & 4. Finally, the combination of CFD & CKM is used to predict the NO_x reduction and ammonia slip expected in the actual application.

NO_xOUT CASCADE®

If the NO_xOUT® reactions are designed to take place in the plateau zone of Figure 2 (1650 – 1900°F), NO_x reduction may be dramatically improved, but ammonia slip rises. We can take advantage of this fortunate condition by installing a compact catalyst bed in the back-end section that can use this excess ammonia to further reduce NO_x. Since the catalyst only has to remove a portion of the NO_x being produced, it is significantly smaller and less capital intensive than a full SCR system. Figure 5 shows how increasing the reliance on SCR for removal increases the depth of catalyst required for a 320 MW utility boiler firing coal.

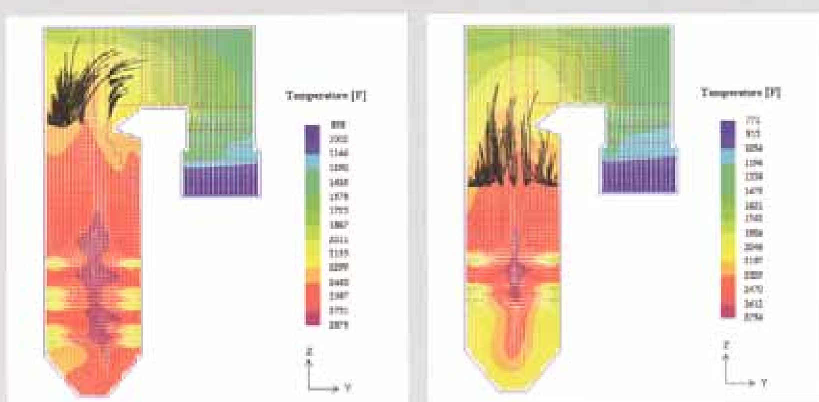
This combination of SNCR and SCR technologies can provide a remarkable combination of flexibility and cost effective design to address the changing needs of industry.

Figure 5: *Percent SCR Reduction*



Figures 6 & 7 show two ways that the back end of the boiler can be modeled to optimize SCR design and provide assurances that the system will work as designed. Figure 6 shows the CFD model of the back end to track gas velocities and distribution. To address questions of the addition of heat recovery equipment to the already complex model, physical Cold Flow models (Figure 7) can be built to broaden our assurance of real world performance.

Figure 3 & 4: *NO_xOUT CASCADE® Temperature Profiles*



Temperature Profile - Full Load *Temperature Profile - 66% Load*

Figure 8 can be used to calculate the fraction of full-scale SCR catalyst reduction needed to achieve the desired level of NO_X reduction. For example, if the compliance goal is an overall reduction of 55% and SNCR alone achieves a 40% reduction, the catalyst volume necessary to achieve the total reduction is only 40% of a full SCR system. The capital outlay will be significantly reduced, as will the volume of replacement catalyst required over time.

The NO_XOUT CASCADE® process from Fuel Tech can provide a cost-effective solution for operators of utility boilers faced with compliance planning.

***Figure 8:** NO_XOUT CASCADE® Fraction of Full-Scale SCR Catalyst Volume Needed to Achieve the Specified Reductions*

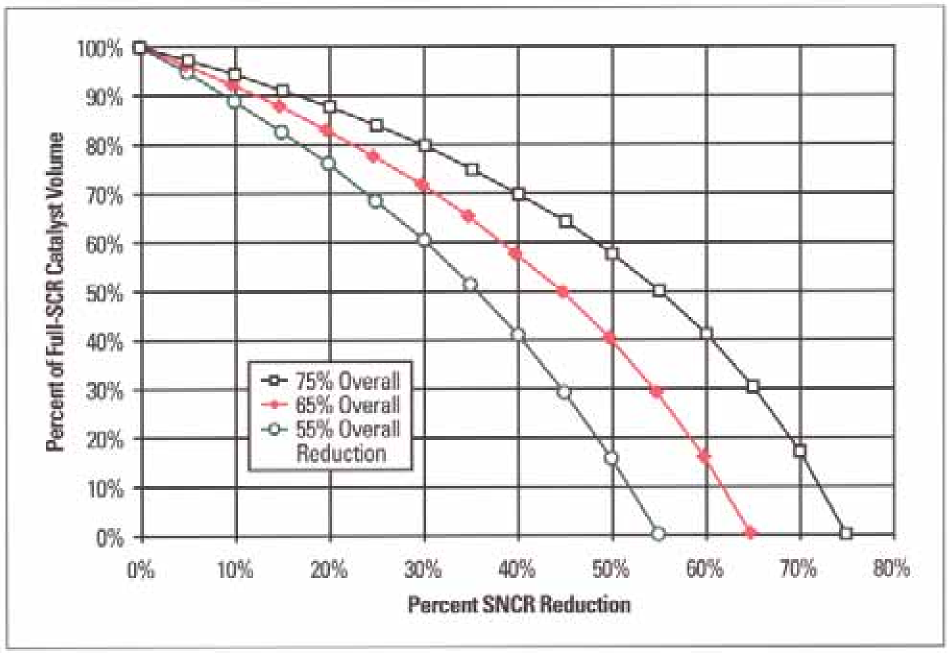
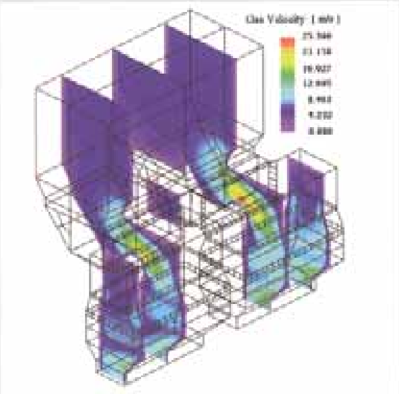


Figure 6



Computer model of back-end gas velocities through the Cascade Catalyst are used to insure proper operating conditions

Figure 7

Physical 1/6 scale models of the same back-end geometries were used to provide additional assurance to the customer

For more information on NO_x reduction programs
available from Fuel Tech, call, fax, or write us at:

Fuel Tech, Inc. • 512 Kingsland Drive • Batavia, IL 60510
Phone 800.666.9688 • 630.845.4500 • Fax 630.845.4501
www.fueltechnv.com • webmaster@fueltechnv.com

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