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Coal-Fired SCR Operating Experience with High Removal Efficiency and Low-No_x Firing Systems

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ABSTRACT

The NO_x credit market, system wide emission caps and environment concerns provide an incentive to design and operate Selective Catalytic Reduction (SCR) systems at the highest efficiency consistent with avoidance of operational risks, such as ammonium bisulfate formation. System-wide emission caps offer the incentive of meeting limits with a lesser number of highly-efficient units while avoiding capital costs and outages for SCR installation on other units. Operation at NO_x removal efficiencies of 90% or more requires stringent control of inlet gas uniformity, ammonia mixing, and ammonia injection rates, particularly for low-NO_x inlet conditions resulting from state-of-the-art low NO_x burner systems. This paper presents the design considerations for coal-fired, high-dust SCR designs with low outlet NO_x concentrations. Results from recent operating SCR systems, with low NO_x burner configurations, verify that outlet NO_x concentrations from 0.05 lb/MBtu to below 0.03 lb/MBtu can be achieved and sustained with current SCR technology.

INTRODUCTION

The combined SCR technology experience that is globally available has allowed for the development and continuous improvement of SCR technology. Outlet NO_x concentrations once unachievable, are now achieved with low ammonia slip and minimal plant impacts. The available NO_x control technologies have allowed the US government to tighten the permissible NO_x emissions and have allowed Utility companies to provide energy in an environmentally safe and health conscience manor. In addition to the regional health benefits to the local communities, power utilities are given incentive to exceed the goals the US government has set forth through the use of NO_x credits.

The application of high removal efficiency, high dust SCR systems on coal fired boilers with low NO_x burner systems requires careful attention to flue gas and ammonia mixing and reagent injection rate control. Current incentives, both financial and environmental, exist for the installation and operation of NO_x control systems which exceed the 2004 SIP Call of 0.15 lb/MBtu. The financial incentives include not only the NO_x credit trading market but also system wide emission caps allowing for the installation of fewer high removal systems to meet compliance emission rates. These incentives did not exist in the European market during the deployment of SCR technology. The European countries have substantial operating experience and proven SCR designs for the reduction and removal of NO_x emissions. However, due to regulations which required all European plants to be equipped with control technology and achieve an outlet NO_x emission of 0.19 to 0.08 lb/MBtu, depending on the country, the incentive for over compliance of NO_x emissions did not exist (1,2).

DESIGN PARAMETERS

The design of high removal efficiency SCR system centers on two main issues: 1) the ability to inject and distribute the reagent, typically ammonia, into the flue gas stream prior to the catalyst inlet surface and 2) the selection of the correct catalyst activity and deactivation rates. In addition the operating parameters of the boiler exit gas stream and future modifications to the boiler and fuels must be fully understood.

NH_3/NO_x Mixing

The correct mixing of the boiler exit flue gases with the ammonia reagent typically consists of two distinct mixing regions, before and after the ammonia injection. The combination of both mixing regions provides a low variation of the ammonia to NO_x mole ratio at the catalyst face. The ratio of NH_3/NO_x is the essential parameter for high removal efficiency SCR systems. The standard deviation of the NH_3/NO_x at the catalyst face is a typical measure of the mixing system's performance; for 90% removal systems a standard deviation of NH_3/NO_x mole ratio of 5% is typically chosen. The mixing of the flue gas stream from the boiler outlet before the ammonia injection is required to ensure the uniform distribution of NO_x to the catalyst face for all operating loads and conditions. Mixing systems before the ammonia injection location need to cross mix the boiler exit gases on a large scale, i.e. from side to side of the unit, to ensure uniform distribution during all operating conditions. It is important to note that if the NO_x concentration at the ammonia injection location varies with load or operating equipment selection (mill groups, etc.) then it is not possible to have a single ammonia injection distribution profile that achieves NH_3 to NO_x mole ratios at the catalyst face for all operating conditions. The inlet stream mixing requirement is determined based on experience and boiler outlet boundary conditions determined from the baseline test program. With the inlet NO_x mixing achieved prior to ammonia injection, the next requirement is to mix the ammonia into the flue gas stream prior to the catalyst face. The ammonia injection profile required to achieve the desired mixing is evenly distributed with proper upstream NO_x mixing. This even distribution of ammonia injection significantly aids the optimization period of the SCR system resulting in reduced commissioning and optimization periods. The mixing system is also designed to provide the temperature, flow angle and velocity distribution required at the catalyst face.

Catalyst Selection

Catalyst selection requires knowledge of both the current coals and boiler systems and future plans for fuels and boiler systems. The current and future coals of the plant are analyzed to determine the need for deactivation rate control such as limestone addition to minimize arsenic poisoning. If arsenic levels in the coal are not balanced with sufficient CaO in the fly ash undesirable deactivation may result. In order to control this balance, limestone addition systems are installed that add limestone to the coal during bunker loading. These systems can have variable speed addition rates to ensure catalyst protection for a wide range of fuels while minimizing limestone addition to protect against furnace and convective back pass slagging and fouling.

Additionally the conversion rate of SO_2 to SO_3 must be carefully specified to avoid undesirable plant and emission impacts. With the current understanding of SO_3 generation and capture, a prediction of the impact the SCR system will have on the plant and emissions can be made based on experience. Based on recent testing and correlations, most plants can be analyzed without extensive testing (3). If the SO_3 generation and capture characteristics of a unit are in question an SO_3 test program can be used to determine specific plant values. With the understanding of the specific plant SO_3 characteristics, the SO_2 to SO_3 conversion of the catalyst can be specified for the initial and final catalyst charges.

The boiler design parameters, flue gas flow rates, economizer outlet gas compositions and distributions, etc. are typically determined from detailed baseline test programs implemented prior to the design of the SCR system. These test programs typically include test matrices that determine a wide range of boiler operating conditions. While the baseline test program provides detailed insight on the characteristics of the unit, a measure of experience must be applied to the results. Using the data collected from the baseline test program and experience with similar applications, boundary conditions for the mixing system and physical flow model study are derived. These boundary conditions include low and part load conditions and plant conditions such as mill groups out of service. Consideration of plant operating conditions is essential for high efficiency across a load range.

DUKE POWER CLIFFSIDE STATION #5 OPERATING EXPERIENCE

Riley Power Inc. and Duke Fluor Daniel (DFD), as part of an SCR Program Alliance with Duke Energy, engineered, procured and constructed the first of three SCR projects for Duke Energy. Cliffside Unit 5 is a tangentially fired, 562 MW generating plant with 4,080,000 lb/hr main steam. The plant, built in 1971 and has been equipped with a low NO_x burner system during the SCR retrofit project. The cold side ESP was also upgraded and rebuilt during the SCR retrofit project. The addition of the Riley Power Inc. Selective Catalytic Reduction system was designed to reduce the outlet NO_x concentration from 0.45 lb/MBtu, by 85%, to 0.0675 lb/MBtu. Figure 1. shows an isometric view of the Cliffside Unit 5 SCR system project. Based on the current and future coals expected for the plant, a limestone addition system was part of the project scope to control gaseous arsenic and prevent catalyst deactivation.

Acceptance testing of the Cliffside Unit 5 SCR system confirmed the operation of the SCR system design. All design criteria were met or exceeded during the acceptance test. The operation of the SCR system for NO_x reductions of greater than 85% will allow for increased NO_x credit accumulation during ozone control periods (May-September) if desired by the plant. The plants current ability to obtain lower than design inlet NO_x concentrations from the new low NO_x burner system has been operationally tested with the SCR system at full removal efficiency. The NH_3/NO_x standard deviation at the catalyst face was measured by the acceptance test to be < 3% for both reactor systems. During acceptance testing of the SCR system ammonia slip measurements were well below the 2.0 PPM (end of life) design value as expected at 85% NO_x removal. The measured ammonia slip values of < 0.1 ppm @ 3% O_2 are below the values expected even at initial catalyst life. The low ammonia slip has resulted in no impact on ash sales, which continue as normal without the need for land filling or chemical treatment. The catalyst deactivation rate has been measured at the end of the first operational season and agrees with predicted values based on the use of a limestone addition system (4). The low ammonia slip, high NO_x removal efficiency and low catalyst deactivation rate are attributed to the effective mixing of NH_3/NO_x distribution, the performance of the Cormetech honeycomb-type catalyst and the limestone addition system. A comparison of Cliffside Unit 5 operating data to national and state regulations for coal and gas fired power plants is provided in Table 1.

Table 1

Outlet NO_x Concentration National and State Regulations

Cliffside Uint 5 Power Plant	2004 SIP Call	2010 North Carolina Clear Skies for Coal Plants (5)	2010 North Carolina Clear Skies for Gas Plants (5)
0.0675 lb/MBtu	0.15 lb/MBtu	0.16 lb/MBtu	0.10 lb/MBtu

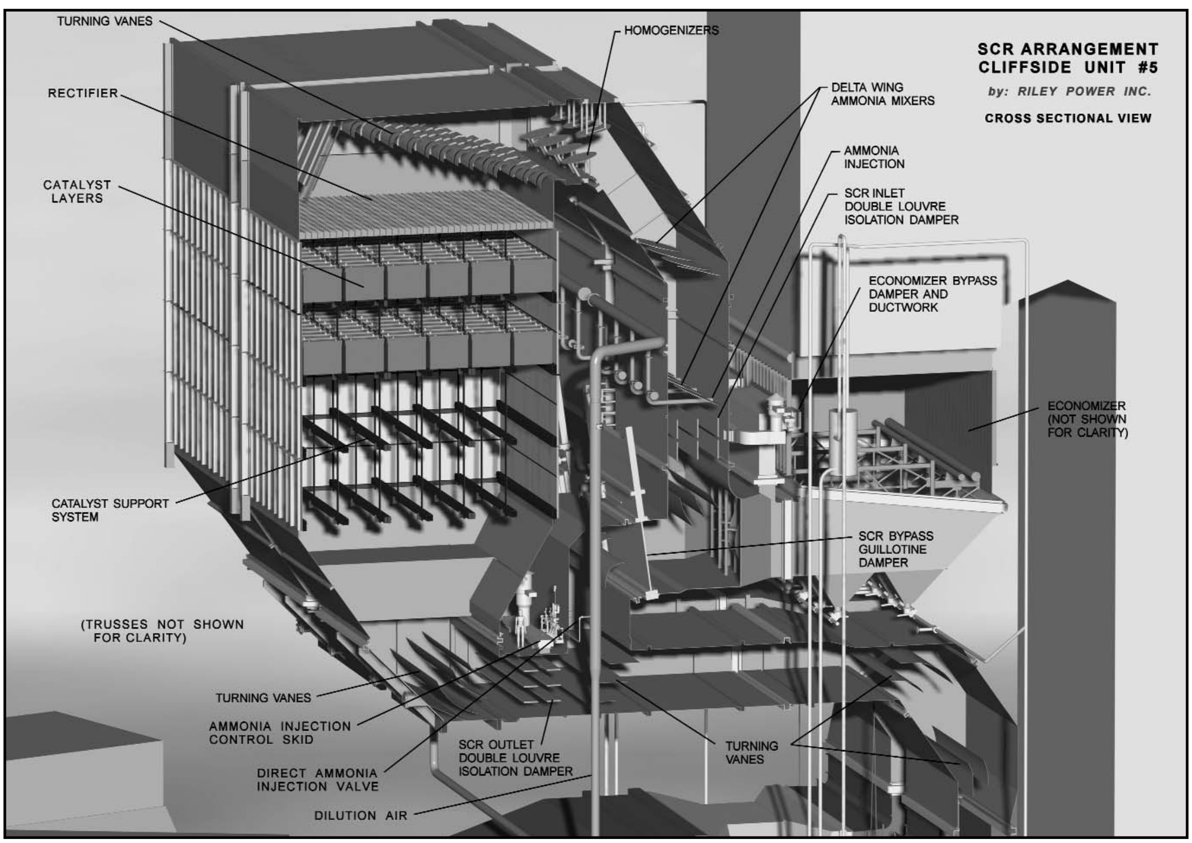

Figure 1. Duke Energy Cliffside Unit 5 SCR Retrofit Arrangement

LG&E ENERGY TRIMBLE COUNTY OPERATING EXPERIENCE

Riley Power Inc. and Duke Fluor Daniel (DFD), as part of an SCR Program Alliance with LG&E Energy Corp. (LEC), engineered, procured and constructed the first of seven SCR projects for LG&E Energy Corp. Trimble County is a tangentially fired, 547 MW generating plant with 3,960,000 lb/hr main steam. The plant, built in 1990, was previously equipped with low NO_x burners, a cold side ESP and a flue gas desulfurization system. The addition of the Riley Power Inc. Selective Catalytic Reduction system was designed to reduce the outlet NO_x concentration from 0.32 lb/MBtu, by 90%, to 0.032 lb/MBtu. Figure 2. shows an isometric view of the Trimble County SCR system project.

Acceptance testing of the Trimble County SCR system confirmed the operation of the SCR system design. All design criteria were met or exceeded during the acceptance test. The low SCR system pressure drop has prevented the need for complicated fan modifications at Trimble County. The operation of the SCR system for NO_x reductions of greater than 90% will allow for increased NO_x credit accumulation during ozone control periods (May-September), if desired by the plant. The application of low NO_x burners in concert with a high efficiency SCR system has proven to result in NO_x reduction beyond guaranteed and target values. The NH_3/NO_x standard deviation was measured to be < 3 % by the acceptance test for both SCR reactors. Ammonia slip measurements were well below the 2.0 PPM (end of life) design value as expected. After approximately 30% catalyst life, the measured ammonia slip values of 0.1 ppm @ 3% O_2 are below the expected values. The low ammonia slip has resulted in no impact on ash sales, which continue as normal without the need for land filling or chemical treatment. The low ammonia slip with high NO_x removal efficiency is attributed to the effective mixing of NH_3/NO_x distribution and performance of the Hitachi plate-type catalyst. A comparison of Trimble County operating data to national and state regulations for coal and gas fired power plants is provided in Table 2.

Table 2

Outlet NOx Concentration National and State Regulations

Trimble County Power Plant	2004 SIP Call	2010 Kentucky Clear Skies for Coal Plants (6)	2010 Kentucky Clear Skies for Gas Plants (6)
0.025 lb/MBtu	0.15 lb/MBtu	0.12 lb/MBtu	0.04 lb/MBtu

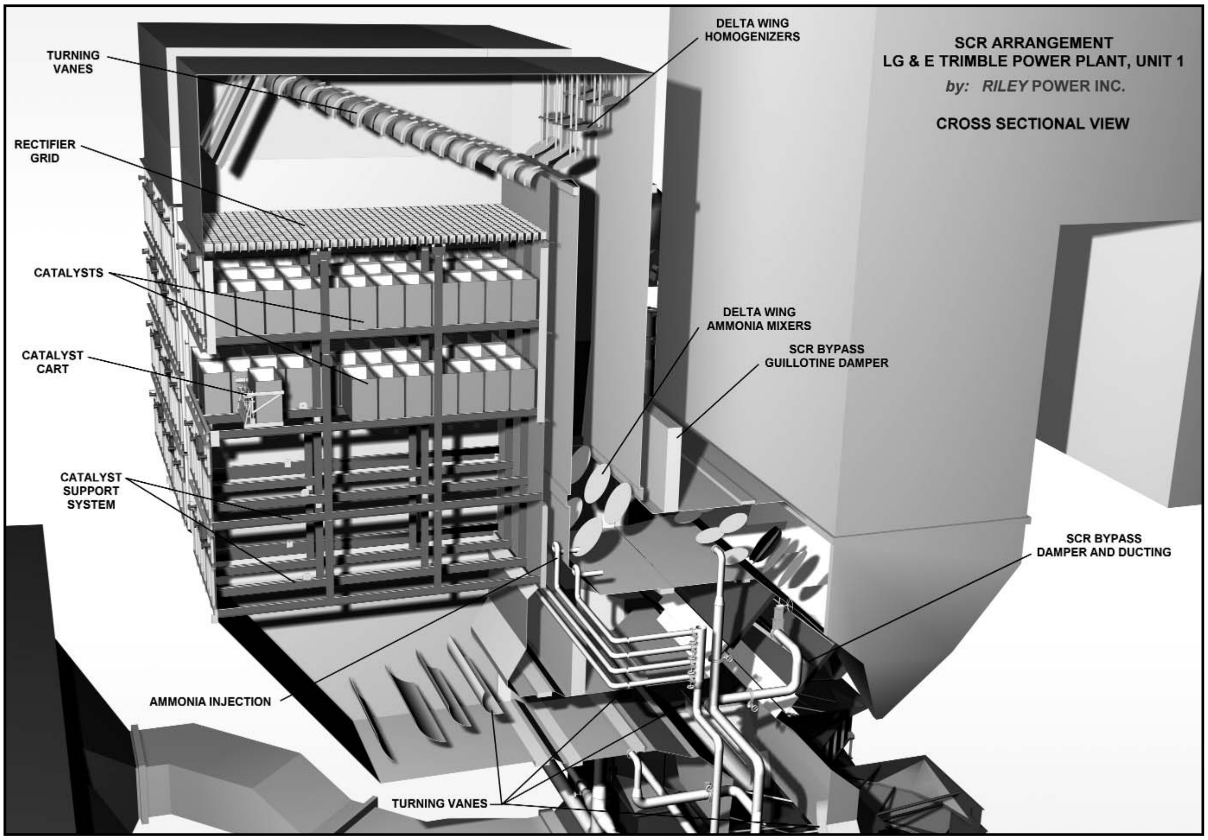

Figure 2. LG&E Energy Corp. Trimble SCR Retrofit Arrangement

RESULTS

Riley Power Inc has installed SCR systems through out the United States for units ranging in fuels, boiler types and required outlet emission concentrations. Two such SCR systems: Cliffside Unit 5 of Duke Energy and Trimble County of LG&E Energy Corp., are examples of successful installations of high removal efficiency, high dust SCR systems in combination with state-of-the-art low NO_x burner technology. Both units employ patented Delta Wing static mixing technology that has met and exceeded the project goals resulting in higher NO_x removal efficiencies with low ammonia slip. The initial catalyst charge has maintained the expected activity levels based on fuels fired.

CONCLUSIONS

The design, installation, and successful operation of high efficiency SCR systems, in conjunction with state-of-the-art low NO_x burner systems, have been achieved. The measured standard deviation of NH_3/NO_x mole ratio at the catalyst face for both systems was < 3%. Based on Riley Power Inc. analysis and industry experience (2,7) mixing systems with < 3% standard deviation can obtain ultra high NO_x removal efficiencies of > 93% with the correct catalyst volume. The Delta Wing static mixing system has successfully achieved high mixing quality with low reagent concentrations and, to date, shows no sign of reaching its full potential.

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