TECHNICAL PUBLICATION

Selective Catalytic Reduction System Performance at LG&E Energy LLC's Mill Creek and Ghent Generating Stations

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Presented at

EPRI Workshop on Selective Catalytic Reduction
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ABSTRACT

A consortium of LG&E Energy LLC, Riley Power Inc. (a Babcock Power Inc. Company) and Duke Fluor Daniel has completed the Engineering, Procurement, Construction (EPC) and acceptance testing for a total of six Selective Catalytic Reduction (SCR) systems. The SCR systems are located at the LG&E Energy LLC's Trimble County, Mill Creek, and Ghent Generating Stations. Each SCR system reduced its respective baseline nitrogen oxides (NO_x) emissions by 90% or greater during the acceptance test periods. These coal-fired facilities generate upwards of 3600 megawatts while burning a variety of fuels and fuel blends.

The wide range of design requirements for these SCR projects in the LG&E Energy fleet included high and low dust loadings, high and low sulfur fuels, bituminous and bituminous/Powder River Basin (PRB) fuel blends, high and low SCR inlet gas temperatures, and a variety of inlet NO_x loadings. Recent acceptance tests for all of the LG&E Energy SCR systems showed performance meeting or exceeding design requirements. The standard deviations of the ammonia to NO_x ratios were between 1.7 to 3.9% at design conditions, which indicates that the ammonia and flue gas were thoroughly mixed on all twelve SCR reactors. The well mixed ammonia and flue gas in turn produced residual ammonia concentrations at the reactor outlet between 0.10 and 0.49 ppm during the initial test period at design NO_x removal rates. In addition to favorable full load results, excellent ammonia-flue gas mixing was demonstrated over a range of boiler loads and plant conditions.

The challenges presented by a variety of coal fired boiler systems have been met with SCR retrofits that have been initially tested to obtain greater than 90% NO_x removal. The publication provides an overview of the SCR system designs, optimization tuning, acceptance testing, and operating experience.

INTRODUCTION

Riley Power Inc. (RPI), a Babcock Power Inc. Company, and Duke Fluor Daniel (DFD), as part of an SCR Program Alliance with LG&E Energy LLC, engineered, procured, and constructed six SCR projects within the LG&E Energy LLC System. The first was at the Trimble County Generating Station's Unit 1. Trimble County's results have been previously published [1] and will not appear in this paper.

The second project was at Mill Creek's Unit 4 which is an opposed wall fired 520 MW generating boiler with 3,660,000 lbs/hr of main steam (Arrangement shown in Figure 1). The SCR system was retrofitted to a unit that contained a cold side ESP and a flue gas desulfurization system. The RPI Selective Catalytic Reduction system was designed to reduce the outlet NO_x concentration from 0.34 lb/MBtu, by 90%, to 0.034 lb/MBtu. Mill Creek 4 is unique in that it has low economizer outlet temperatures and to allow for a wide SCR operating range, an economizer bypass system was installed as part of the SCR system.

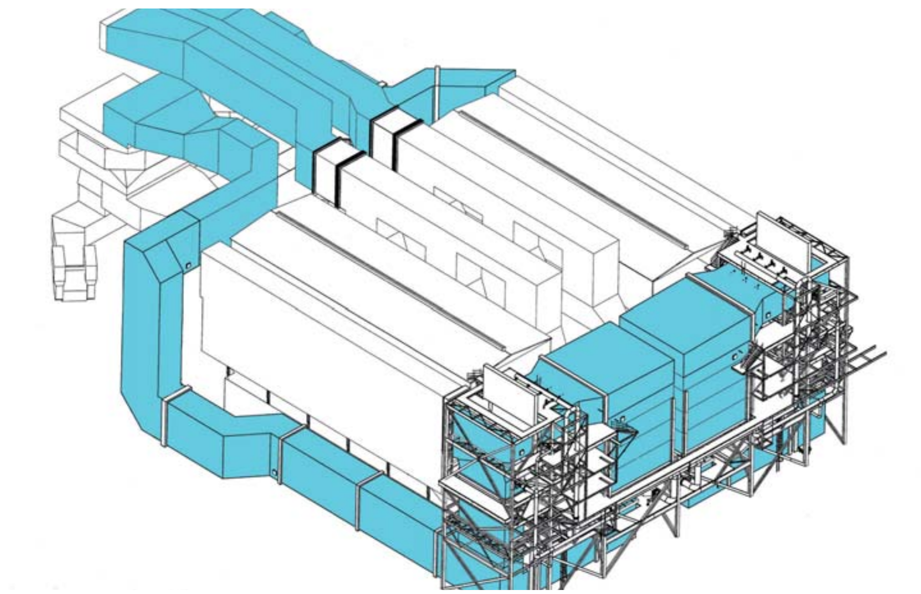

Figure 1. Mill Creek 4 Arrangement

Mill Creek Unit 3, which is an opposed wall fired 410 MW boiler with 3,144,000 lbs/hr of main steam, was the next SCR project. The SCR system on the Unit 3 boiler is nearly identical to that one on the Unit 4 boiler. The SCR system was also designed to remove 90% of the outlet NO_x, from 0.35 lb/MBtu to 0.035 lb/MBtu. Unit 3 like Unit 4 burns a high sulfur coal and also has an economizer bypass system to allow for a broader SCR operating range.

The fourth and fifth projects are identical systems at Ghent Station. Ghent's Units 3 and 4 are 520 MW opposed wall fired boilers with 3,800,000 lbs/hr of main steam (Arrangement shown in Figure 2). These SCR systems were retrofitted downstream of a hot side ESP to reduce 90% of the outlet NO_x from 0.34 lb/MBtu to 0.034 lb/MBtu. Units 3 and 4 unlike all of the other LG&E Energy SCRs, burn a low sulfur bituminous coal and a blend of low sulfur bituminous and Powder River Basin (PRB) coals.

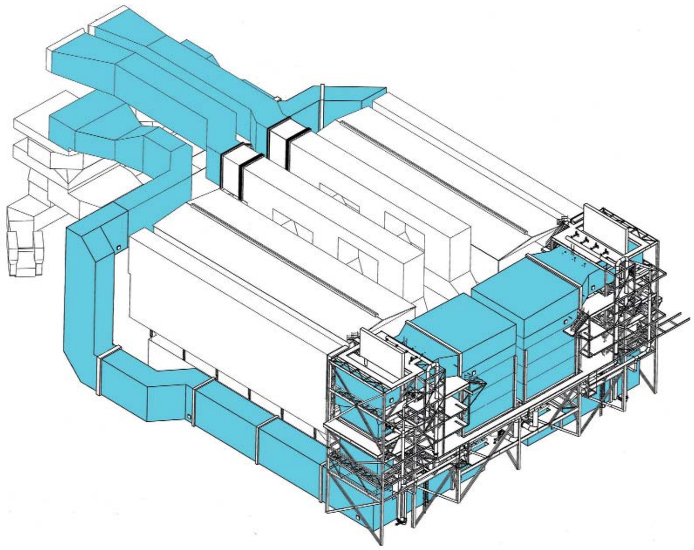

Figure 2. Ghent 3 & 4 SCR System Arrangement

Ghent Generating Station's Unit 1 was the final SCR project, which is a tangentially fired 520 MW boiler with 3,800,000 lbs/hr of main steam (Arrangement shown in Figure 3). Like the Mill Creek and the Trimble projects, the SCR system was retrofitted to a system with a cold side ESP and a flue gas desulfurization system. The SCR was designed to remove 90% of the outlet NO_x concentration from 0.45 lb/MBtu to 0.045 lb/MBtu.

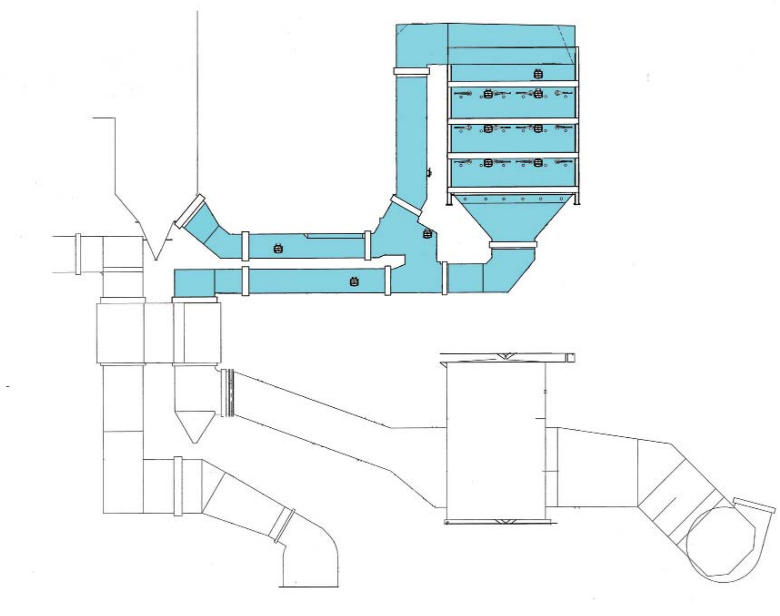

Figure 3. Ghent 1 SCR System Arrangement

With a variety of boilers, operating conditions, and space restrictions, each project required its own flow model. In the case of Ghent units 3 and 4 the flow and dust models were the same for both units but additional modeling was necessary for the ESP to determine the optimal position of the mixing systems. The mixing systems themselves varied between projects as there were either one or two sets of cross mixing discs to thoroughly mix the gas before ammonia injection. With different operating flue gas conditions, the number of Delta Wings™ varied project to project. With uniquely different boiler systems, the modeling of the mixers became an integral part of the design, as the ammonia slip at the reactor outlet was to be less than 2 ppm (2.7 ppm for Mill Creek 3 & 4) at the end of the catalyst life.

The ammonia systems themselves, while similar in design, contain different design aspects such as support for two, four, or six SCR reactors. In supporting a different number of reactors, the sizes of the equipment may be different but all systems contain similar components and operate under the same philosophy.

OBJECTIVES

The most important task in achieving high NO_x removal with low ammonia slip is the design of the mixing system. With an entire fleet of SCR systems to design, modeling the mixing system for each was the first step. A properly designed mixing system yields many benefits, some of which are:

* Well mixed NO_x and O_2 profiles at the reactor inlet
* Minor changes in the reactor inlet NO_x and O_2 profiles over a variety of operating conditions
* Small variations in NH_3/NO_x ratio with changes in operating conditions
* Few localized areas for potential ammonia slip
* Minimal number of ammonia injectors
* One optimized ammonia injection position for all operating conditions
* Short optimization and acceptance test periods

The mixing system has many benefits with the goal of achieving a well-mixed ammonia and flue gas mixture. In evaluating how well mixed the ammonia is in the flue gas, there are several factors that can be looked at. These factors include the removal efficiency, the ammonia slip, the outlet NO_x variation, and the variation of the NH_3/NO_x ratio. In optimizing an SCR all of these factors are reviewed, but from experience RPI has found that the best indication of well-mixed gases is the standard deviation of the NH_3/NO_x ratio variation. Since the standard deviation measures how widely dispersed the NH_3/NO_x ratio variations are from the mean, using this statistical method will show how close these variations are. RPI considers deviations less than 5% to be well mixed and increasingly more uniform as the deviations approach 0%.

To optimize the SCR reactors, RPI followed a test procedure of initially running a baseline with no ammonia injected, then to inject ammonia at a low reduction level (50-60% reduction), increase the reduction to another intermediate level (75-85% reduction), and finally to 90% reduction. Taking NO_x and O_2 measurements at these different levels ensures that there is no area for ammonia slip. The reason this step approach is taken is because the installed valves are usually at a position between 100% and 50% open.

Throughout the optimization and acceptance test periods, the NO_x and O_2 profiles were measured at the reactor inlet and outlet grids and during the acceptance tests Ammonia slip was measured as well. This data allowed RPI to analyze different aspects of the reactor to determine optimum reactor set points. Measurements were taken by RPI utilizing portable TESTO 350 analyzers and a third party testing company, E.On Engineering. E.On Engineering has the capability to measure an inlet and outlet grid (as large as 42-points each in some of these projects) simultaneously and therefore reducing the total test time, which is useful in capturing data between boiler outlet NO_x fluctuations.

RESULTS

The LG&E Energy LLC SCR systems each went through an optimization test period followed by an acceptance test period. During the optimization test period ammonia injection valves were fixed, some welded, so that reactor would be in its optimized state for the acceptance test period. Each projects' results is organized separately for clarity.

MILL CREEK UNIT 4

After the optimization of the Mill Creek 4 SCR system, acceptance testing was performed to demonstrate the system's performance. To demonstrate the system NO_x cleaning performance, NO_x and O_2 were measured before the first layer of catalyst and after the last layer of catalyst. In addition to this data, the ammonia slip was measured at the reactor outlet. NO_x pre-mixers and the Delta Wing™ Mixers, allow the SCR system to operate at any load with any mill configuration without having to readjust the ammonia injection valves. During the acceptance of the SCR system, the reactors were tested at full load (500 — 515 MW) and a partial load (290 MW). The resulting NH_3/NO_x ratios showed minor changes.

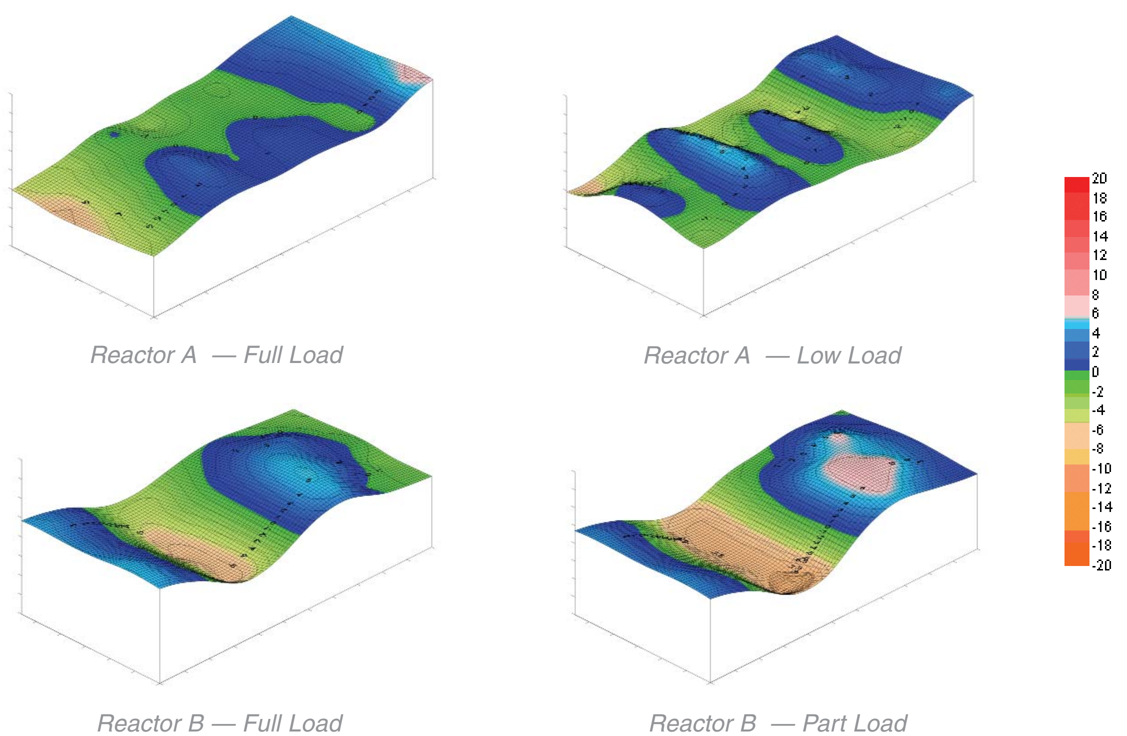

Figure 4. Mill Creek Unit 4 Full Load and Low Load NH_3/NO_x Distributions

Figure 4 shows the NH_3/NO_x ratio profiles of the Mill Creek Unit 4 reactor at both full load and a partial load (~ 57% MCR). From the profiles in Figure 4, the majority of the area is in the blue and green region. The blue and green regions represent a ±5% range for the NH_3/NO_x ratio variation. In focusing on certain areas, some variations of the NH_3/NO_x ratio profile are evident. However, considering the overall profile, rather than the specific areas of variation, the profile is relatively uniform. For a more detailed analysis, Table 1 was constructed with acceptance test data.

Table 1

Mill Creek Unit 4 SCR System Acceptance Test Data

		Reactor A	Reactor A	Reactor B	Reactor B	Full Load Ave	Part Load Ave
Boiler Load	MW	500	289	515	290	508	290
Grid NO_x Reduction	%	92.3	89.7	92.4	91.4	92.4	90.6
Ammonia Slip	ppm	0.36	0.20	0.49	0.30	0.43	0.25
Inlet NO_x Variation	ppm	± 23.0	± 9.5	± 11.7	± 9.8	± 17.4	± 9.7
Inlet NO_x Variation	%	± 9.0	± 4.8	± 4.5	± 4.3	± 6.8	± 4.6
Inlet NO_x Standard Deviation	ppm	10.7	5.7	5.5	4.9	8.1	5.3
Outlet NO_x Variation	ppm	± 15.8	± 9.3	± 14.0	± 15.8	± 14.9	± 12.6
Outlet NO_x Variation	%	± 64.8	± 47.4	± 65.6	± 74.1	± 65.2	± 60.8
Outlet NO_x Standard Deviation	ppm	6.3	5.2	8.3	9.7	7.3	7.5
NH_3/NO_x Ratio Variation	%	± 5.7	± 5.2	± 5.8	± 7.7	± 5.8	± 6.5
NH_3/NO_x Standard Deviation	%	2.7	2.9	3.4	4.7	3.1	3.8

In looking at the NH_3/NO_x standard deviation, the partial load tests do show a minor change in the mixing quality, which is expected at non-design conditions. However, even at the partial load, the standard deviation of the NH_3/NO_x ratio variation is still below 5% indicating a homogeneous mixing of gases.

MILL CREEK UNIT 3

The optimization of Mill Creek's Unit 3 SCR system was done in a slightly different manner than its Unit 4 SCR system. An ID Fan upgrade and design rating on the ductwork and ESP, limited the load and the amount of optimization that could be performed. However, preliminary optimization revealed a mal-distribution of NH_3/NO_x with the standard deviation of the NH_3/NO_x ratio variation between 7 — 13 %. RPI utilized the upgrade period to modify the design and optimize the flow model and SCR system. To do this, additional ammonia injection valve influence tests were performed in the field. The results of these tests were to be compared to identical tests performed on the revised flow model, which was scaled precisely to the as-built reactor. The conclusion of the testing was that the NO_x pre-mixers and the Delta Wings™ needed minor modifications.

To verify that the changes to the mixing system, a series of field influence test were conducted during the optimization period. These tests were done to mimic identical tests done in the flow model where a constant ammonia flow was fed through each of the four injection valves while the remaining three remained closed. The results of the field test after the modifications (Figure 5) matched the flow model results exactly.

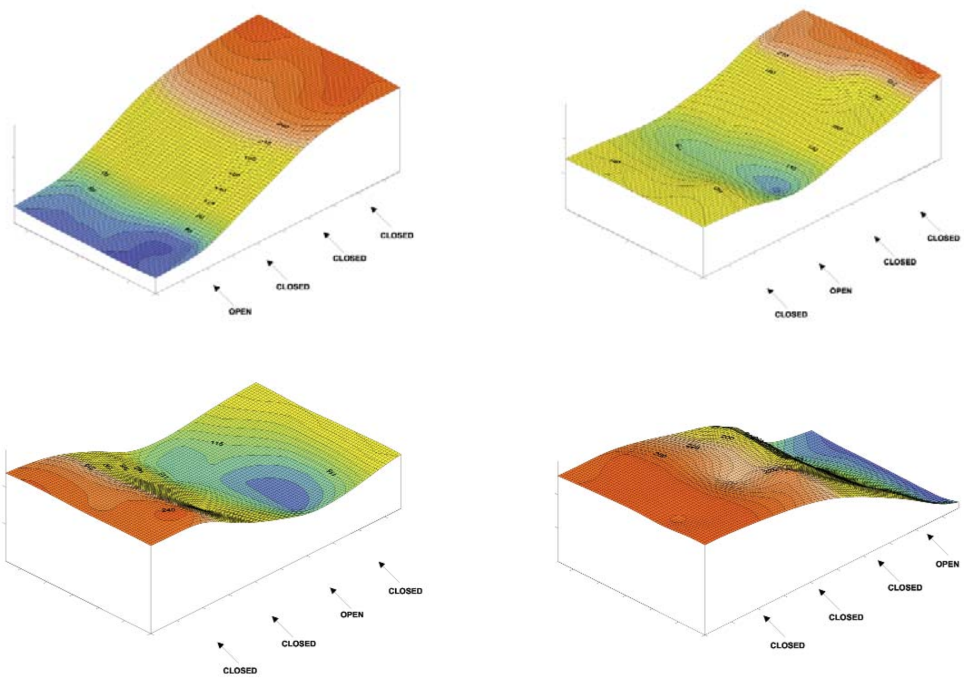

Figure 5. Field Influence Testing of Mill Creek Unit 3 SCR System

After the above testing was conducted, the system was optimized. The improvements to the NH_3/NO_x ratio variation can be seen in Figure 6.

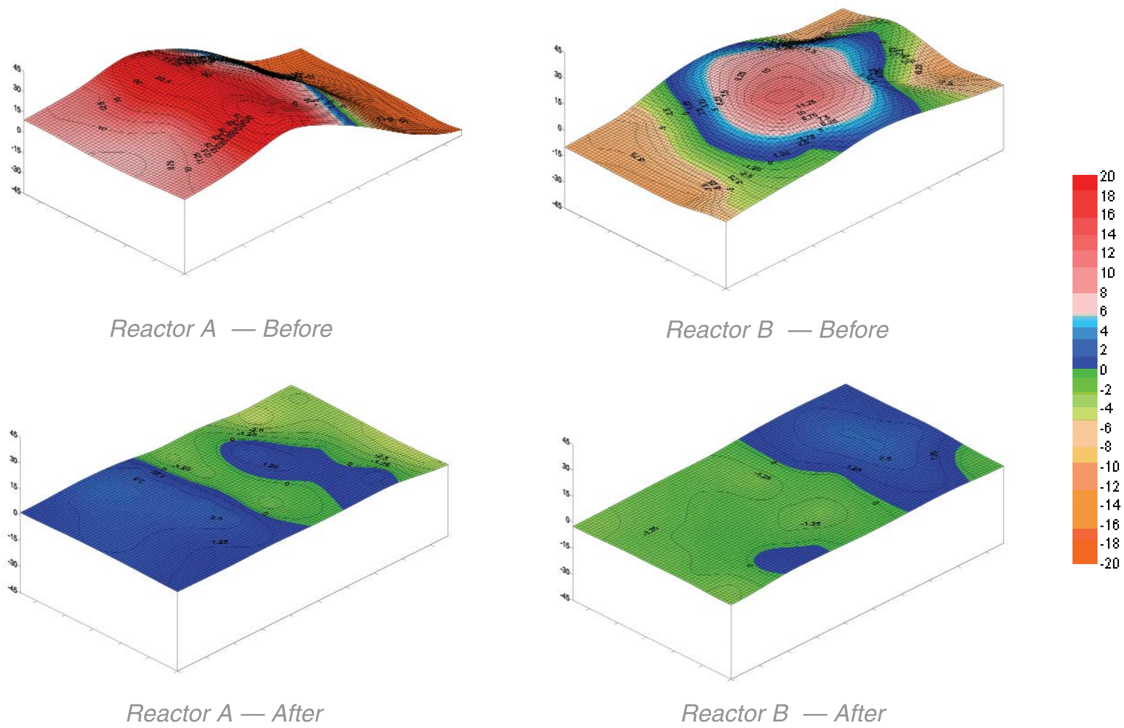

Figure 6. Mill Creek Unit 3 SCR System NH_3/NO_x Ratio Before and After Modifications

With the mixing system modified, the optimization the SCR system was conducted and was followed by the acceptance test period. The result of the acceptance testing (Table 2) was that the standard deviation of the NH_3/NO_x ratio variation decreased from 7 — 10 % to 1.7 — 2.3 %.

Table 2

Mill Creek Unit 3 SCR System Acceptance Test Results

		Reactor A	Reactor B	Average
Boiler Load	MW	422	430	426
Grid NO_x Reduction	%	92.3	91.7	92.0
Ammonia Slip	ppm	0.22	0.11	0.17
Inlet NO_x Variation	ppm	± 14.0	± 12.9	± 13.5
Inlet NO_x Variation	%	± 5.3	± 4.7	± 5.0
Inlet NO_x Standard Deviation	ppm	7.3	6.8	7.1
Outlet NO_x Variation	ppm	± 10.5	± 7.8	± 9.2
Outlet NO_x Variation	%	± 45.9	± 35.8	± 40.9
Outlet NO_x Standard Deviation	ppm	5.5	4.3	4.9
NH_3/NO_x Ratio Variation	%	± 4.3	± 3.1	± 3.7
NH_3/NO_x Standard Deviation	%	2.3	1.7	2.0

GHENT 3

The Ghent Unit 3 SCR system had an element, which the Mill Creek SCR systems did not. Ghent Unit 3 regularly burns either a low sulfur bituminous coal or a blend of the low sulfur bituminous coal and PRB coal. With the plant frequently alternating fuels, the optimization and acceptance test periods incorporated testing with the two fuels. With the installed mixing system, the ammonia injection valves did not have to be adjusted while switching fuels. The NO_x pre-mixers produce relatively the same distributions regardless of plant operating conditions. Furthermore, the NH_3/NO_x ratio will not change if the boiler operates under different loads, mill configurations, or fuels. Figure 7 shows the similarity in the NH_3/NO_x profiles with the two different fuels without a change in the ammonia injection valves.

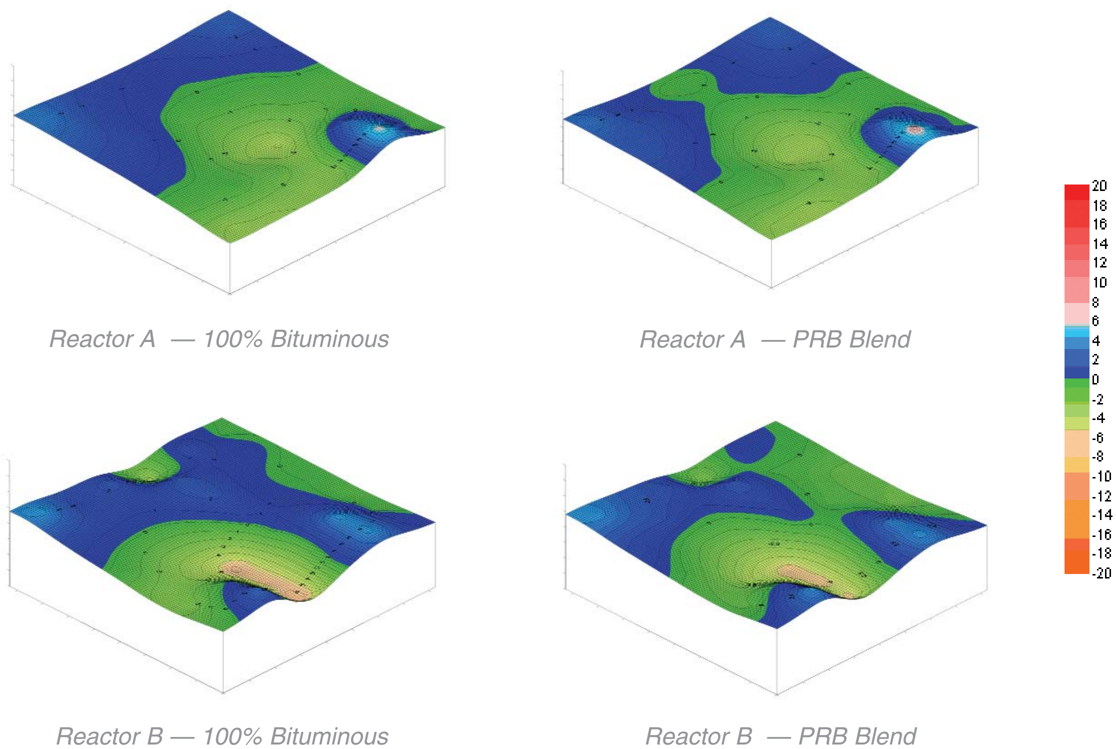

Figure 7. Ghent Unit 3 SCR System NH_3/NO_x Ratio Profiles for the Two Fuels

Figure 6 shows that the majority of the area is blue and green. Using the color scale at the right, this would translate into a range for the NH_3/NO_x ratio to be approximately ± 5 % over 100 % of the catalyst area. A more detailed comparison of the acceptance test data is contained in Table 3.

Table 3

Ghent Unit 3 SCR System Acceptance Test Results

		Reactor A Bit	Reactor A Blend	Reactor B Bit	Reactor B Blend	Bit Ave	Bit Blend	Overall Ave
Boiler Load	MW	530	530	530	530	530	530	530
Grid NO_x Reduction	%	91.9	91.4	90.4	90.5	91.2	91.0	91.1
Ammonia Slip	ppm	0.17	0.24	0.10	NA	0.14	0.24	0.17
Inlet NO_x Variation	ppm	± 16.3	± 10.3	± 7.0	± 6.5	± 11.7	± 8.4	± 10.0
Inlet NO_x Variation	%	± 6.6	± 4.8	± 3.2	± 3.3	± 4.9	± 4.1	± 4.5
Inlet NO_x Standard Deviation	ppm	8.3	4.6	3.3	3.5	5.8	4.1	4.9
Outlet NO_x Variation	ppm	± 12.5	± 11.3	± 11.8	± 9.8	± 12.2	± 10.6	± 11.4
Outlet NO_x Variation	%	± 69.5	± 71.4	± 48.5	± 46.9	± 59.0	± 59.2	± 59.1
Outlet NO_x Standard Deviation	ppm	5.5	4.6	5.4	4.5	5.5	4.6	5.1
NH_3/NO_x Ratio Variation	%	± 5.5	± 5.7	± 5.8	± 5.4	± 5.7	± 5.6	± 5.6
NH_3/NO_x Standard Deviation	%	2.4	2.3	2.7	2.5	2.6	2.4	2.5

Figure 6 shows that there are some variations between fuels. However, when the data is compared, the magnitude of these changes can be seen. Table 3 illustrates that when fuels are switched the effect to the NH_3/NO_x ratio is less than or equal to 0.2%.

GHENT 4

Ghent's Unit 4 SCR system is a mirror image of Unit 3's. In addition, unit 4 also frequently switches between the same two fuels as Unit 3 so the optimization and acceptance tests were very similar. One element that was added to the Unit 4 acceptance test period was testing the SCR with both fuels at full and part loads. The resulting acceptance test data is presented in Tables 4 and 5. The NH_3/NO_x mixing results are also presented graphically in Figure 8.

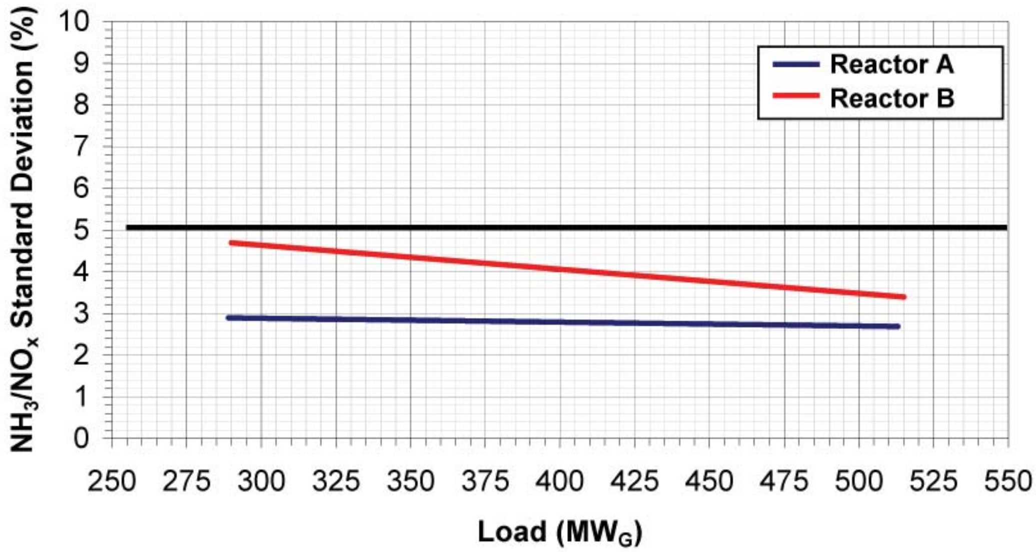

Figure 8. NH_3/NO_x Mixing Results for the Ghent Unit 4 SCR System

Table 4

Ghent Unit 4 SCR System Full Load Acceptance Test Results

		Reactor A Bit	Reactor A Blend	Reactor B Bit	Reactor B Blend	Bit Ave	Blend Ave	Full Load Ave
Boiler Load	MW	518	523	524	529	521	526	524
Grid NO_x Reduction	%	89.9	91.6	92.2	93.2	91.1	92.4	91.7
Ammonia Slip	ppm	0.26	0.12	0.10	0.16	0.18	0.14	0.16
Inlet NO_x Variation	ppm	± 20.5	± 22.5	± 33.8	± 15.0	± 27.2	± 18.8	± 23.0
Inlet NO_x Variation	%	± 8.3	± 8.5	± 10.3	± 5.5	± 9.3	± 7.0	± 8.2
Inlet NO_x Standard Deviation	ppm	8.0	10.0	16.0	7.3	12.0	8.7	10.3
Outlet NO_x Variation	ppm	± 17.8	± 25.3	± 18.8	± 15.5	± 18.3	± 20.4	± 19.4
Outlet NO_x Variation	%	± 70.3	± 93.4	± 70.0	± 79.5	± 70.2	± 86.5	± 78.4
Outlet NO_x Standard Deviation	ppm	7.8	8.3	8.2	6.6	8.0	7.5	7.7
NH_3/NO_x Ratio Variation	%	± 7.8	± 8.8	± 6.2	± 5.7	± 7.0	± 7.3	± 7.2
NH_3/NO_x Standard Deviation	%	3.4	3.4	2.7	2.7	3.1	3.1	3.1

Table 5

Ghent Unit 4 SCR System Part Load Acceptance Test Results

		Reactor A Bit	Reactor A Blend	Reactor B Bit	Reactor B Blend	Bit Ave	Blend Ave	Part Load Ave
Boiler Load	MW	392	303	395	306	394	305	349
Grid NO_x Reduction	%	91.3	90.9	93.7	93.3	92.5	92.1	92.3
Ammonia Slip	ppm	NA	NA	NA	NA	NA	NA	NA
Inlet NO_x Variation	ppm	± 11.8	± 17.0	± 13.5	± 12.0	± 12.7	± 14.5	± 13.6
Inlet NO_x Variation	%	± 5.4	± 7.7	± 5.2	± 6.0	± 5.3	± 6.9	± 6.1
Inlet NO_x Standard Deviation	ppm	5.2	6.6	6.2	5.4	5.7	6.0	5.9
Outlet NO_x Variation	ppm	± 16.3	± 15.3	± 15.8	± 12.3	± 16.1	± 13.8	± 14.9
Outlet NO_x Variation	%	± 91.7	± 83.6	± 79.7	± 77.6	± 85.7	± 80.6	± 83.2
Outlet NO_x Standard Deviation	ppm	6.4	5.9	7.0	5.5	6.7	5.7	6.2
NH_3/NO_x Ratio Variation	%	± 8.1	± 7.5	± 6.5	± 6.6	± 7.3	± 7.1	± 7.2
NH_3/NO_x Standard Deviation	%	3.2	2.9	2.9	3.0	3.1	3.0	3.0

As seen in Mill Creek Unit 4 and Ghent Unit 3, changing the fuel or the load only affects the mixing on a minor scale. By comparing the data in Table 4 and Table 5, the same conclusion can be reached. All of the changes to the NH_3/NO_x standard deviation by switching fuels or changing loads are less than or equal to 0.5%.

GHENT 1

The Ghent Unit 1 SCR system is quite different than the Unit 3 and 4 SCR systems at Ghent. Unit 1 burns a high sulfur coal instead of the low sulfur coal or coal blend. Even the boilers themselves are different. However, the approach to the optimization and acceptance were similar. The results from the acceptance test can be seen in Table 6.

Table 6

Ghent Unit 1 SCR System Acceptance Test Results

		Reactor A	Reactor A	Reactor B	Reactor B	Full Load Ave	Part Load Ave
Boiler Load	MW	534	454	528	454	531	454
Grid NO_x Reduction	%	92.7	91.3	91.2	91.0	92.0	91.2
Ammonia Slip	ppm	0.22	0.15	0.24	0.13	0.23	0.14
Inlet NO_x Variation	ppm	± 34.3	± 15.8	± 22.5	± 11.8	± 28.4	± 13.8
Inlet NO_x Variation	%	± 11.8	± 6.0	± 10.1	± 5.8	± 11.0	± 5.9
Inlet NO_x Standard Deviation	ppm	11.7	6.5	10.4	5.1	11.1	5.8
Outlet NO_x Variation	ppm	± 13.8	± 9.3	± 15.5	± 8.5	± 14.7	± 8.9
Outlet NO_x Variation	%	± 56.0	± 38.7	± 63.5	± 39.6	± 60.0	± 39.2
Outlet NO_x Standard Deviation	ppm	6.9	4.3	8.2	4.8	7.6	4.6
NH_3/NO_x Ratio Variation	%	± 4.8	± 3.8	± 7.4	± 4.5	± 6.1	± 4.2
NH_3/NO_x Standard Deviation	%	2.4	1.8	3.9	2.5	3.2	2.2

CONCLUSIONS

The results from all of the LG&E Energy LLC SCR systems confirm that they have met or exceeded the design performance. The additional parameters such as partial loads and different fuels have also met the design criteria and also show the effectiveness of the mixing systems. The static mixing system simplifies the SCR system by having one ammonia injection valve setting for all operating conditions. By using the static mixing system in their SCRs, LG&E Energy LLC has obtained systems with low ammonia slip and the potential for > 90% removal efficiency.

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(1). Pear, Eric, et al. SCR System Performance at LG&E's Trimble County Generating Station. Atlanta: EPRI Workshop on Selective Catalytic Reduction (T-177), 2002