SECOND GENERATION ADVANCED REBURNING FOR HIGH EFFICIENCY NOx CONTROL

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ABSTRACT

This project is designed to develop a family of novel NO_x control technologies, called Second Generation Advanced Reburning which has the potential to achieve 90+% NO_x control in coal fired boilers at a significantly lower cost than SCR. The third reporting period in Phase II (April 1 – June 30, 1998) included experimental activities at pilot scale and comparison of the results with full-scale data. The pilot scale tests were performed with the objective of simulating furnace conditions of ongoing full-scale tests at the Greenidge boiler No. 6 owned and operated by NYSEG and defining the processes controlling AR performance to subsequently improve the performance. The tests were conducted in EER's Boiler Simulator Facility. The main fuel pulsing system was used at the BSF to control the degree of unmixedness, thus providing control over furnace gas O_2 and CO concentrations. Results on AR-Lean, presented in the previous quarterly report, were compared with full-scale data. Performance of reburn+SNCR was tested to predict NO_x control at Greenidge. The results of the BSF reburn+SNCR simulation tests demonstrated that there are synergistic advantages of using these two technologies in series. In particular, injection of overfire air provides additional mixing that reduces negative effects on AR performance at the temperature regime of the Greenidge boiler.

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EXECUTIVE SUMMARY

This project is designed to develop a family of novel NO_x control technologies, called Second Generation Advanced Reburning, which has the potential to achieve 90+% NO_x control in coal fired boilers at a significantly lower cost than SCR. The third reporting period in Phase II (April 1 – June 30, 1998) included comparison of the previous AR-Lean results with full-scale data and pilot-scale testing of reburn+SNCR. The pilot scale tests were performed with the objective of predicting reburn+SNCR full-scale tests at the Greenidge boiler scheduled to be conducted in fall 1998. The pilot scale tests were conducted using natural gas as both main and reburning fuel.

The 105 MW Greenidge boiler No. 6, owned and operated by NYSEG, is a tangentially fired unit. The boiler is characterized by upper furnace fluctuations in gas concentrations, and contains zones that have simultaneously high levels of CO and O_2 due to incomplete mixing. To evaluate and optimize AR process performance for Greenidge, these fluctuations were simulated along with boiler design features. The tests were conducted in EER's 300 kW Boiler Simulator Facility (BSF). The main fuel pulsing system described previously was used to simulate the non-uniform conditions at Greenidge.

As in the previous Greenidge simulation tests, two cooling arrays were used in the furnace of the BSF: one simulating the high temperature secondary superheater, which lowers gas temperature from 1450 to 1340 K, and one simulating the reheater, which lowers gas temperature from 1280 to 1170 K. Reburn fuel and OFA were injected upstream of the first cooling array. The N-agent was injected between the two cooling banks or downstream of the second bank. CEM sampling was performed at three locations: just upstream of the first cooling array, just downstream of the second cooling array, and in the convective pass.

Test results demonstrated that fuel pulsing, and consequently pulsations of CO and O_2 concentrations, do not affect the performance of basic reburning, but decrease NO_x reduction of SNCR by about 10% for tested experimental configuration. Performance in combined reburn+SNCR tests was almost independent on pulsing frequency and the reburn fuel flow rate, but decreased with pulsing amplitude. NO reduction in the range of 73-87% was achieved at a pulsing amplitude of 5% for 10% reburning and NSR=1.0. Higher N-agent levels (NSR = 1.5 and 2) increased NO reduction to 85-94%. Results demonstrated that about 70-80% NO reduction can be achieved under Greenidge conditions using an optimized reburn+SNCR regime. Combination of reburning and SNCR has several synergistic advantages over using reburning or SNCR alone. In particular, injection of OFA upstream of the N-agent injection provides additional mixing in the upper furnace zone, reduces the concentrations of CO, and prepares conditions for a more effective SNCR process. Thus, deterioration of SNCR performance in the presence of CO might be minimized by injecting the N-agent after the OFA.

Comparison of the BSF and Greenidge AR-Lean tests demonstrated that high CO concentrations have negative effects on AR-Lean performance. For optimum AR-Lean performance, the CO concentration at the point of N-agent/OFA injection should be below 5000 ppm, preferably 1000-2000 ppm, with a low (less than 0.5%) concentration of oxygen. Experimental observations at Greenidge demonstrate that the upper furnace zone is affected by stratification and there are regions with much higher and much lower CO and O_2 concentrations. In both cases, the performance of AR-Lean is lower than under optimum conditions.

A combined chemistry-mixing AR model is being developed to predict the effect of unmixedness. The Two Stage Lagrangian mixing code with detailed chemistry was applied to model NO_x emissions in AR. Modeling results and comparison with experiments are presented.

1.0 INTRODUCTION

This project is designed to develop a family of novel NO_x control technologies, called Second Generation Advanced Reburning (SGAR or AR), which has the potential to achieve 90+% NO_x control in coal fired boilers at a significantly lower cost than SCR. Phase II consists of six tasks:

- Task 2.1 Project Coordination and Reporting/Deliverables
- Task 2.2 Studies of Other Prospective Additives
- Task 2.3 Development of Combined Chemistry/Mixing Model
- Task 2.4 Optimization of Process Synergism in 1 x 10^6 Btu/hr Tests
- Task 2.5 10.0 x 10^6 Btu/hr Proof-of-Concept Tests
- Task 2.6 Design Methodology Validation

The third quarter of the project (April 1 – June 30, 1998) included pilot scale testing of reburn+SNCR and comparison of the previous results on AR-Lean with full-scale data. The pilot scale tests were performed with the objective of predicting furnace conditions of scheduled for fall 1998 full-scale reburn+SNCR tests at the Greenidge boiler and defining major factors controlling process performance.

Results demonstrated that about 70-80% NO reduction can be achieved under Greenidge conditions using an optimized reburn+SNCR regime. Combination of reburning and SNCR has several synergistic advantages over using reburning or SNCR alone. Comparison of the BSF and Greenidge AR-Lean tests demonstrated that high CO concentrations have negative effects on AR-Lean performance. The upper furnace zone at Greenidge is affected by stratification and there are regions with much higher and much lower CO and O_2 concentrations. In both cases, the performance of AR-Lean is lower than under optimum conditions.

An initial attempt on development of a combined chemistry-mixing AR model is reported. The model will predict the effect of unmixedness in different AR variants. The Two Stage Lagrangian mixing code with detailed chemistry was applied jointly with researchers from Stanford University to model NO_X emissions in basic and advanced reburning.

Results reported below were recently presented at the Advanced Coal-Based Power and Environmental Systemns ’98 Conference (*Zamansky et al., 1998*).

2.0 REBURN+SNCR PILOT-SCALE COMBUSTION TESTS

A series of pilot scale tests was performed in which a combination of reburning and SNCR was applied to the BSF under conditions simulating the furnace fluctuations observed at Greenidge. Previous AR-Lean tests suggested that furnace fluctuations and high CO concentrations might be detrimental to process performance. The objective of these tests was to achieve higher NO_x reductions by injecting the N-agent downstream of the overfire air (reburn+SNCR). It was believed that in this AR configuration, CO concentrations at the point of N-agent injection are lower than in the reburn zone and fluctuations can be dampened out. Addition of promoters into both reburning and SNCR zones in future tests may increase process performance. To examine the effect of fluctuations on performance of the reburn+SNCR process, it was necessary to find out how the fluctuations affect reburning alone, SNCR alone, and then reburning followed by SNCR. The test work was performed at EER’s Boiler Simulator Facility. Description of the facility and experimental methods was included in the previous quarterly report (*Zamansky and Maly, 1998*).

The following paragraphs describe the experimental arrangements in current tests and the observed effect of fluctuations on NO reduction under different test conditions: (1) basic reburning, (2) SNCR alone, (3) combined reburn+SNCR, and (4) variation of fuel pulsing parameters. The results will be used to develop a test matrix for reburn+SNCR experiments at Greenidge.

2.1 Experimental

The pilot scale test work was conducted in EER’s Boiler Simulator Facility (BSF), which has a full load firing capacity of 300 kW (1 MMBtu/hr). The BSF consists of a burner, vertically down–fired radiant furnace, horizontal convective pass, and baghouse. Numerous ports located along the axis of the facility allow access for supplementary equipment such as reburn injectors, additive injectors, overfire air injectors, and sampling probes. The cylindrical furnace section is constructed of eight modular refractory lined sections with an inside diameter of 22 inches. For the Greenidge simulation tests natural gas was used as both the main and reburn fuels. The reburn injector was elbow-shaped, and was installed along the centerline of the furnace, aligned in the direction of gas flow. Overfire air was injected through an elbow-shaped injector to burn out combustibles generated in the reburn zone. Gaseous ammonia, aqueous ammonia, and aqueous urea were used as the N-agent. The N-agent was co-injected downstream of the overfire air.

The Greenidge boiler is characterized by upper furnace fluctuations in gas concentrations, and contains zones that have simultaneously high levels of CO and O_2 due to incomplete mixing. To simulate boiler design, two cooling arrays were installed in the furnace of the BSF: one simulating the high temperature secondary superheater, which lowers gas temperature from 1450 to 1340 K, and one simulating the reheater, which lowers gas temperature from 1280 to 1170 K. Reburn fuel and OFA were injected upstream of the first cooling array. N-agent was injected between the two cooling banks and downstream of the second one. CEM sampling was performed at three locations: just upstream of the first cooling array, just downstream of the second cooling array, and in the convective pass.

The main fuel pulsation system used previously (*Zamansky and Maly, 1998*) was utilized to simulate the fluctuations in furnace gas composition that occur at Greenidge. The fuel delivery system consisted of two lines. One carried the nominal main burner gas at a constant flow rate. The other carried 5-10% of the total main fuel flow rate, and was pulsed from full-open to full-closed. The valve was open and closed for equal time periods. Actual time-averaged SR_2 values (stoichiometric ratios in the reburning zone) were determined by measuring all air flow rates and exhaust O_2 in the convective pass after burnout of most CO and performing a mass balance.

2.2 Effect of Pulsing on Basic Reburning

The effect of fluctuations on reburning alone can be seen from data presented in Figure 2-1 that compares NO reduction for basic reburning at different time-averaged SR_2 and pulsing frequencies. The results suggest that there is no visible effect of pulsing on basic reburning. Fuel fluctuations form regions with increased and decreased SR_2, but the time-averaged SR_2 value is the main parameter defining NO emissions. Observed performance, 17-60% NO reduction, is somewhat low for reburning systems, primarily due to short residence time (0.4 sec) and low initial NO concentration (300 ppm).

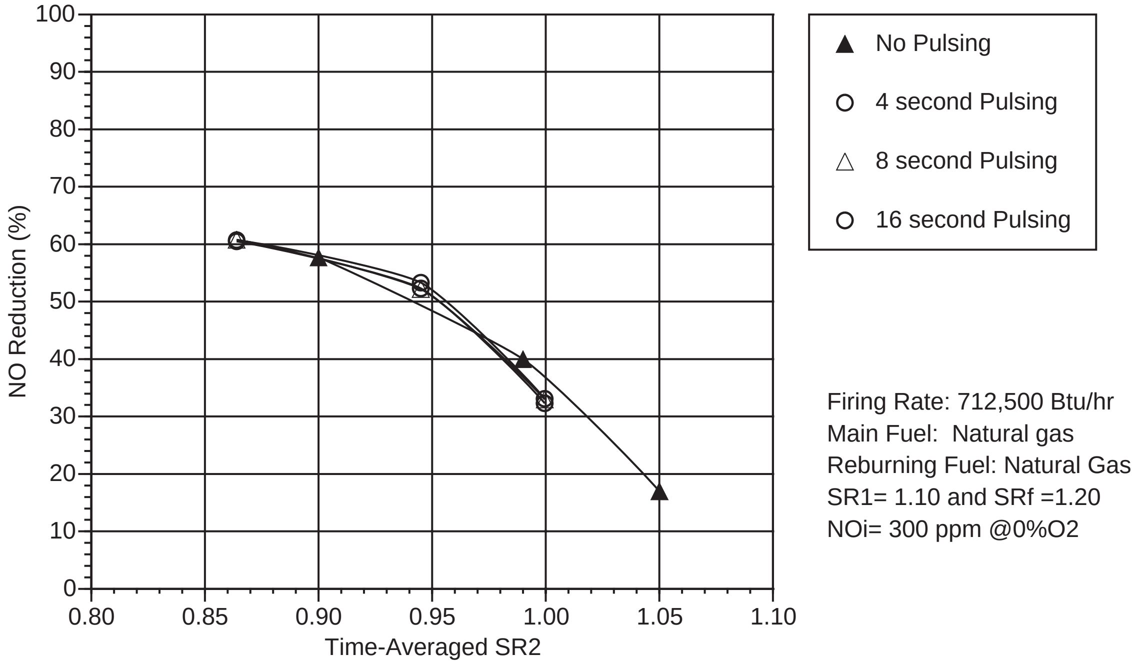

Figure 2-1. Performance of basic reburning at different pulsing frequencies.

2.3 Effect of Pulsing on SNCR

BSF tests were conducted with SNCR alone, to determine how gas fluctuations and high CO concentrations affect N-agent performance in the absence of reburning. Tests were conducted at NSR values ranging from 0.5 to 1.5 at different ammonia injection temperatures. Figure 2-2 shows SNCR performance with and without pulsing. NO reduction increased with increasing NSR and was, at the optimum point, about 10 percentage points better with no pulsing. At NSR = 1.5, a maximum of 88% NO reduction was obtained at 1280 K without pulsing and 78% with pulsing.

2.4 Initial Characterization of Combined Reburning-SNCR Performance

The initial tests were designed to provide combined reburn and SNCR performance data for injection temperatures and residence times simulating those available at Greenidge. Aqueous NH_3 and gaseous NH_3 were tested along with urea as N-agents. Figure 2-3 compares performance of different N-agents in the reburn+SNCR process without pulsing. It appears that gaseous NH_3 has a lower optimum injection temperature than urea or aqueous NH_3. Figure 2-4 compares

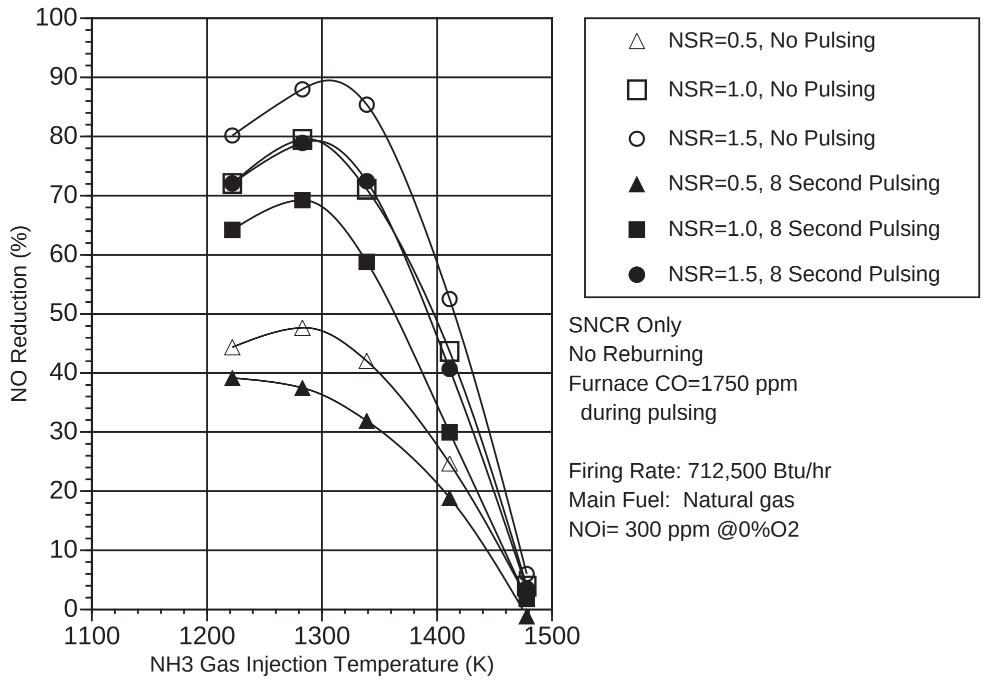

Figure 2-2. SNCR performance as a function of N-agent injection temperature with and without pulsing.

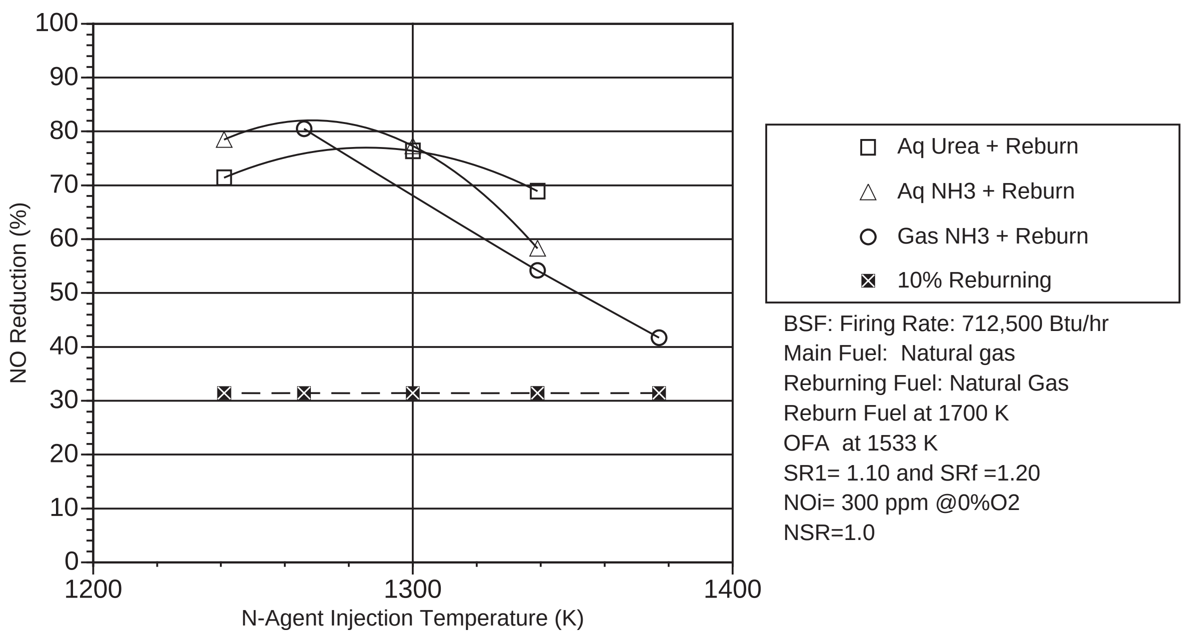

Figure 2-3. Performance of different N-agents as a function of injection temperature without pulsing.

performance of the different N-agents as a function of NSR at two different injection temperatures (also without pulsing). At the lower temperature (1270-1300 K), best performance was obtained with gaseous NH_3. At the higher temperature (1340 K), best performance was obtained with urea.

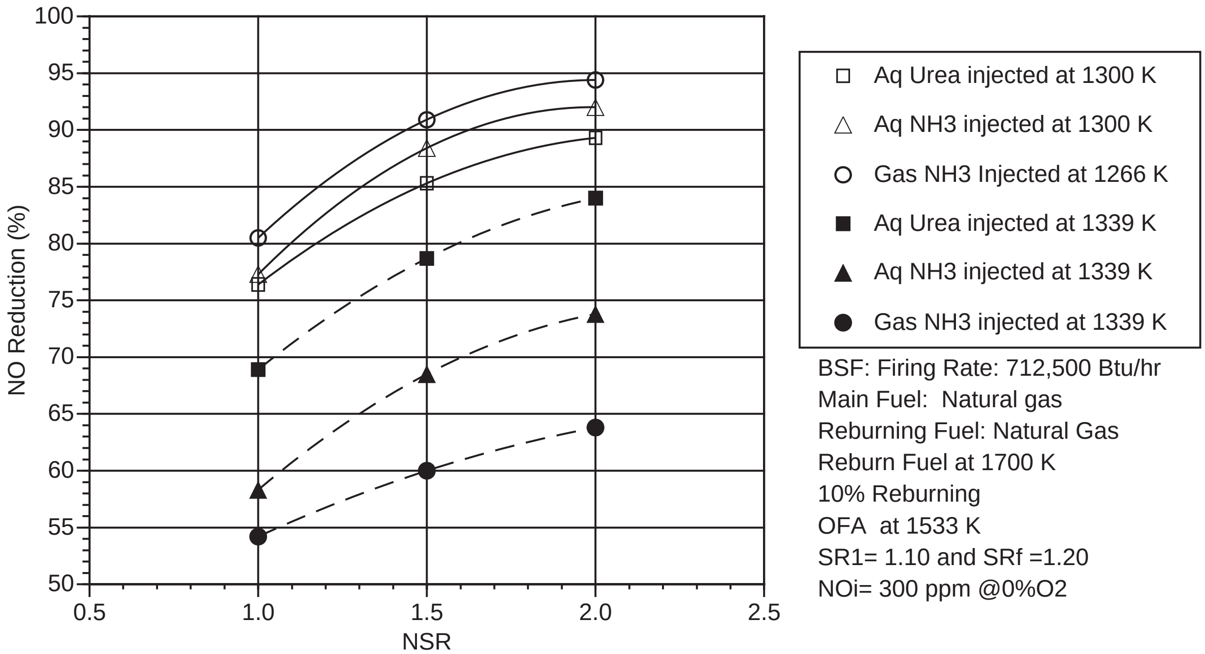

Figure 2-4. Performance of different N-agents as a function of NSR without pulsing.

Figure 2-5 compares results obtained with the three N-agents during pulsing of the main fuel. High NO reductions, in the range of 73-87%, were obtained in these tests. Results appear to be best with gaseous NH_3, although this is largely a function of the injection temperature selected (see Figure 2-3). The impacts of pulsing frequency upon performance were minimal, again suggesting that injecting the N-agent downstream of the OFA might minimize the detrimental impacts of furnace fluctuations.

2.5 Effects of Fuel Pulsing Parameters on Performance

Tests were performed to characterize the concentration of CO in the reburning and SNCR zones and to examine the effects of reburn fuel flow rate and pulsing amplitude. CEM sampling was performed at three locations: in the reburn zone, in the N-agent injection zone (downstream of the OFA) and in the convective pass. The frequency and amplitude of the pulsing were each varied at 10% and 20% reburning. Measurements of CO concentrations as a function of pulsing frequency demonstrated that CO levels were high in the reburn zone (8,000-40,000 ppm depending on reburn heat input), but were lower than 50 ppm in the N-agent injection zone and convective pass.

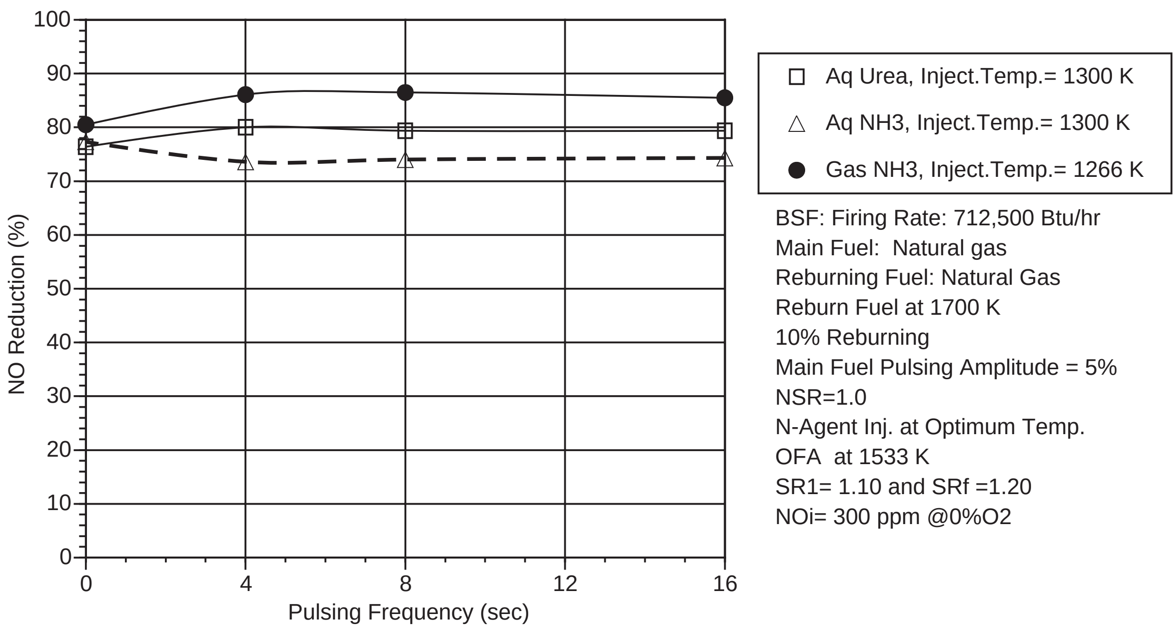

Figure 2-5. Performance of different N-agents during main fuel pulsing.

Figure 2-6 shows reburn+SNCR results as a function of pulsing frequency at 10% and 20% reburning. Varying pulsing frequency did not significantly impact NO reduction. It can be also observed that results are similar at 10% and 20% reburning. It is noted that the urea injection location was the same for 10% and 20% reburning, but injection temperature varied slightly due to impacts of reburn heat input on temperature profile. Figure 2-7 compares results obtained at different pulsing amplitudes. Performance was worse at 10% pulsing than at 5% pulsing.

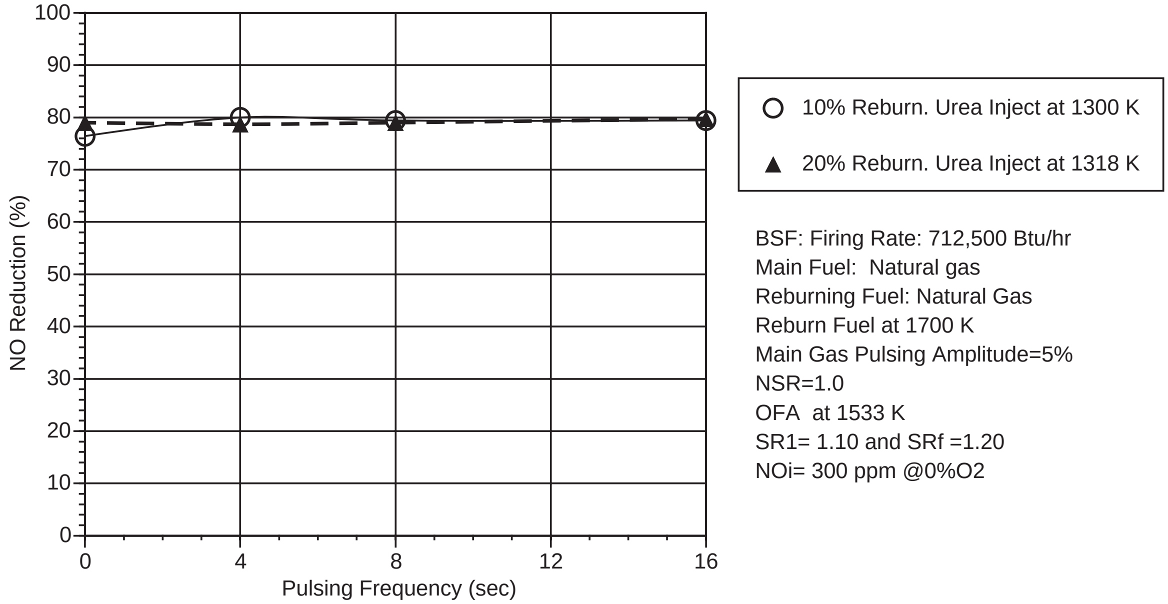

Figure 2-6. Effect of pulsing frequency on performance at 10% and 20% reburning.

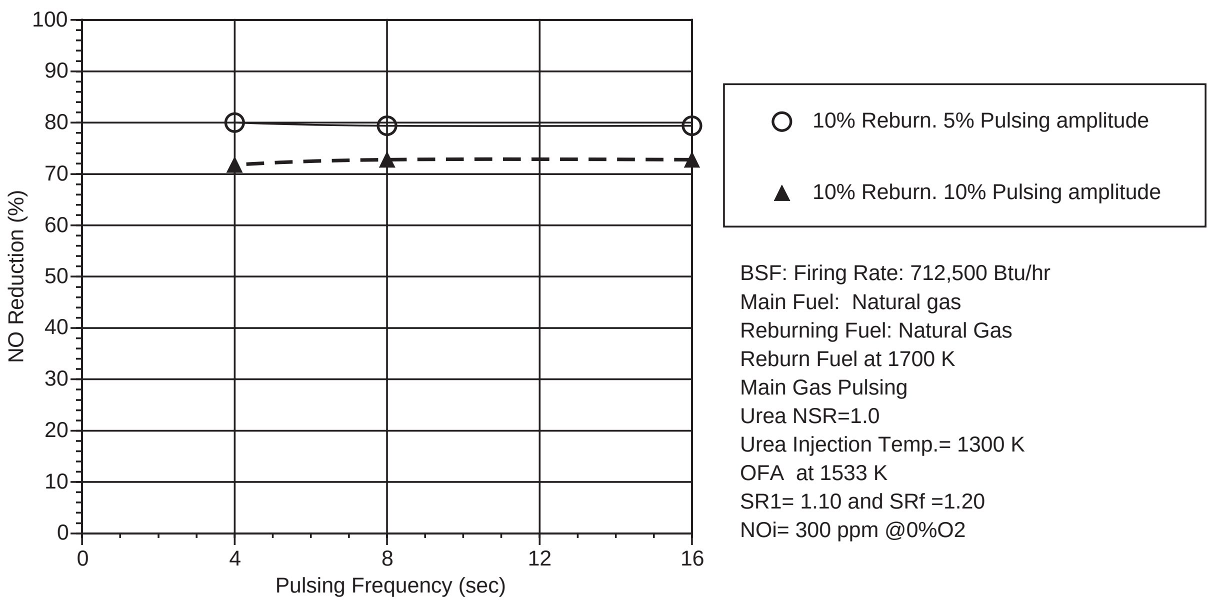

Figure 2-7. Effect of pulsing frequency on performance at 5% and 10% amplitude.

3.0 COMPARISON OF GREENIDGE AND BSF AR-LEAN DATA

This section of the report presents a comparison of AR-Lean data of the Greenidge and BSF systems. In AR-Lean, the N-agent was injected into the furnace along with the OFA. In the following sections, the AR system arrangement on the Greenidge boiler is described, baseline and gas reburning data obtained at Greenidge is presented, and comparison between the Greenidge and BSF AR-Lean data is presented and discussed.

3.1 Description of Greenidge AR System

The Greenidge boiler is a tangentially fired boiler rated at 105 MWe with four burner packs located at the furnace corners. Each corner has four burners, totaling 16 burners. Figure 3-1 shows an overview of the advanced gas reburn system installed on the Greenidge boiler. The reburning fuel system consists of 16 gas injectors, with four injectors located at each corner a short distance above the burner pack. The *furnace OFA* system, which is used during gas reburning tests only, consists of four OFA ports, with one port located at each corner. The *convective pass OFA* system, which is used during advanced gas reburning, consists of a total of 10 ports; with five ports located on each sidewall at the convective pass cavity between the superheater and the reheater platens. Ammonia is injected along with OFA through the convective pass OFA ports. During 1996 parametric tests, ammonia was sprayed into two sidewall ducts upstream of the OFA openings via two individual spray nozzles located in the ducts. This spray system was tested during 1996 parametric tests and indicated maldistribution of ammonia among the East and the West OFA ports. In 1997, the spray system was modified using an individual spray nozzle in each port to provide flexibility in controlling splits among the ports and between each side of the boiler.

3.2 Baseline and Gas Reburn NO_x Data

Since the performance of ammonia is calculated based on the initial NO_x levels after reburning, the gas reburning data is shown for reference purposes. Figure 3-2 shows a plot comparing the gas reburning GR data obtained during 1996 and 1997 parametric tests at Greenidge. As can be seen, the 1997 baseline NO_x level was slightly less than the 1996 level. After the first round of AR tests in 1996, EER recommended to conduct burner modifications to try improving CO/O_2

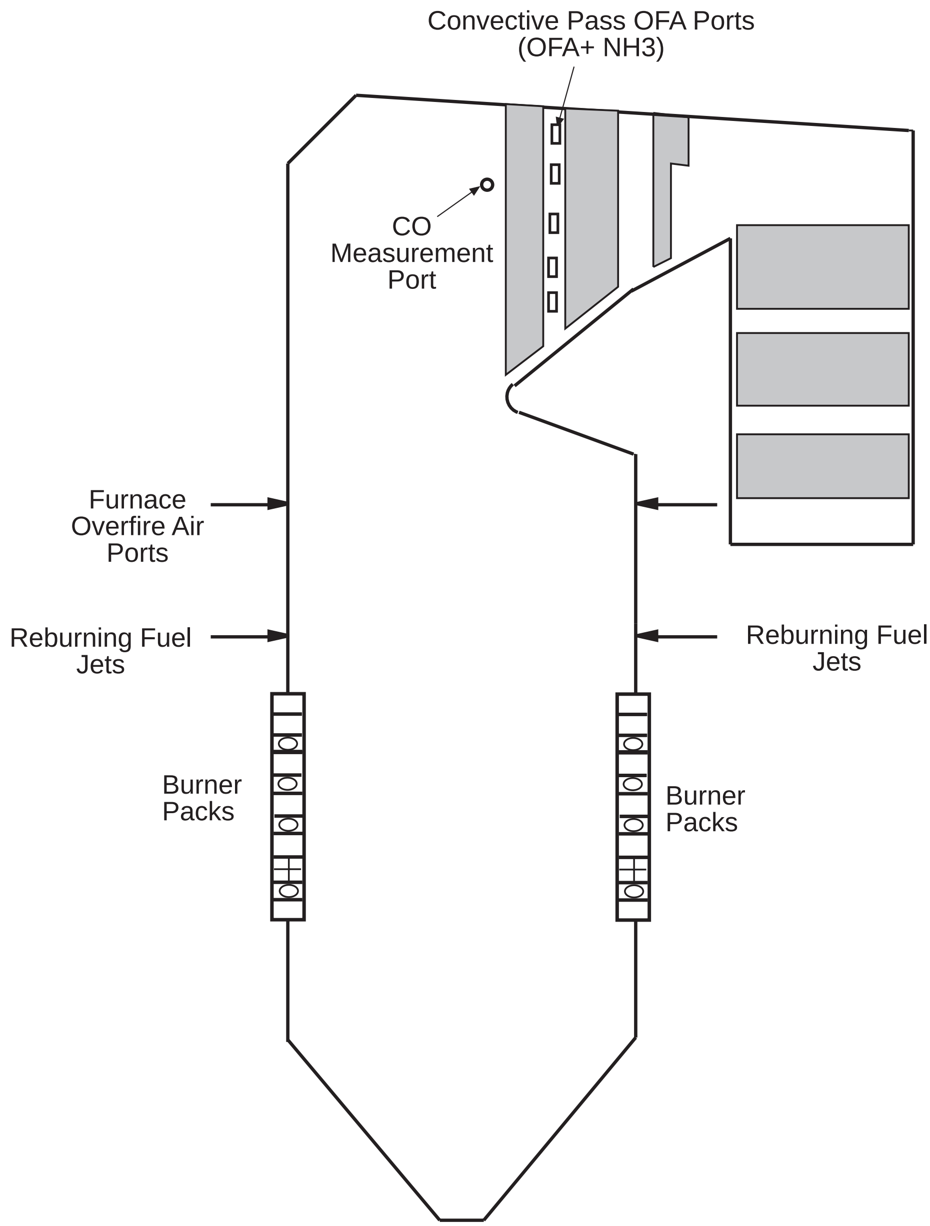

Figure 3-1. Overview of AR injection system arrangement at Greenidge.

distribution in the furnace. In early 1997, some riffle box modifications were performed as well as SMG-10 tests to determine the degree of burner air/fuel distribution. These activities resulted in slight decreases in baseline NO_x emissions and moderate increases in LOI as compared to pre-reburning system installation levels. At typical boiler stoichiometry of 25% excess air, the 1996 baseline NO_x emissions was 0.56 lb/10^6 Btu (485 ppm @ 0% O_2) and the 1997 baseline NO_x level was 0.52 lb/10^6 Btu (450 ppm @ 0% O_2). EER also recommended replacing the gas injectors with supersonic injectors to try improving CO/O_2 distribution in the upper furnace. This resulted in better NO_x reductions, as shown in the plot.

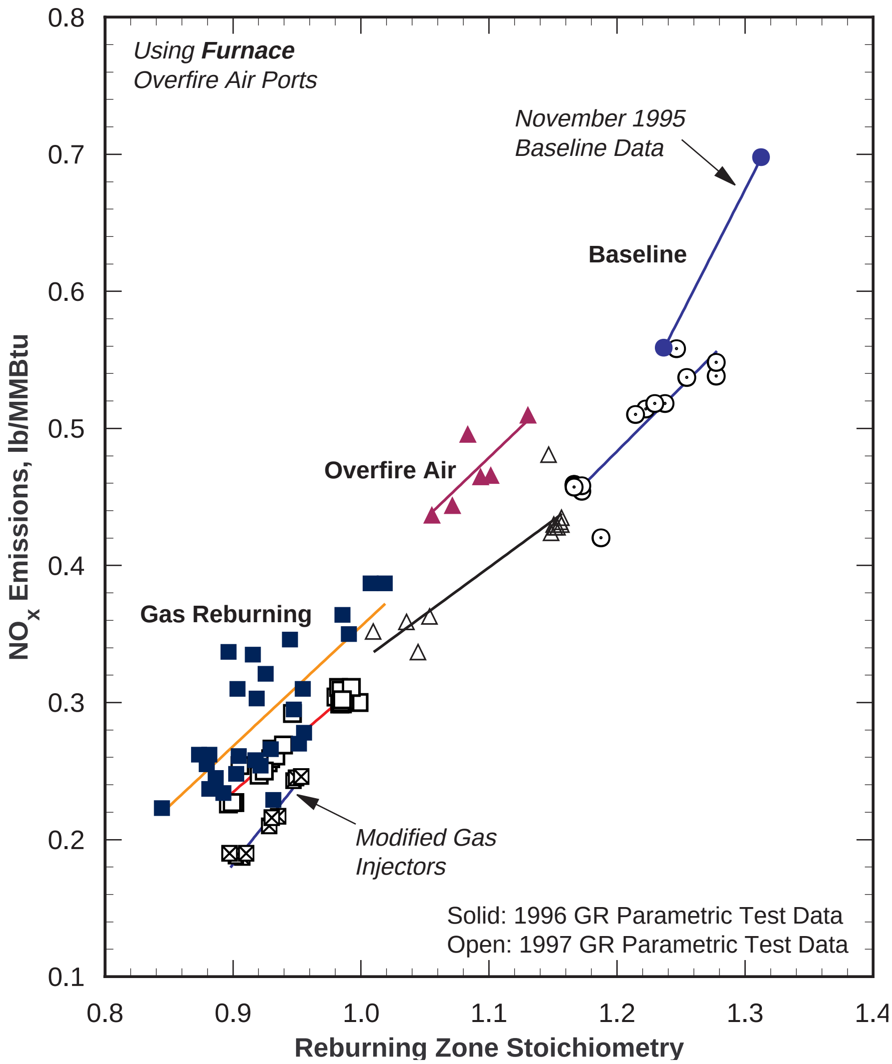

Figure 3-2. Comparison of 1996 and 1997 GR data.

Figure 3-3 shows a comparison of NO_x reduction efficiency due to GR only for the Greenidge and BSF systems. It can be seen that gas reburning efficiency was high for both systems, with the BSF showing a slight better NO_x reduction. At SR_2 of 0.99, which was the typical SR_2 level during the AGR tests, reburning resulted in approximately 39% NO_x reduction in the BSF and about 35 to 40% reduction in the Greenidge boiler. Typically, the SR_2 of 0.99 was achieved with approximately 10% gas reburn heat input when the burners were operated with 10% excess air.

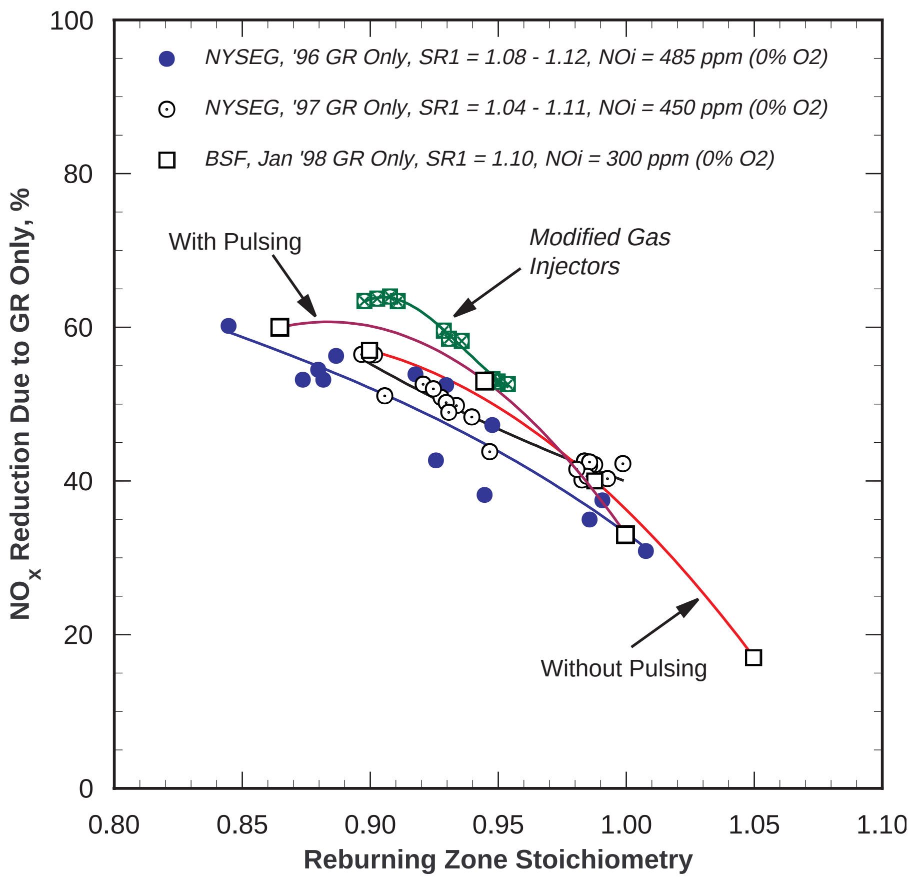

Figure 3-3. Comparison of GR performance between Greenidge and BSF.

3.3 Comparison Between Greenidge and BSF Data

Figure 3-4 shows a plot comparing the impacts of CO concentration on NO_x reduction for the Greenidge and BSF systems. (Please note that the 1996 Greenidge data, which had high NH_3 slip (0 - 100 ppm), were obtained before modifications to the ammonia injection system. The 1997 data, which had much better NH_3 slip (0 - 25 ppm), were obtained after the ammonia system modifications). This plot shows the key difference between the NYSEG and BSF systems. In the BSF furnace, high CO concentrations showed a detrimental impact on NO_x reduction in the BSF system, which is consistent with the results, obtained during the Phase I PRDA studies. As CO concentration in the furnace increased, NO_x reduction performance decreased. Quantitatively, as CO concentration increased to about 15,000 ppm, NO_x reduction percentage decreased to -20% below the GR initial NO_x level. In the Greenidge furnace, CO concentrations varied significantly, both temporal and spatial. In addition, the control for a specific level of CO concentration had been extremely difficult. Although the reburning zone in both systems was set at 0.99, there was no guarantee that they would have had similar levels of CO concentration at the ammonia injection location. One of the key differences might have been due to fluctuating characteristics associated with a full-scale system caused by the unmixedness of the flow from the burners and reburning fuel injectors. Another difference might have been due to the air leakages of the *furnace* OFA ports in the Greenidge system. The furnace OFA ports might have burned some CO as CO entered the superheater platens. Therefore, CO concentrations at the ammonia injection location might actually have been lower that the concentration levels measured in front of the superheater platens. Another piece of data to show the impacts of the furnace OFA ports was the test A, during which the furnace OFA ports were shut down. Test A resulted in negative NO_x reduction (-27% at NSR = 1.0), similar to the BSF results. Because the opacity was very unstable during this test, in-furnace data were not recorded. However, readings during the test set-up indicated CO concentration levels of approximately 20,000 ppm.

Figure 3-5 shows the impacts of injection temperature on NO_x reduction performance of ammonia for both systems. The figure shows three plots for NSR at 0.5, 1.0 and 1.5. Temperatures in the BSF were measured at the NH_3/OFA injection elevation. Injection temperatures for Greenidge were determined by subtracting 125 K (225°F) (based upon heat transfer modeling results) from the measured temperatures in front of the superheater platens. The BSF data indicated that injecting ammonia at high temperatures, i.e., greater than 1367 K (2000°F), had negative impacts on AR-Lean performance, as indicated by decreases in NO_x reduction efficiency as temperature

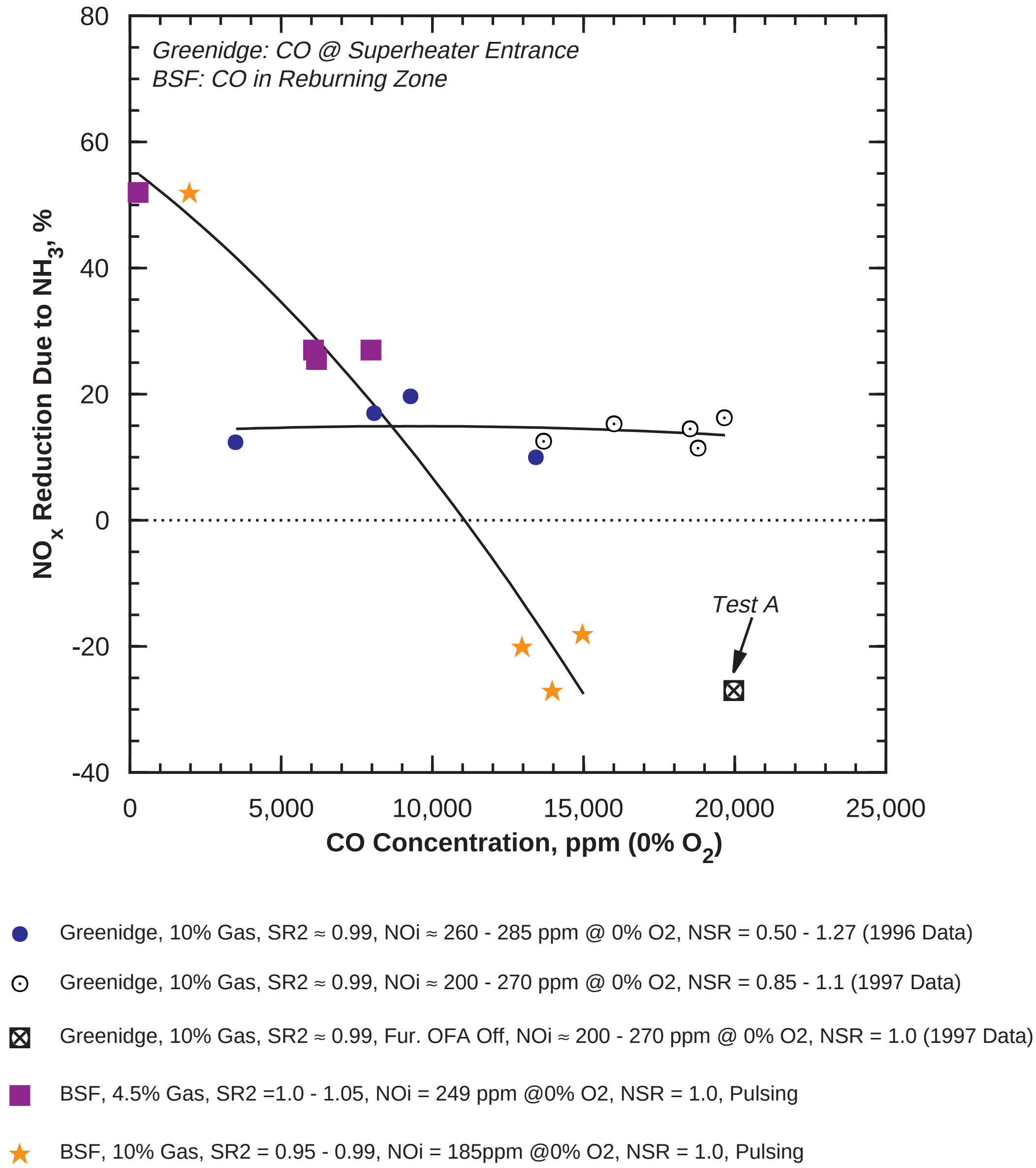

Figure 3-4. Comparison of the impacts of CO concentration on NO_x reduction in AR Lean tests.

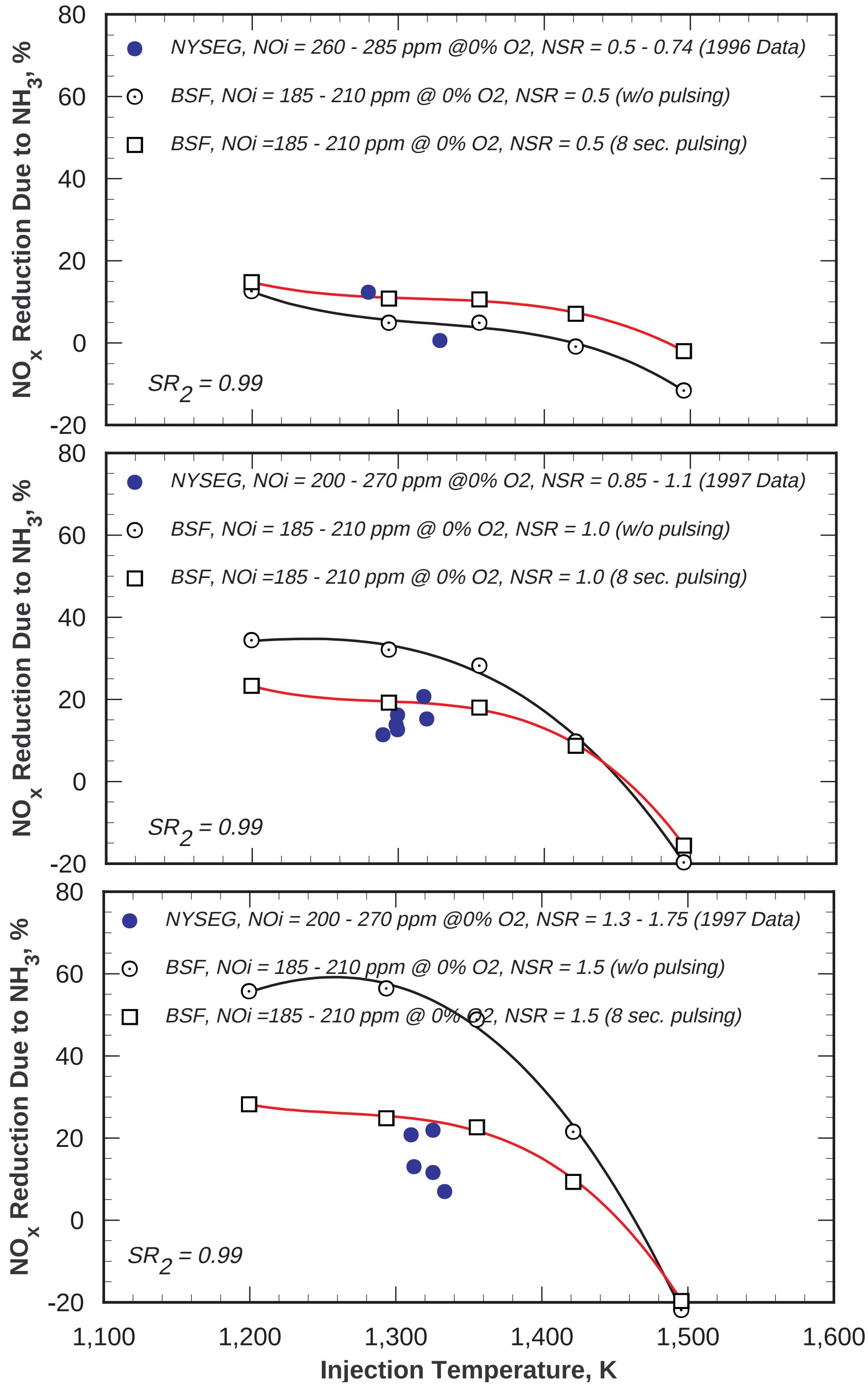

Figure 3-5. Comparison of the impacts of injection temperature on NO_x reduction.

increased. The full-scale data appear to be in the range with pulsing data of the BSF. The comparison seems to suggest that the injection location for the Greenidge AR-Lean system is reasonable because the injection temperatures reside at the region before performance starts to drop off. The rapid quench rate of the Greenidge reheater section may have been responsible for the relatively high ammonia slip that was obtained in the field.

Figure 3-6 shows a plot of NO_x reduction due to ammonia only as a function of NSR. For the BSF, the data were collected with ammonia injected with OFA at 1355°K and two levels of CO concentration: 2,000 and 6,000 ppm. The plot shows that the full-scale system was substantially less effective than the pilot-scale system. As previously discussed about the effect of CO concentration, the data seem to suggest that (keeping the effect of flow field stratification in mind) the average CO concentrations at the convective pass cavity of Greenidge must have been higher than 6,000 ppm, possibly in the order of 10,000 ppm. The measured CO concentrations in front of the superheater platens were 14,000 to 20,000 ppm.

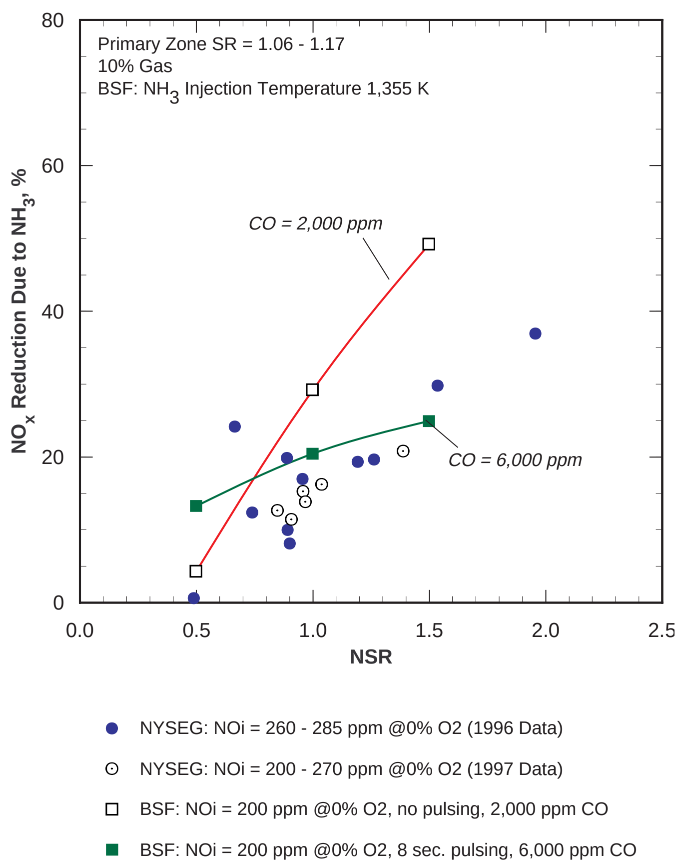

Figure 3-6. NO_x reduction due to ammonia only (AR-Lean).

4.0 PILOT-SCALE TESTS: DISCUSSTION AND CONCLUSIONS

Pilot-scale tests were conducted under different process conditions to simulate and predict the performance of AR-Lean and reburn+SNCR in the Greenidge 105 MW tangentially fired boiler. The boiler is characterized by upper furnace fluctuations in CO and O_2 concentrations due to incomplete mixing. A pulsing system was installed in the main fuel delivery line to simulate the fluctuations in furnace gas composition that occur at Greenidge. Pilot-scale test results are discussed separately for two experimental configurations: AR-Lean and reburn+SNCR.

4.1 Reburn+SNCR

Test results demonstrated that fuel pulsing, and consequently pulsations of CO and O_2 concentrations, do not affect the performance of basic reburning, but decrease NO_x reduction of SNCR by about 10% for tested experimental configuration.

Performance in combined reburn–SNCR tests was almost independent on pulsing frequency and the reburn fuel flow rate, but decreased with pulsing amplitude. NO reduction in the range of 73-87% was achieved at a pulsing amplitude of 5% for 10% reburning and NSR=1.0 (Figure 2-5). Higher N-agent levels (NSR = 1.5 and 2) increased NO reduction to 85-94% (Figure 2-4). Results demonstrate that about 70-80% NO reduction can be achieved under Greenidge conditions using an optimized reburn+SNCR regime. Combination of reburning and SNCR has the following synergistic advantages over using reburning or SNCR alone:

- The combined method can provide higher level of NO reduction at full scale than individual technologies.
- SNCR performance is higher at low fuel pulsations and relatively low concentration of CO in the gas mixture. Injection of OFA upstream of the N-agent injection provides additional mixing in the upper furnace zone, reduces the concentrations of CO, and prepares conditions for a more effective SNCR process. Thus, deterioration of SNCR performance in the presence of CO might be minimized by injecting the N-agent after the OFA.
- Combined reburn-SNCR process requires relatively low input of the reburning fuel. As shown in Figure 2-6, injection of 10% and 20% reburning fuel resulted in almost identical high level of NO reduction, about 80%.
- High NO reduction level can be achieved with relatively low input of the N-agent compared

to SNCR alone. For example, if the initial NO concentration is 300 ppm, SNCR alone requires 300 ppm ammonia or urea to provide NSR=1. In the combined process, reburning reduces NO by about 50-60%, and 120-150 ppm of N-agent is necessary for providing NSR=1. Reduced consumption of N-agent reduces ammonia slip and N_2O emissions.

4.2 AR-Lean

The NO_x reduction performance at Greenidge is similar to that of the BSF pulsing tests for basic reburning, but less than the BSF counterpart for AR-Lean. This discrepancy is most likely due to the difficulty in controlling the amount of CO concentration in the ammonia injection elevation at full scale. The rapid quench rate at the Greenidge reheater section is probably responsible for the relatively high ammonia slip.

The results of the BSF simulation tests demonstrated that high CO concentrations have negative effects on AR-Lean performance at the NH_3/OFA injection location in the Greenidge boiler. For optimum AR-Lean performance, the CO concentration at the point of N-agent/OFA injection should be below 5000 ppm, preferably 1000-2000 ppm, with a low (less than 0.5%) concentration of oxygen. Experimental observations at Greenidge demonstrate that the upper furnace zone is affected by stratification and there are regions with much higher and much lower CO and O_2 concentrations. In both cases, the performance of AR-Lean is lower than under optimum conditions. The results show that high CO concentrations in the N-agent/OFA injection zone of AR-Lean may result in negative NO reductions, i.e. NO increases. This effect can be explained by formation of higher concentrations of active species (OH radicals and O atoms) due to the chain branching reaction of CO oxidation. Under these conditions, the NH_2 radicals formed from the N-agent have higher tendency for oxidation to NO than for NO reduction.

The performance of AR-Lean is better at lower flow rate of the reburning fuel. For instance, 78% NO reduction was achieved at 5% reburning and ammonia/OFA injection at 1280 K compared to only 55% NO reduction at 10% reburning (Figures 3-4 and 3-5). This can be attributed to the negative effect of higher CO levels formed in the gas mixture due to increased fuel concentration.

The comparison of OFA/N-agent injection temperatures suggests that the Greenidge NH_3/OFA ports, located at a temperature of about 1300 K, approximately correspond to optimum injection temperature for urea and slightly higher than the optimum injection temperature for gaseous ammonia.

5.0 CHEMISTRY-MIXING MODELING

The objective of combined chemistry-mixing modeling is to create a model for predicting the NO_x control performance via reburning and AR in a real boiler. It was recently demonstrated by utilizing EER's One Dimensional Flame code (*Zamansky et al., 1997*) that distributed fuel addition significantly affects NO_x emissions in AR.

Modeling results reported here were obtained jointly with G. Mungal and D. Han from Stanford University. In the current study, the Two Stage Lagrangian (TSL) model (*Broadwell, 1988; Broadwell and Lutz, 1998)* was applied. The model was initially utilized for predicting performance of the BSF reactor without taking into account the fluctuations in furnace gas composition observed at Greenidge. In the TSL model, the reaction of fuel and oxidizer is modeled as two well-stirred reactors. The first reactor represents the initial meeting of fuel and air forming a flame sheet, and the products are fed to a second reactor in which a fuel reacts with product mixture. The fuel concentration in the second reactor decreases due to dilution with the products. Simplified description of mixing thus eliminates the need to calculate the detailed flow field, allowing incorporating a detailed chemical mechanism.

The strength of the TSL model is that it allows computation of some important features of mixing with detailed chemistry, so that the effect of various fuels, N-agents, and reburning promoters can be explored. It is important to incorporate the full chemistry in the model since concentrations of NO_X in flue gas are highly sensitive to chemical additives.

In the TSL model, the entrainment rate is an empirical input; for this application, the results of the jet in crossflow were taken from *Mungal et al., 1998*.

The reaction mechanism used for modeling was based on the GRI-Mech version 2.11 (*Bowman et al., 1995*) with additional reactions (*Bowman, 1996*) characterizing the Thermal $DeNO_x$ process and the effect of sodium. The complete mechanism was presented elsewhere (*Zamansky et al., 1996 and 1997*). The total mechanism included 355 reactions of 65 species.

TSL model inputs for the BSF are shown in Figure 5-1. Comparison of experimental and modeling results is presented in Figure 5-2. The initial NO concentration was 600 ppm. The combustion process in the main combustion zone was modeled as a well-stirred reactor and solved using Chemkin-II (*Kee et al., 1992*) code with the measured temperature profile. The reburning fuel is injected at 1710 K in the form of 8 transverse jets oriented at 27^o upstream, and originating from a single pipe. Injection of the reburning fuel results in slightly fuel rich mixture, $SR_2 = 0.99$. Aqueous urea is added as an N-agent with NSR = 1.5. Mixing of the N-agent with the products was assumed instantaneous. OFA was added in the form of 24 transverse jets.

Figure 5-2 shows the experimental data and initial modeling results on prediction of NO reduction by basic and advanced reburning processes. The unknown temperature of the overfire air jets was used (within a range consistent with operating conditions) as a single fitting parameter for all predictions. For basic reburning, the model predicts 51% remaining NO, compared with the experimental results showing the remaining NO to be between 49 to 53%. For the advanced reburning process, the model predicts NO remaining in the range of 30-40% depending on the injection temperatures with a very good agreement with the test data.

It should be pointed out that although the TSL-based model includes a detailed chemical mechanism, the calculation time is minimal. It requires about 20 minutes of computation time using an Intel Pentium-based machine to simulate the BSF with selected operating conditions. Thus, the model can be utilized as a practical design tool for the determination of optimal operating conditions.

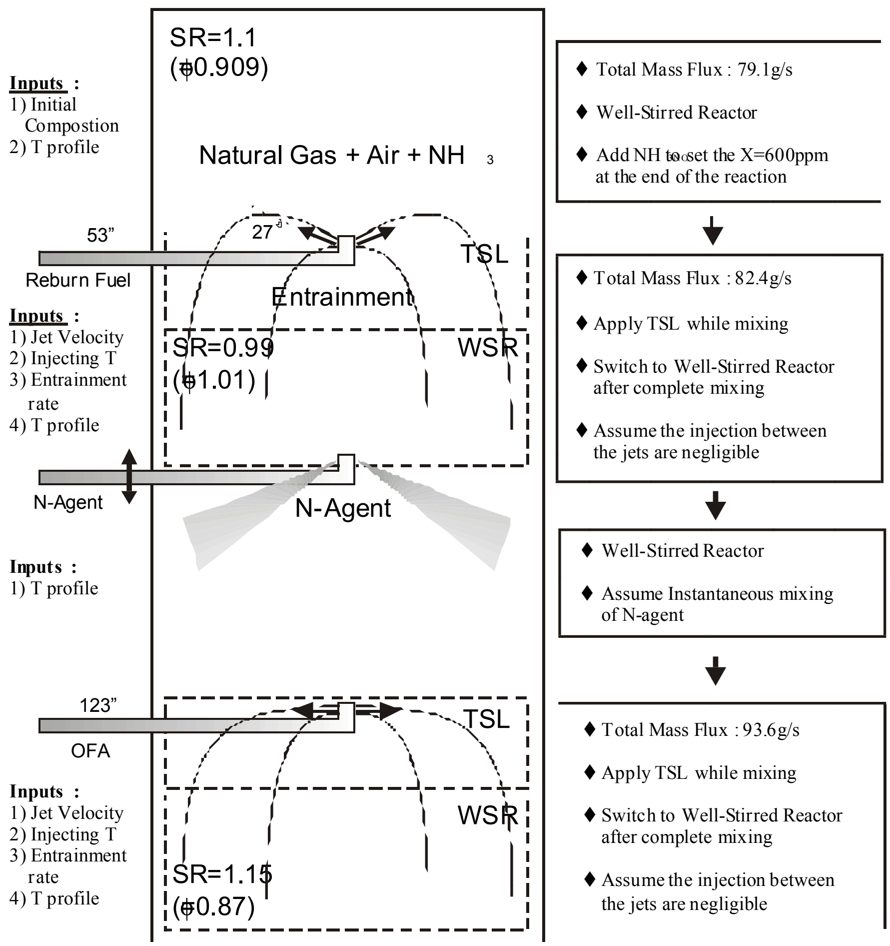

Figure 5-1. The modeling scheme and inputs required at each stage.

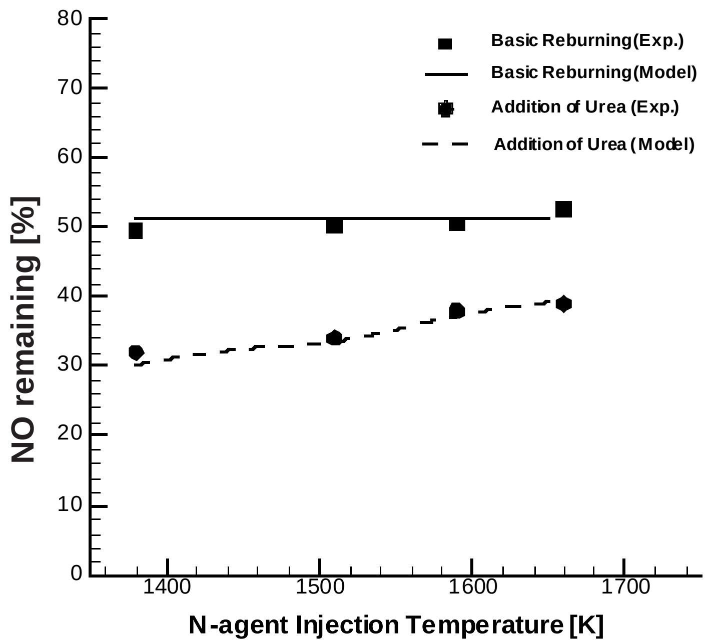

Figure 5-2. Comparison of TSL model predictions with experimental data.

6.0 FUTURE PLANS

Results of the pilot scale Greenidge simulation tests explained the low efficiency of the AR-Lean system under non-uniform, stratified conditions at Greenidge. The results also predicted a higher performance of reburn+SNCR in full scale. The next step is to conduct full-scale parametric tests with the objective to achieve higher AR process performance. These tests are scheduled for fall 1998. The test matrix will be based on the pilot-scale results reported here and in the previous quarterly report.

Pilot-scale tests on simulation of Greenidge conditions are currently continued in two directions. First, conditions of N-agent injection are being optimized for minimization of ammonia slip. Second, addition of sodium compounds is tested as a means for increasing NO reduction.

Other project activities of the next quarter will include further combined chemistry-mixing modeling studies for description of basic and AR processes and BSF testing of alternative AR promoters.

7.0 REFERENCES

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