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ABSTRACT

An Alliance of LG&E Energy Corp., Riley Power Inc. (formerly Babcock Borsig Power Inc.), and Duke/Fluor Daniel completed the Engineering, Procurement, and Construction (EPC) of Selective Catalytic Reduction (SCR) equipment at Louisville Gas and Electric Company's Trimble County Generating Station in Bedford, KY. The SCR equipment reduces the plant's emission of nitrogen oxides (NO_X), by more than 90 percent. The 547-megawatt unit began commercial operation in 1990 and fires high sulfur coals with a flue gas desulfurization system.

Past utility experience with the introduction of SCR technology has witnessed NO_X outlet emissions as low as 0.040 lbs/MBtu. European SCR experience has generally been limited to the reduction of NO_X outlet levels to > 0.12 lb/MBtu due to compliance laws. This has not been the case with the Trimble County facility where SCR technology in combination with modern low NOx burner technology, guaranteed an outlet NO_X emission of less than 0.032 lb/MBtu. The SCR NO_X removal efficiency was specified at ≥90% at the end of catalyst life. In order to achieve such an aggressive goal, detailed baseline testing and overall system understanding was required. The understanding of the overall system was necessary to accurately simulate the boundary conditions of the boiler system for the physical flow models. Accurately identifying boiler exit distribution and stratification of the flue gas were imperative when developing the design and configuration of the mixing devices in the system.

The challenges of an SCR retrofit in conjunction with Low NO_X burner technology have been met while obtaining more than 90% NO_X removal by the SCR. Recent acceptance test data has shown the SCR at 91.3% NO_X removal with an average outlet NO_X emission of 0.025 lb/MBtu (19 PPM @ 3% O2) with < 0.1 PPM ammonia slip. The ability to achieve this level of NO_X removal performance is based on the mixing system, which has obtained a NH3/NO_X distribution of ± 3.4% over the catalyst surface. The Trimble County SCR project has successfully matched high performance (>90% NO_X removal) with low NO_X burner technology.

INTRODUCTION

Riley Power Inc. (RPI), formerly Babcock Borsig 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 NOx burners, a cold side ESP and a flue gas desulfurization system. The addition of the RPI Selective Catalytic Reduction system was designed to reduce the outlet NO_X concentration from 0.32 lb/MBtu, by 90%, to 0.032 lb/hr.

The challenges posed at the Trimble County plant include the space restriction of a power plant retrofit, the complexities of secondary catalytic reactions with the constituents of the fuels burned (i.e. high sulfur), and the diminishing return of pushing the SCR reactor to very low outlet NO_X concentrations already equipped with low NO_X burners. In order to meet these challenges, extensive base line test data, along with detailed flow and dust model studies, were used to determine the optimal SCR design.

The SCR reactor consisted of 674.6 cubic meters of plate-type catalyst using anhydrous ammonia as a reducing reagent. Two sets of Delta Wing™ mixing devices were implement-

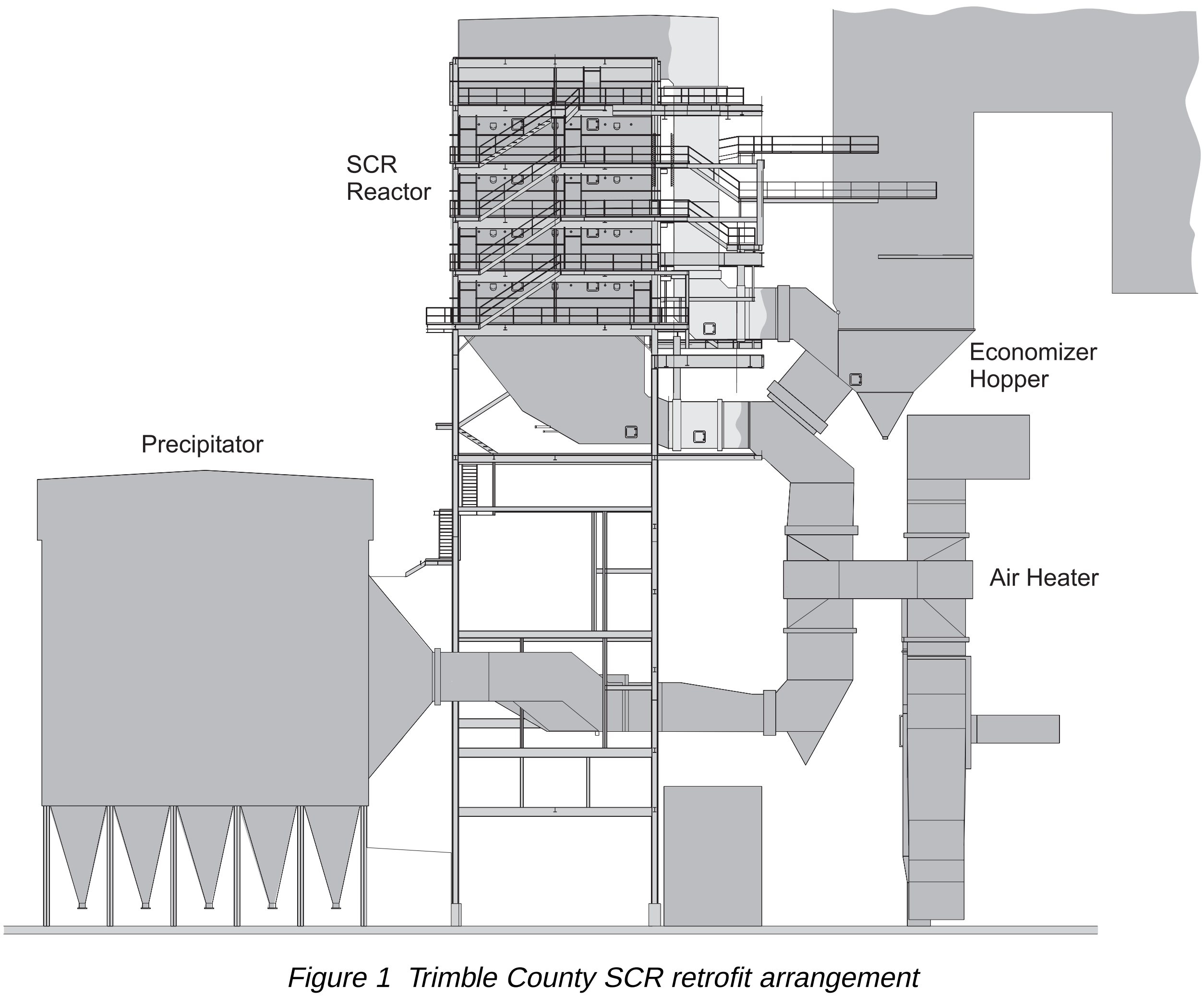

Figure 1 Trimble County SCR retrofit arrangement

ed for the Trimble County reactors. A cross mixing set of discs were used to mix the flue gases laterally, and a second set of mixing devices, located at the point of ammonia injection, was used to mix the flue gases vertically and mix in the ammonia stream. Four ammonia injection points were used and later optimized to produce the best distribution of NH_3 and NO_X possible. Figure 2 shows the four valves used to tune the SCR reactor and obtain the best possible outlet NO_X distribution.

Figure 2 Dilution air and ammonia injection to SCR reactor

The Process Target values set at the start of the project are described below:

- Pressure Drop: The pressure total drop of catalyst, mixing devices, internal structures, and changes in ductwork was to be limited to 6.8 IWC at a dirty condition. The pressure drop was measured from the economizer outlet to the air heater inlet.
- NO_X removal Efficiency: The inlet NO_X concentration was to be reduced by 90%; limited to an inlet NO_X loading of ≥0.30 lb/MBtu.
- Ammonia Slip: The injection of ammonia was to be mixed effectively to limit the concentration of ammonia at the outlet of the reactor to less than 2 PPM at end of catalyst life.
- SO_2 to SO_3 Conversion: The catalyst used to reduce NO_X will also oxidize sulfur dioxide to sulfur trioxide. This reaction was to be limited to 1.5%.

As a design restriction, the Trimble County SCR system was to be built to minimize the pressure loss experienced so that no fan modifications would be necessary. In order to accomplish this, flow modeling became an increasingly critical part of the design.

OBJECTIVES

Key to designing the Trimble County SCR system was optimizing the mixing of NO_X, ammonia, ash, and temperature distribution, while simultaneously minimizing the pressure drop required to achieve optimal mixing. For the Trimble County SCR system, four mixing devices (the patented Delta Wings™), were used to facilitate the optimal distribution of flue gas. With sufficient mixing, limited tuning of the four injection points would be required and an accurate amount of ammonia could be injected to each of the four nozzles. As designed, the NH_3/NO_x distribution required to maximize the NO_x reduction reaction would have to be below ±5%, as calculated in equation 1-1.

$$[(InletAvg - OutletAct) / (InletAvg - OutletAvg) - 1] * 100\% \qquad \text{(Eq. 1-1)}$$

Variables in Equation 1-1 are as follows: InletAvg is the average of all measurements made at the SCR inlet grid, OutletAct is one of 42 actual measurements made at the outlet grid and OutletAvg is the average of all measurements made at the SCR outlet grid.

To test the SCR reactor at Trimble County, an independent third party, E.ON Engineering, was brought in to test and verify that all design guarantees were met. The procedures used to test the guarantee design values are listed below.

The testing of the SCR reactor followed the following standard test methods:

- Pressure Drop: Manometer readings at the outlet of the economizer, inlet to the SCR, outlet of the SCR and inlet to the air heater where taken to give a pressure profile of the SCR system. U-tube water manometers were used for this application.
- NO_x Efficiency: NO_x concentrations were measured at the inlet and outlet of the SCR using an extractive dilution method. At any one time, the testing equipment was capable of reading five NO_x measurements: one inlet measurement and four outlet measurements. The outlet NO_x concentration was measured continuously throughout the duration of each test. The changes in the NO_x concentration at this point were used to observe any changes in the overall NO_x flow rate through the SCR (i.e. fuel changes, boiler upsets, etc.). An average of the inlet NO_x concentrations and outlet NO_x concentrations were taken and the overall removal efficiency was calculated as shown in equation 1-2.

$$[1 - (\text{Outlet } NO_x \text{ AVG}) / (\text{Inlet } NO_x \text{ AVG})]*100 = \text{Removal Efficiency} \qquad \text{(Eq. 1-2)}$$

- Ammonia Slip: Once the SCR NO_x grids were taken, ammonia slip measurements were made at three points along the outlet grid. The points along the grid that gave the highest outlet NO_x concentration, lowest NO_x concentration and a moderate outlet NO_x concentration where measured for ammonia slip. Ammonia is dissolved in a sulfuric acid solution and measured by titration. EPA Method 350.3 was used for ammonia slip measurements.
- SO_2 to SO_3 Conversion: Measurement of SO_2 and SO_3 were made both before and after the SCR catalyst. The Controlled Condensation Method (CCM) is used with special extractive probes required for these measurements, because the stainless steel test grid interferes with the measurements. Additionally, the sample line must be heated so that no SO_2 or SO_3 falls out of the gas stream and condenses in and on the test equipment. Once a sample of the gas steam is taken, EPA Method 6 (barium perchlorate titration) was used to quantify the amount of sulfur oxides. The SO_2 to SO_3 conversion was calculated using equation 1-3.

$$(\text{Outlet } SO_3 - \text{Inlet } SO_3) / \text{Inlet } SO_2 = SO_2 \text{ to } SO_3 \text{ Conversion} \qquad \text{(Eq. 1-3)}$$

E.ON Engineering provided a state-of-the-art, mobile testing truck (MARA) equipped with 60 sample lines. Each line was connected to one of 60 points on two test grids: an 18-point inlet test grid and a 42-point outlet test grid.

RESULTS

The acceptance testing of the Trimble County SCR reactor took place the week of September 23, 2002. The results of each test gave the following results:

Table 1-1 Trimble County acceptance test results

	SCR - 1A	SCR – 1A	SCR – 1B	SCR – 1B	Test Avg.
Boiler Load	547 MW	547 MW	548 MW	547 MW	547 MW
Pressure Drop	6.2 IWC	6.2 IWC	6.0 IWC	6.2 IWC	6.2 IWC
NO_x Efficiency	90.7%	90.5%	92.9%	91.1%	91.3%
Ammonia Slip	0.1 PPM	-	0.1 PPM	-	0.1 PPM
SO_2 Conversion	0.43%	-	0.65%	-	0.54%

Note: Testing was conducted after one ozone season of operation ~30% of catalyst life.

Reactor Pressure Drop

In all test cases the SCR system pressure drop measured was within the guarantee value. The baseline conditions under which the SCR system was designed were slightly different than those of the test conditions. To correct for the increased boiler load (from 525 MW to 547 MW) and the changes in fuel (from 10,000 Btu/lb to 12,000 Btu/lb) the pressure drop values were adjusted, and remained well below the guarantee values.

NO_X Reduction Efficiency

Of particular importance is the confirmation of NO_X removal capability of >90% during the acceptance tests. Trimble County's SCR reactor is one of the first to accomplish such high removal efficiency with the combination of low NO_X burners. The RPI design of mixing devices allows for increasingly high removal efficiencies while limiting the ammonia slip concentrations.

SO_2 Conversion

The conversion of SO_2 to SO_3 across the SCR reactor was measured to determine the rate of conversion. Tests were made of SO_2 to SO_3 conversion at full and part loads. In both conditions, the SO_2 conversion was well below the 1.5% guarantee target.

Ammonia Slip Measurements

The measurement of ammonia slip was made at the SCR outlet and found to be well less than 2.0 PPM in the flue gas. Although the guarantee value of 2.0 PPM is representative of the end of catalyst life condition, no ammonia slip was found at concentrations above 0.1 PPM. Based on the current test data of 0.1 PPM over the first four months of operation, RPI estimates ammonia slip will not exceed 0.5 PPM when extrapolated out over 10,000 hours. This performance estimate is based on using correction curves provided by the catalyst manufacturer.

CONCLUSIONS

The Trimble County acceptance testing confirmed the operation of the SCR reactor design. All design criteria were met and exceeded target conditions. The resulting pressure drop has prevented the complications of existing fan modifications and will give Trimble County higher net electricity generation. Further, the plant will be able to achieve longer durations between air heater washings due to preserved fan margins. The operation of the SCR reactor to NO_X reduction of greater than 90% will allow for more flexibility during ozone control periods (May-September). 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 values. Ammonia slip measurements were well below the 2.0 PPM (end of life) design value and therefore, will allow ash sales to continue or be landfilled without the concern of chemical treatment. The low ammonia slip with high NO_X removal efficiency is attributed to the effective mixing of NH3/NO_X distribution and performance of the Hitachi plate-type catalyst.

To put the outlet concentrations of the Trimble County SCR system in perspective, the following tables contain the national average outlet NO_X concentration for over 2,548 individual power plants burning natural gas, oil, and coal in comparison to that of the Trimble County station (Table 1-2), as well as national and state regulations for coal and gas fired power plants (Table 1-3).

Table 1-2 Outlet NO_X concentration comparisons corrected to 3% O2

Trimble County Power Plant	National Avg. for Coal Fired Plants*	National Avg. for Oil Fired Plants*	National Avg. for Gas Fired Plant*
0.025 lb/MBtu	0.424 lb/MBtu	0.318 lb/MBtu	0.133 lb/MBtu

*Data averaged from http://www.epa.gov/airmarkets/emissions/score01/index.html Table B1 of the EPA Emissions Scorecard 2001, Appendix B.

Table 1-3 Outlet NO_X concentration national and state regulations

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

*Data taken from http://www.epa.gov/clearskies/pdfs/KY-summary-9-16.PDF Table 1. Projected Emission Rates in 2010 and 2020 in Kentucky from Power Generators.

Startup Issues

As in most large-scale operations, there were a number of difficulties encountered during startup and commissioning of the SCR system. These included the operation of the insitu NO_X analyzers, canned motor pumps, and thermal stress issues associated with the reactor dampers and expansion joints.

Due to the temperature gradient across the guillotine damper and resultant thermal expansion, the guillotine dampers would hang-up partway through the stroking process. To resolve this problem, the damper vendor reinforced and retrofitted their design. These design changes have been incorporated into the design and fabrication of future dampers for the LEC SCR Alliance.

The Trimble County power plant burns high sulfur coal (~4% by weight), resulting in high SO_2 concentrations in the flue gas. In-situ NO_x analyzers were initially installed to measure SCR inlet and outlet NO_x concentrations and control ammonia injection into the system. These analyzers utilize Differential Optical Absorption Spectroscopy (DOAS) with optimized evaluation algorithms. This technology was found to be limited in its ability to measure low SCR NO_x outlet concentrations in the presence of high SO_2 concentrations. The higher levels of SO_2 masked the readings of NO_x and increased the error in measurement. As a solution to this problem, a dilutive-extractive NO_x analyzer was purchased to operate in its place. This system extracts a sample of flue gas and measures the sample in a remote analyzer building.

The last major issue that arose during the commissioning of the SCR system was that of the anhydrous ammonia pumps. Since ammonia is a pressurized liquid, the opportunity for ammonia to change phases within the process is present. Pumping two-phase flow is extremely difficult. As such, it is critical to the ammonia design that the process fluid remained liquid. To accomplish this, the storage tanks were elevated well above grade and the process lines were insulated to protect the liquid from external radiant heat. This was sufficient for continuous operation. However, when the pump stopped, it heated the liquid and created a vapor lock around the pump. This prevented the pump from restarting. The solution to this problem was to make a change in the control logic that allowed ammonia vapor to vent back to the storage tank.

Figure 3 Trimble County completed SCR retrofit

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