Coal-Fired SCR Applications in the US – Challenges and Strategies for Successful Operation and Emission Compliance

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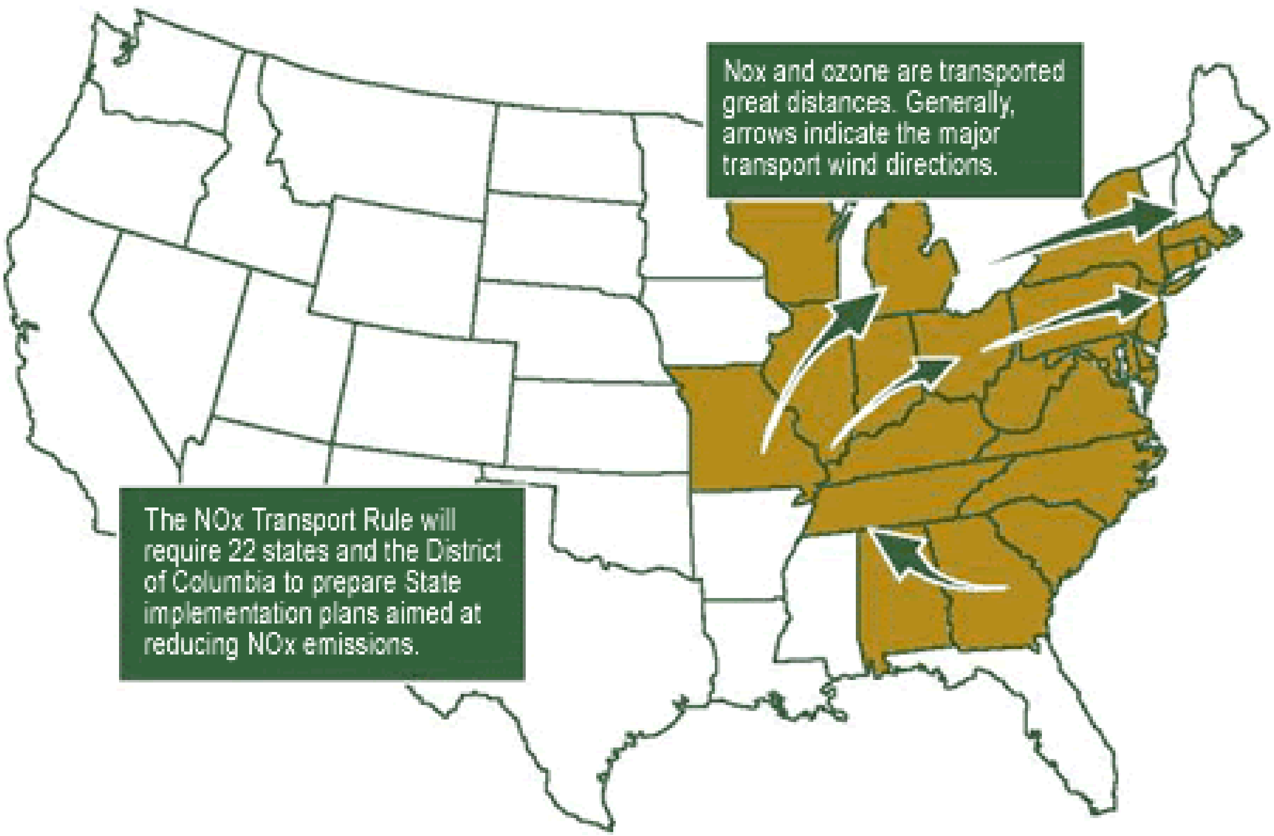
Introduction

The United States is the third major region to implement Selective Catalytic Reduction (SCR) technology on coal fired utility boiler applications, after Japan and parts of Europe. Several SCRs were installed in the US in the early/mid 1990s, and the majority of the SCR currently in operation in the US were installed between 1999 and 2003. Utilities are continuing to retrofit existing boilers with SCR as well as installing SCR on new boilers that are currently in construction. There are many aspects of operation of SCR in the US that differ from the historical experience; this includes regulatory drivers, fuels and owner/operators’ approaches to meeting emissions goals. This paper addresses the key considerations, both SCR catalyst and SCR system related, for successful operation in the diverse US market.

US Regulatory Drivers and Background

It has long been determined that ozone smog can lead to public health issues, and NOx is considered to be the main pollutant that is responsible for the formation of ground level ozone. The US Federal Clean Air Act (CAA) was first enacted in 1963 and has undergone several amendments throughout the years. Although the original CAA and subsequent amendments targeted multiple pollutants, the focus herein is primarily related to nitrogen oxides or NOx. Provisions of the CCA amendments of 1990 resulted in significant reductions in NOx. Specifically under Title I of the act, geographical locations that did not meet National Ambient Air Quality Standards (NAAQS) were required to reduce NOx as the primary means of reducing ozone. Large emitters of NOx in the eastern US were most affected by this change to the Clean Air Act. In the 1990’s, many large coal fired steam generators were retrofitted with low NOx burners and over fire air technology in order to comply with these new rules.

During the summer months, many areas located in the eastern half of the US are impacted by ozone smog, although the source of the pollution may not be proximate to the location of the areas that are most affected. Large populated areas located in the eastern US are directly impacted by pollution that is generated by industry sources located in the Midwestern US region. In order to reduce interstate transport of NOx to regions of the US that have difficulty maintaining ozone levels per the NAAQS, in 1998 the Environmental Protection Agency (EPA) applied additional rules to 22 eastern states that required further reduction of NOx emissions from May 1st to September 30th (See Figure 1). This period of time is known as the "ozone season". The EPA rule, known as the "NOx SIP Call" [SIP stands for State Implementation Plan] required that individual states develop plans for complying with tighter seasonal NOx emissions requirements. Implementation of the plan was in 2003 and 2004. The EPA's NOx emissions budget was in part derived from a NOx emissions rate of 0.15 lb/MMBtu of fuel input for electric generating units greater than 25 MW. Rather than taking a "command and control" or rate based approach where every generating unit is required to meet this emission level, the NOx budget program provides flexibility with achieving the overall emissions goals and utilizes a "cap and trade" market based approach. As a result of the NOx SIP Call SCR units were added on coal fired units totaling approximately 85 GW of power generation [72 to meet the NOx SIP Call and 13 for state multi-pollutant regulations].

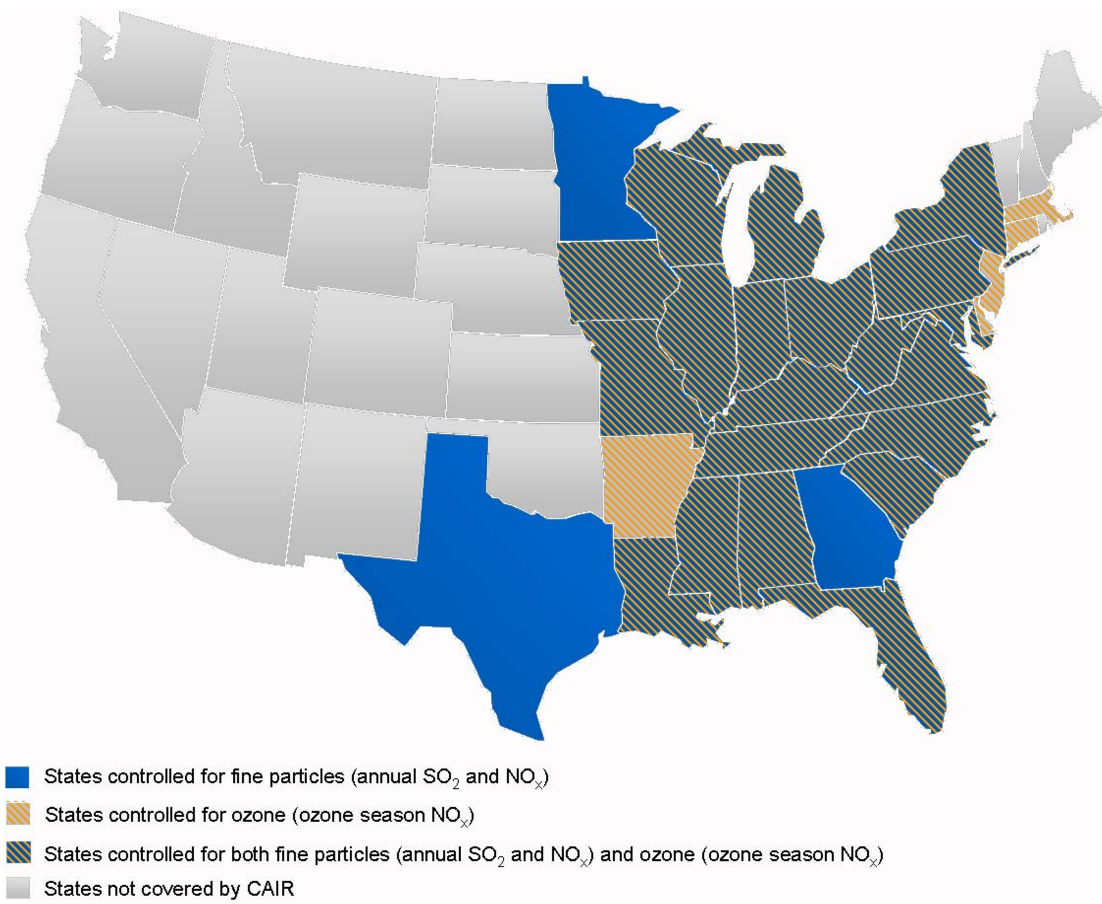


Source: United States Environmental Protection Agency[1]

Figure 1

Today the Clean Air Interstate Rule (CAIR) puts into place additional directives that will result in further overall reduction of NOx emissions by expanding the geographical region of compliance and lowering source NOx emissions (See Figure 2). Under this plan each state has an emissions budget and can decide which sources to control in order to meet the budget; this is also a cap and trade based program. CAIR is a two-phase program with compliance deadlines in 2009 and 2015. The total annual caps for power plant NOx emissions for the two deadlines are 1.5 million tons (US) and 1.3 million tons (US) respectively.

Along with CAIR is the Clean Air Mercury Rule (CAMR) which is also a two-phase program targeting mercury emission from coal fired power plants. This rule may affect operation, design and management of SCR systems and catalyst as the catalyst has been proven to oxidize Hg such that it can be captured in downstream air pollution control equipment.



Source: United States Environmental Protection Agency[2]

Figure 2

It should be noted that the EPA sets minimum standards. State and local governments have the option of making the standards more stringent than the federal EPA mandates.

"Ozone Season" and Year-Round Operation of SCR

As described previously, most coal-fired SCR units are currently required to operate only during the NOx ozone season from May 1st to September 30th of each year. This leads to unique considerations associated with SCR catalyst and SCR system design, operation, and maintenance.

Most SCR systems that are required to operate on a seasonal basis are designed with an SCR bypass system configuration. The ductwork, dampers and controls required for such a system adds significant complexity and cost to SCR system, but provide operational flexibility to the SCR unit. During the non-ozone season, the ammonia injection system is brought off line and flue gas is bypassed around the SCR. In some cases, the SCR isolation dampers are considered to be man-safe, and routine maintenance is performed while the boiler remains in operation. In other cases, access to the SCR requires that the boiler be shut down. During the prolonged shut down it is advised that the catalyst and SCR reactor box be in a clean condition. Cleaning entails a combination of vacuuming and air blowing to remove ash from all catalyst surfaces. Cleaning of surfaces above the catalyst is also critical in order to prevent ash from falling onto the catalyst during the lay-up period. These surfaces include turning vanes, sootblower lances, catalyst support beams and any other area where ash has accumulated. While the SCR is accessible, catalyst samples are removed and tested as part of the catalyst management protocol. It is common that catalyst is designed for an initial lifetime of 16,000 operating hours, or approximately four ozone seasons.

Ammonia process equipment such as anhydrous and aqueous ammonia vaporization systems and rotary equipment such as pumps and blowers must be properly decommissioned and maintained throughout the non-ozone season.

To comply with the upcoming CAIR rules, it is anticipated that coal-fired utility boilers will be required to operate their SCR on a year-round basis beginning in 2009. Many of the new SCR units being built do not include SCR bypass systems. On units that have SCR bypass systems, this change will affect utilities' catalyst management strategies as the catalyst lifetime will effectively be cut in half. This increased operation of SCRs will result in fewer opportunities for monitoring catalyst performance. Furthermore, the ageing catalyst factor, along with the regulatory and operational considerations of managing an SCR system, means that power plants have to consider a comprehensive catalyst management strategy that accounts for a wide range of traditional and new variables with a goal of achieving an optimized solution. Some of these variables include:

- Projected plant outage schedules & demands
- Boiler/SCR operations assessment
- System inspections & field sample data analysis
- Fuel management & flexibility
- NOx Performance & SO_2 Conversion objectives
- Cost of NOx credits & capital budgeting
- Mercury oxidation
- Catalyst technology advancements, and
- Integration with multi-pollutant control (NOx, Hg, SO3) programs

Shown below in Figure 3 is a typical catalyst management graph showing declining catalytic potential and corresponding increasing ammonia slip over time.

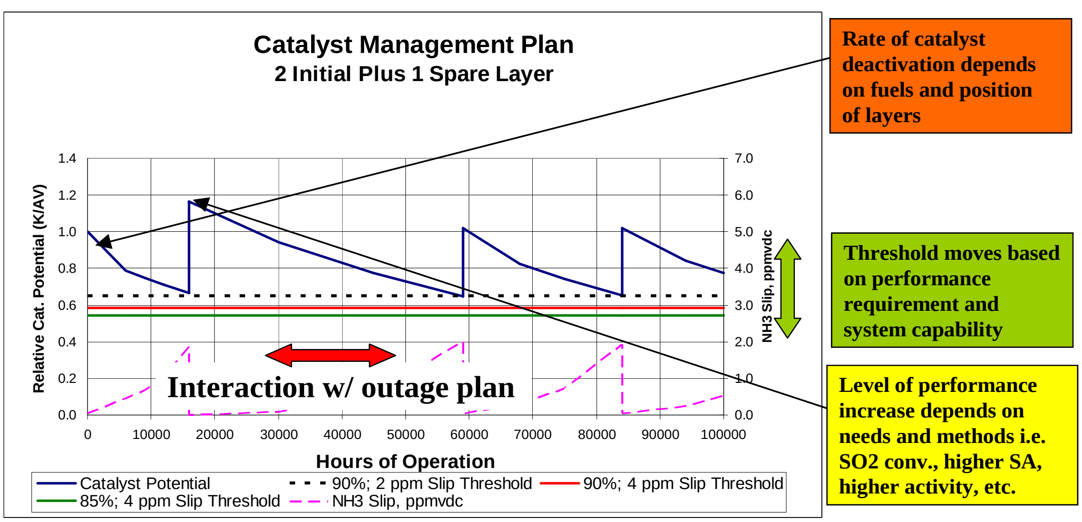


Figure 3 - Sample Catalyst Management Plan

In addition to managing the life/performance of the catalyst, there are various "mechanical" factors associated with changing operation of the SCR system to year round. Although these items are logical and relatively straight forward, they nonetheless require attention.

- The SCR system must be at least a reliable as the boiler
    - SCR units that have had histories of ash plugging due to flow maldistributions or carryover of large particle ash may need to implement longer-term solutions to reach scheduled boiler outages
    - Units that fire fuels that lead to rapid catalyst deactivation rates will need to manage catalyst accordingly
- Year round procurement and handling of ammonia
- Operation of ammonia process equipment, which in many cases is located outdoors, during the winter months

High Performance Operation

Most individual boilers in the US are not required to meet specified rate based emissions levels i.e. units are not subject to a command and control or rate based approach. In most cases, an electric utility has an emissions limit for a period of time, and they manage the operation of their fleet of steam generators to achieve their overall emission goals. Due to NOx budget programs and cap & trade provisions, power producers oftentimes operate their SCR to achieve higher levels of performance than had been done historically on units that met rate based requirements. For instance, a power producer who operates multiple coal fired units may choose to install SCR on a select few larger units that are base loaded. Alternate, lower capital cost NOx control technology such as SNCR and low NOx burners can be applied to smaller units that operate with lower capacity factors. By designing and operating these SCR to achieve high levels of NOx removal, they achieve their overall NOx emissions requirements. Additionally, under the cap and trade program NOx allowances can be accumulated (banked) to be used at a later time or they can be sold. It is common for units to be designed for NOx removal efficiencies of 90%, and operate at efficiencies that are greater than the design value. As catalyst performance guarantees are defined to be those associated with the end of a specified lifetime, SCR catalyst that is early in its functional life has considerably higher capability. As an example, catalyst that is designed to achieve 90% NOx removal and 2 ppm ammonia slip after a lifetime of 24,000 operating hours will operate with virtually no ammonia slip at the beginning of its life. Given this capability, the unit can be operated above its design NOx removal efficiency, with the upper threshold being driven by the SCR system design. These high performance design consideration include:

- Design of an ammonia injection grid or ammonia mixing system to achieve very good ammonia/NOx distribution at the catalyst; 5% RMS maldistribution of NH_3/NOx or better to achieve 90+% NOx removal efficiency while maintaining NH_3 slip <2 ppm.
- Design of ductwork and flow correction devices to achieve even flow and temperature profiles.
- Installation of proper catalytic potential (K/AV) in the SCR system to enable high NOx removal efficiency and low NH_3 slip. Additionally the catalyst should be formulated to control SO_3 conversion and can be designed to maximize oxidation of elemental mercury.

Maintaining the SCR in well-tuned condition is critical to high performance. The effectiveness of an SCR system is dependent on satisfying the design criteria of uniformity for velocity and NH_3/NOx distribution at the catalyst inlet. The NH_3 /NOx ratio uniformity has a profound effect on SCR performance with maldistribution of NH_3/NOx affecting not only NOx reduction but also the extent of NH_3 slip. Tuning of the AIG to obtain an even ammonia-NOx molar ratio distribution at the catalyst minimizes ammonia slip, system fouling and undesired chemical reactions. Proper tuning ensures better system efficiency, proper ammonia distribution and improved catalyst life. The process also eliminates localized regions of high ammonia slip which can lead to air preheater (APH) fouling.

Figure 4 illustrates NH_3/NOx molar ratio and the effect on NOx removal and ammonia slip for a given design.

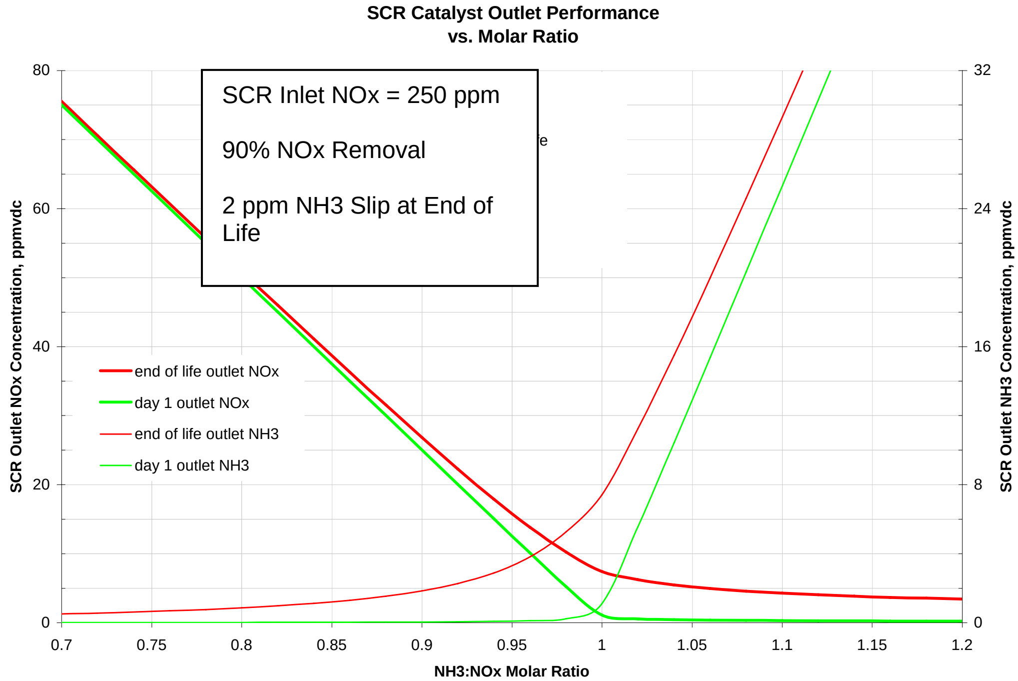


Figure 4 – SCR Performance vs. Molar Ratio

Figure 5 shows the effect of a NH_3/NOX distribution on NOx removal efficiency and ammonia slip. Wider distribution will make it more difficult to achieve the desired level of performance within the acceptable average and local ammonia slip.

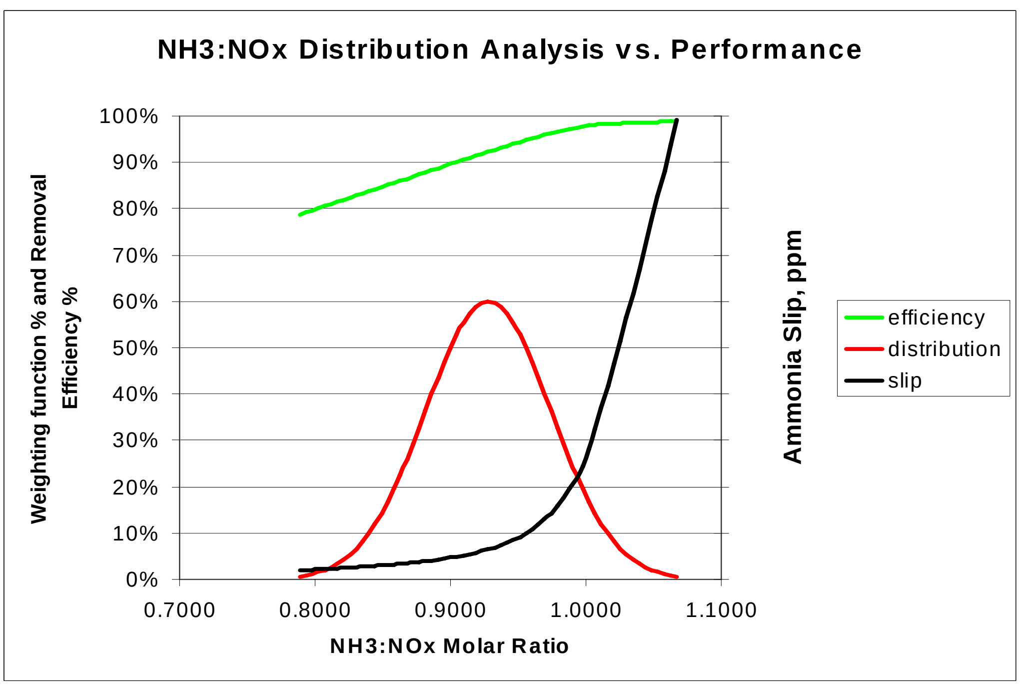


Figure 5 - Ammonia/NOx Distribution Analysis vs. Performance

Considerations for SO_3 and Mercury Control

The Clean Air Interstate Rule (CAIR) regulations that govern SO_2 emissions and the Clean Air Mercury Rule (CAMR) play a role in the design and operation of SCR.

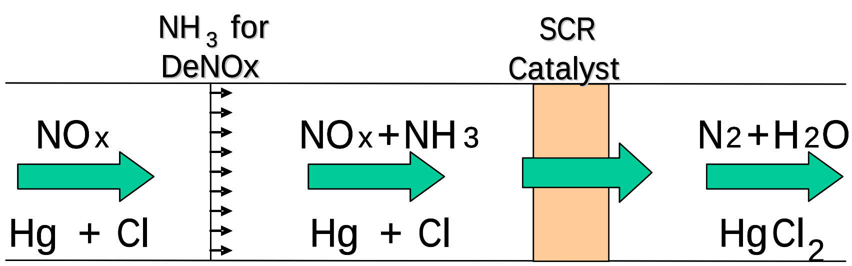
SO_3 Control Considerations - The CAIR rules that are to further regulate NOx are to also requiring further reduction in SO_2 emissions. It is estimated that an additional 64 GW of power will be retrofitted with FGD by 2015 as a result of CAIR. As utility boilers are retrofitted with flue gas desulfurization (FGD) units and firing high sulfur coals, the requirements for the SCR catalyst SO_2 to SO_3 conversion are becoming stricter. Historically, minimizing SO_2 conversion while maintaining high levels of NOx reduction were in conflict and in some cases could not be achieved. Focus has been put on developing additional catalyst product features to minimize SO_2 conversion while maintaining high catalyst activity yielding high NOx reduction capability with low ammonia slip. A method of achieving this balance has been through the application of product extensions that utilize advanced extrusion, product and materials know-how in combination with a well proven product base. The performance enhancement can, in some cases, achieve less than 0.1% SO_2 oxidation while maintaining all other key product performance and durability features. Use of the advanced SCR product may be exclusive or combined with other SO_3 mitigation techniques including; fuel switching, in-furnace mitigation with reagent, and pre/post APH mitigation with reagent.

The higher performance capability of the low SO_2 conversion catalyst relative to a conventional catalyst is due to greater open area, thinner catalyst cell walls, improved composition and geometry for strength. The design is optimized to reduce volume, pressure drop and SO_2 oxidation rate. Table 1 outlines the performance characteristics of the new product in comparison to the conventional catalyst in terms of relative catalyst volume, pressure drop and SO_2 oxidation. Two cases are shown to illustrate the alternative methods for utilizing the features of the high open area product.

	Product			Case 1		Case 2	
Product	Pitch	Opening (mm)	GSA (m^2/m^3)	Relative Volume Required	Relative Pressure Drop	Relative Volume Required	Relative SO2 Oxidation Required
Conventional	7.4	6.3	445	100%	100%	100%	100%
High Performance	6.9	6.3	539	75%	61%	100%	25%

Table 1: Advanced SO_2 Conversion Catalyst Performance Summary

Mercury Oxidation Considerations – The largest source of mercury emissions in the US is from coal-fired power plants. The EPA’s implementation of CAMR will reduce the emissions of mercury from 48 tons to 15 tons per year by the year 2018. SCR catalyst will oxidize mercury to varying degrees based on a wide variety of inputs including catalyst type, NH_3 concentration, temperature, HCl concentration, etc. The basic reaction process is described in Figure 6.



DeNO$_x$ and Mercury Oxidation Reactions

$NO + NH_3 + 1/4\ O_2 \rightarrow N_2 + 3/2\ H_2O$ (NO_x Reduction)

$Hg + 2\ HCl + ½\ O_2 \rightarrow HgCl_2 + H_2O$ (Hg Oxidation)

$HgCl_2 + NH_3 + ¼\ O_2 \rightarrow Hg + 2\ HCl + ½\ N_2 + ½\ H_2O$ ($HgCl_2$ Reduction)

Figure 6 - General SCR Chemistry for Hg Oxidation

Use of the SCR in combination with a wet FGD system can be an effective method for meeting Hg emission limits. Cormetech has worked with industry partners, EPA, and utilities over the last 3 to 4 years to develop and demonstrate know-how related to predicting and guaranteeing the level of Hg oxidation through its SCR catalyst. Figure 7 shows an example of actual field performance versus predictive models for aged SCR catalyst.

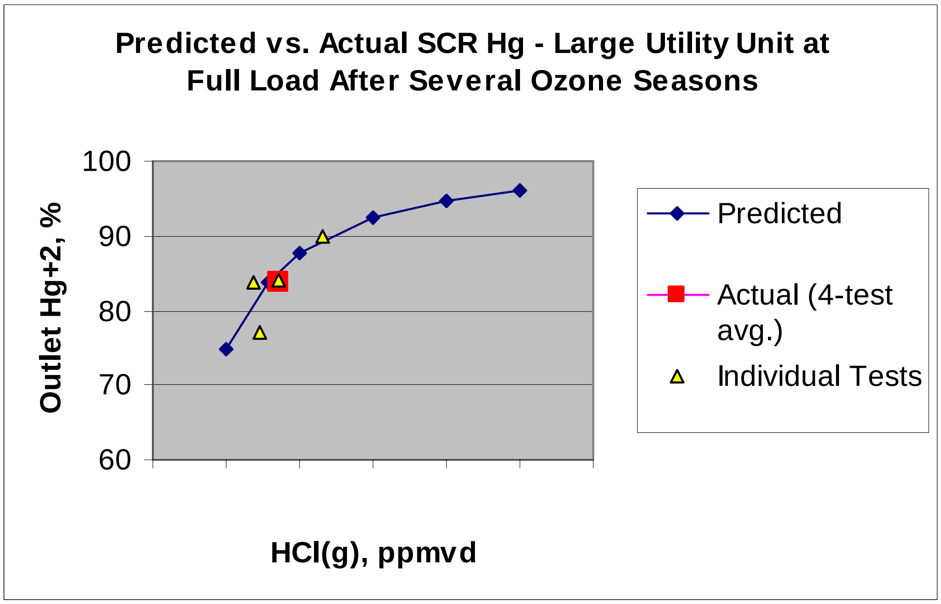


Figure 7 - Full Scale Hg Oxidation Results on Aged SCR Catalyst

Fuel Considerations

Coal fired power plants in the US have ready access to a wide range of coal sources and as a result, a wide range of fuel characteristics that the SCR system must contend. Plants located in the eastern US have predominantly utilized bituminous coals. Midwestern states have access to bituminous and sub-bituminous sources such as Powder River Basin coal (PRB). Western plants fire mostly sub-bituminous and lignite coals.

Operators who have been utilizing “compliance coals” containing lower sulfur levels will be expanding their fuel choices as they install FGD systems. As the units change coals, there may be an impact to the operation and management of the SCR system. This includes:

- Catalyst Deactivation Rate
    - Example: a change to the relationship between As/CaO/S may cause the catalyst deactivation rate to change
- Changes to the SCR process conditions
    - Inlet NOx – changes the catalyst volume requirement
    - Gas Flow Rate – changes the catalyst volume requirement, SO_2 conversion rate
    - Gas Temperature - can change the catalyst activity [catalyst volume requirement] and catalyst SO_2 conversion rate
- Catalyst Formulation for SO_2 conversion
    - Example: a catalyst formulated for a 1% sulfur coal may no longer be optimal for a 3% sulfur coal

As greenhouse gases become more of a concern, it is anticipated that coal units will co-fire biomass of various types to a greater extent. This will require that due diligence be paid to assess the impact on the SCR catalyst. Biomass covers a large range of potential fuels, and its effect on catalyst deactivation will need to be considered carefully

Conclusion

The design and operation of SCR units on coal-fired boiler applications has challenges that are unique to the US. The combination of regulations on multiple pollutants, seasonal and year round operation of SCR, market-based emissions budget programs, and diversity of fuel sources results in a complex matrix of considerations.

References

1. EPA's Effort to Reduce NOx. (n.d.). Retrieved May 1, 2007, from http://www.epa.gov/air/urbanair/nox/effrt.htm
2. Srivastava, R.K.. "Clean Air Interstate & Mercury Rules and Their Impact on Control Technology," presented to American Boilers Manufacturers Association; Washington, DC, June 2005.

About CORMETECH, Inc.

Cormetech was formed in 1989 as a joint equity company of proven industrial leaders: Mitsubishi Heavy Industries (MHI), Corning Incorporated, and Mitsubishi Petrochemical (MPC). Corning Incorporated is acknowledged worldwide as a leader in glass and ceramic processing technologies and in the automotive emission control field. Corning Incorporated’s ceramic honeycomb substrates are used in more than 50% of automotive catalytic converters worldwide. Mitsubishi Heavy Industries, Ltd. (MHI) is one of the world's leading heavy machinery manufacturers. Mitsubishi and its licensees have supplied over half the SCR systems used on utility and industrial boilers and combustion turbines worldwide. Cormetech’s catalyst technologies uniquely benefit from the ceramic extrusion technology of Corning Incorporated and SCR system design, engineering, and experience of MHI.

We leverage our parent companies’ solid base of more than 30 years of SCR experience and ceramic extrusion technology, to create innovative catalyst products and services that meet our customer’s needs. Our own experience approaches 14 years of providing our services to the industry. To date in 2007, we have supplied services and delivered operating catalysts worldwide for over 900 SCR systems, including 132 coal fired units, totaling over 100,000 MW.

Headquartered in Durham, North Carolina, USA, with sales offices in Europe and China, Cormetech has fully dedicated, state-of-the art manufacturing facilities, R&D centers and testing laboratories in Durham, North Carolina and Cleveland, Tennessee.