This report includes colored pictures

SECOND GENERATION ADVANCED REBURNING FOR HIGH EFFICIENCY NO_x CONTROL

Quarterly Report No. 8

for Period July 1 – September 26, 1999

Prepared by:

Vladimir M. Zamansky, Peter M. Maly and Vitali V. Lissianski

October 29, 1999

DOE Contract No. DE-AC22-95PC95251--16

Submitted by:

GE Energy and Environmental Research Corporation

18 Mason, Irvine, CA 92618

Disclaimer

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 Selective Catalytic Reduction. The eighth reporting period in Phase II (July 1 – September 26, 1999) included combined chemistry-mixing modeling on advanced gas reburning and experimental activities in support of modeling. Modeling efforts focused on description of AR-Lean – combination of basic reburning and co-injection of N-agent with overfire air. Modeling suggests that efficiency of AR-Lean strongly depends on the amount of the reburning fuel, temperature of flue gas at the point of OFA/N-agent injection, and evaporation time of N-agent. The model describes the most important features of AR-Lean and can be used for AR-Lean optimization.

Table of Contents

Section	Page
Abstract	3
Executive Summary	5
1.0 Introduction	6
2.0 Mapping of AR-Lean at NSR = 1.5	7
3.0 Mapping of AR-Lean at NSR = 0.7	8
4.0 Conclusions	11
5.0 Future Work	12
6.0 Reference	12

List of Figures

Figures	Page
Figure 1. Map of the AR-Lean process at NSR = 1.5	8
Figure 2. Map of the AR-Lean process at NSR = 0.7	9
Figure 3. Diagram of AR-Lean at 1300 K. NSR = 0.7	10
Figure 4. Predicted performances of basic reburning, AR-Lean and reburning + SNCR	11

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 eighth reporting period in Phase II (July 1 – September 26, 1999) included combined chemistry-mixing modeling on advanced gas reburning and experimental activities in support of modeling efforts.

The modeling efforts concentrated on description of AR-Lean – combination of basic reburning and co-injection of N-agent with OFA. The purposes of kinetic modeling were to 1) identify parameters affecting AR-Lean, 2) determine ranges of active parameters that result in the best technology performance, and 3) optimize AR-Lean. Modeling suggested that efficiency of AR-Lean strongly depends on the amount of the reburning fuel, temperature of flue gas at the point of OFA/N-agent injection, and evaporation time of N-agent. Modeling predicted that selection of these parameters in the optimum range results in the efficiency of the AR-Lean process in BSF as high as 90+% at NSR = 1.5. Process parameters in the model can be adjusted to optimize AR-Lean for a specific facility.

The goal of combustion tests was to support model development. Tests were conducted in the Boiler Simulator Facility. The test variables included the temperature of flue gas at the point of N-agent injection, the amount of the reburning fuel, and the amount of N-agent. Modeling predictions agree with experimental data in a wide range of conditions.

1.0 Introduction

As it was previously demonstrated by Zamansky et al. [1], the AR-Lean model correctly describes the main features of the process observed in experiments. This allows use of the model to optimize AR-Lean to obtain the best possible performance. Because of the model limitations (mostly due to simplified representation of mixing), this approach can hardly be used to determine exact values of parameters (for example, amount of the reburning fuel and N-agent, temperature of flue gas at the point of N-agent injection, etc.) that result in the best performance. However, the model can determine ranges of these parameters required for the best performance. The guidance of the model then can be used for experimental optimization of the AR-Lean technology.

The developed model [1] of the AR-Lean process incorporates some features that are specific for the BSF. For example, mixing time in the reburning and OFA zones were estimated using characteristics of nozzles utilized in the BSF. Modeling also took into account temperature profile measured in the BSF. Other combustion facilities have different thermal and mixing characteristics, and this may result in different optimum conditions for AR-Lean. However, differences in the process characteristics can be taken into account by adjusting appropriate parameters in the model to optimize AR-Lean for a specific facility.

The following sections describe how the proposed approach can be used to "map" the AR-Lean process. "Mapping" is defined here as creation of diagrams that show efficiency of NO_x reduction as a function of two parameters while other parameters are kept constant. Such diagrams can be used to identify effective ranges of process parameters. They also can be used to estimate the maximum level of NO_x reduction that can be achieved at optimum conditions in a particular facility.

Modeling was used to determine the effects of several process parameters on performance of AR-Lean. The following parameters were considered:

- The amount of the reburning fuel.
- Temperature of flue gas at the point of OFA/N-agent injection.
- Evaporation time of the N-agent.
- The amount of N-agent.
- Initial temperature of OFA/N-agent.

Modeling predicted [1] that selection of these parameters in the optimum range results in the efficiency of the AR-Lean process in BSF as high as 90+%. It also showed that some of the parameters can be excluded from consideration since their variations have small or negative impact on NO_x reduction. For example, it was shown [1] that preheating of OFA and N-agent results in degradation of the AR-Lean performance. Thus, minimum available initial temperature of OFA gives the best process performance. Modeling also identified optimum range for the amount of N-agent [1]. Assuming that the amount of N-agent is in this range (for example, NSR = 1.5), the remaining parameters of interest are amount of the reburning fuel, temperature of flue gas at the point of OFA/N-agent injection and evaporation time of N-agent.

Experimental data on AR-Lean that were used for the model development were obtained at constant N-agent spray characteristics. Thus, evaporation time of N-agent was not a test variable. To enable comparison of model predictions with experimental data, the mapping of AR-Lean at NSR = 1.5 was limited to two parameters only: the amount of the reburning fuel and temperature of flue gas at the point of OFA/N-agent injection. It was assumed in modeling that evaporation of N-agent was fast and occurred within time scale of the mixing process in OFA zone. This assumption was made based on estimation of droplet evaporation times for typical BSF conditions. The effect of N-agent evaporation time on NO_x reduction will be considered in *Section 3.0*.

2.0 Mapping of AR-Lean at NSR = 1.5

A series of modeling runs were conducted to determine the effects of the amount of the reburning fuel and temperature of flue gas at the point of OFA/N-agent injection on the AR-Lean performance. The amount of the reburning fuel varied from 0 to 10% of the total amount of fuel. For each amount of reburning fuel, the OFA/N-agent injection temperature varied from 1200 K to 1500 K. These calculations were conducted in addition to efforts undertaken during model development and validation to give more detailed information on the process performance.

Figure 1 shows a contour diagram, or a map, of the AR-Lean performance. The experimental data are shown in Fig. 1 as symbols. Colors of symbols and lines correspond to different levels of NO_x reduction. Comparison of modeling predictions with experimental data shows good agreement for a wide range of conditions. Modeling identified the following region with highest NO_x reductions: amount of the reburning fuel in the range 0-5%, OFA/N-agent injection temperature around 1300 K. Modeling suggests (and confirmed by experiments) that the efficiency of NO_x reduction in this region is in the range 90-95%.

It is known that the optimum temperature range for the reaction of N-agent and NO in the presence of CO shifts toward lower temperatures. As the amount of reburning fuel increases over 5%, the amount of CO coming from the reburning becomes significant. As a result, optimum AR-Lean performance at higher than 5% reburning fuel occurs at OFA/N-agent injection temperatures less than 1300 K. At 10% reburning, the optimum OFA/N-agent injection temperatures lie in the range 1150-1200 K.

Figure 1 summarizes most of the modeling results presented in previous study [1]. Thus, conclusions that can be made from mapping AR-Lean at NSR = 1.5 are not different from what was stated earlier. *The AR-Lean process is the most effective at small amounts of the reburning fuel and OFA/N-agent injection temperatures that are found to be effective in the SNCR process.*

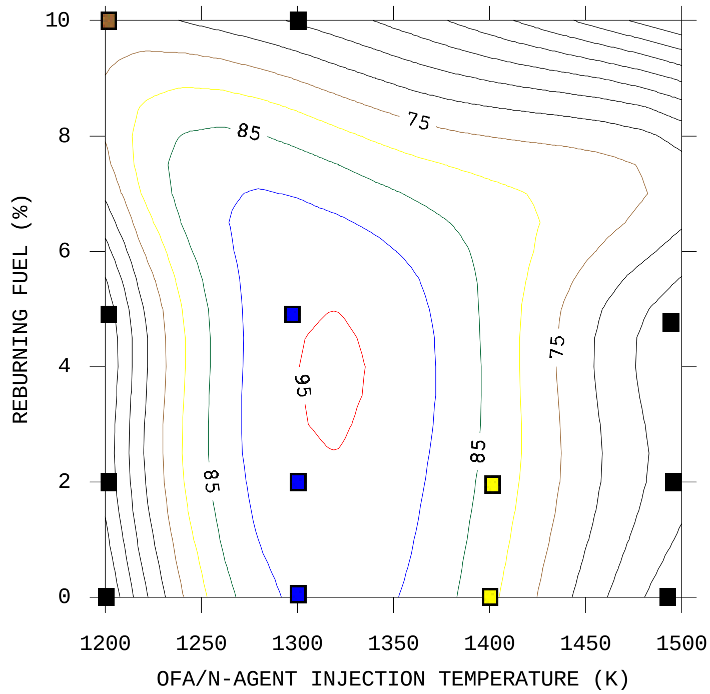

Figure 1. Map of the AR-Lean process at NSR = 1.5. Lines represent calculations, symbols experimental data. Colors of the symbols and lines correspond to different levels of NO_x reduction. Evaporation time of the N-agent is less than OFA mixing time.

3.0 Mapping of AR-Lean at NSR = 0.7

Modeling predicts (and experiments confirm) that due to effective mixing, the efficiency of the SNCR process in BSF at 1300 K and NSR = 1.5 is very high (about 90% NO_x reduction). It is not surprising that increasing the amount of reburning fuel up to 5% does not significantly improve NO_x reduction. It is known, however, that in practical full-scale installations, the non-uniformity of the temperature profile, difficulties of mixing the N-Agent across the full boiler cross section, and limited residence time for reactions limit effectiveness of SNCR to 30-50%. The remaining N-agent passes through the system and appears as ammonia slip. Under such mixing conditions, the efficiency of AR-Lean process may depend more strongly on the amount of the reburning fuel. One way to simulate poor mixing of N-agent with flue gas is to reduce the amount of N-agent to the level that provides 40-50% NO_x reduction, thus reflecting the N-agent available to react. Thus, it is of practical interest to study AR-Lean for NSR smaller than 1.5.

Figure 2 shows performance of the AR-Lean process at NSR = 0.7. The maximum NO_x reduction in the SNCR process (no reburning fuel), predicted by modeling, is 54%. Modeling results show that at 1300 K (optimum temperature for injection of OFA/N-agent) the efficiency of AR-Lean process first increases as the amount of the reburning fuel increases, and then decreases. The maximum NO_x reduction predicted by modeling is 62% and is achieved at 5% reburning.

Based on modeling predictions, a series of tests were conducted in BSF to determine the effect of the amount of the reburning fuel on NO_x reduction in AR-Lean. Test results are shown in Fig. 2 as symbols. Tests confirmed that maximum NO_x

reduction at NSR = 0.7 and 1300 K is achieved at 5% of the reburning fuel. Maximum reduction observed in tests was 66% - slightly higher than that predicted by modeling.

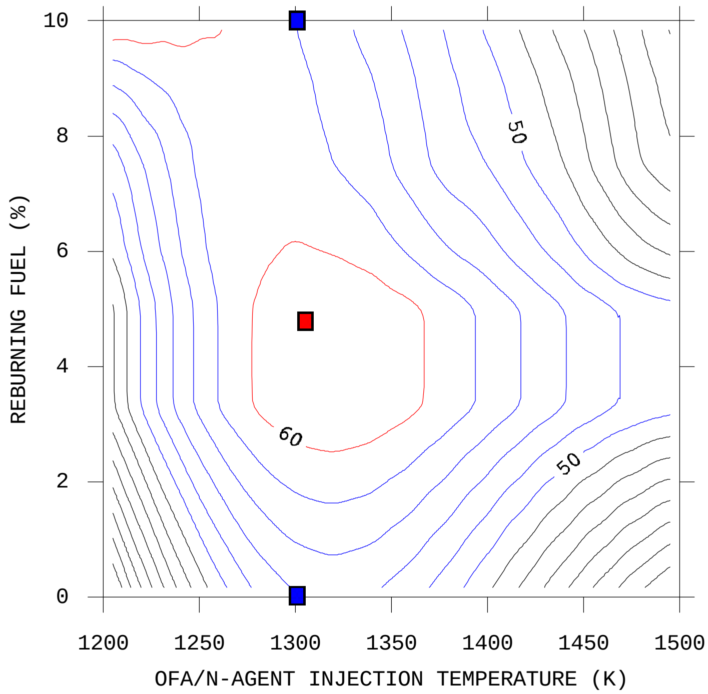

Figure 2. Map of the AR-Lean process at NSR = 0.7. Evaporation time of the N-agent is less than OFA mixing time.

The following conclusions can be derived from mapping of AR-Lean at NSR =1.5 and 0.7:

1. When evaporation time is smaller than mixing time of OFA in the burnout zone (N-agent is injected as a gas or as droplets of small size), the AR-Lean process is most efficient at an amount of the reburning fuel less than or equal to 5% of total fuel and at OFA/N-agent injection temperatures in the range 1280-1350 K. However, it should be considered that the efficiency of AR-Lean depends on evaporation time of the N-agent.
2. Maximum NO_x reduction for these conditions depends on the amount of N-agent and efficiency of the mixing process in the burnout zone. The efficiency of AR-Lean at optimum conditions is 6-15 percentage points higher than the efficiency of SNCR under similar conditions.

The second region of high NO_x reduction identified by modeling for NSR = 0.7 is located at 10% reburning and around l200 K OFA/N-agent injection temperatures. Since in full-scale boilers OFA is usually injected temperatures at higher than 1200 K, this result can be considered as being mostly of theoretical interest. The occurrence of high NO_x reduction region at large heat inputs of the reburning fuel and low temperatures is due to the fact that CO formed in the reburning zone interacts with the chemistry of NO_x reduction by N-agent in the burnout zone. As a result, the most optimum conditions for NO_x reduction are shifted toward lower temperatures. Optimum conditions for NO_x

reduction can occur at higher injection temperatures if the evaporation time of N-agent is increased. This will allow CO to be oxidized before N-agent reaches gas phase and reacts with NO. The increase in droplet evaporation time can be achieved, for example, by increasing the average droplet size of N-agent.

Figure 3 shows the predicted performance of AR-Lean as function of the amount of the reburning fuel and evaporation time of N-agent. The N-agent is injected at a flue gas temperature of 1300 K. This temperature was selected for the contour diagram because the highest levels of NO_x reduction for small droplets of N-agent were observed at 1300 K. Figure 14 predicts that combination of 18% reburning and injection of N-agent results in about 80% NO_x reduction when droplets of larger size are used, while 5% reburning provides no more than 65% NO_x reduction at any droplet size.

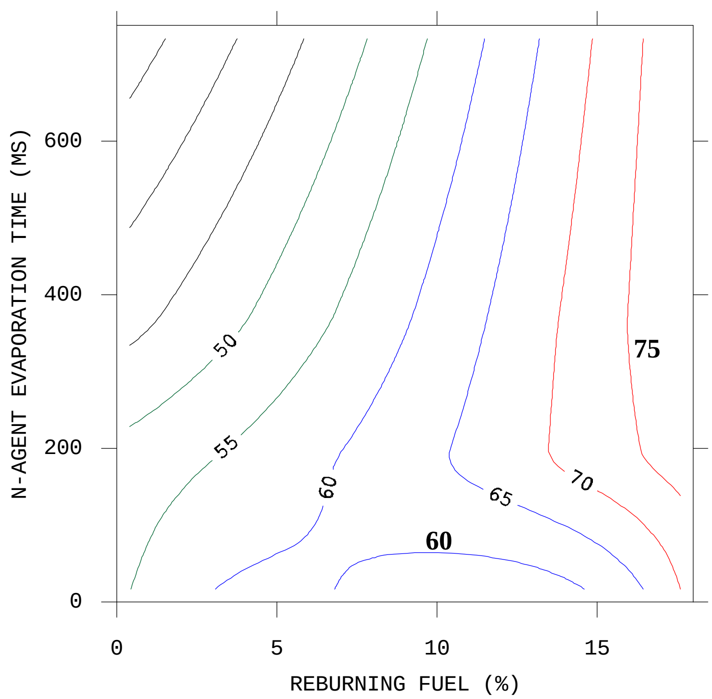

Figure 3. Diagram of AR-Lean at 1300 K. NSR = 0.7.

Injection of large droplets of N-agent along with OFA places N-agent deeper in OFA zone and is an equivalent of combining reburning with SNCR. Thus, performances of AR-Lean and Reburning + SNCR at optimum conditions should be similar. Model of AR-Lean developed in this work can be used to model the Reburning + SNCR process as well: it only requires introduction of additional mixing zone that describes mixing of N-agent with flue gas after OFA is added to flue gas. Figure 4 compares predicted performances of basic reburning, AR-Lean and Reburning + SNCR at conditions (temperatures of flue gas at the point of N-agent injection and droplet evaporation times) that result in the highest level of NO_x reduction. Thus, Fig. 4 demonstrates the best possible performances of the above technologies predicted by modeling. It also shows AR-Lean performance for injection of small droplets of N-agent (non-optimized AR-Lean). It was assumed that in Reburning + SNCR OFA is injected at 1500 K. Figure 4 shows that by adjusting the temperature of N-agent injection and droplet evaporation time, the efficiency of AR-Lean can be set as high as efficiency of reburning + SNCR.

Figure 4 also clearly demonstrates the importance of optimizing droplet evaporation time in AR-Lean to achieve high NO_x reduction at large heat inputs of the reburning fuel. Figure 15 shows that injection of N-agent in the burnout zone along with OFA (AR-Lean) or with some offset in the injection location (Reburning + SNCR) results in significant increase of NO_x reduction in comparison with basic reburning. However, as the amount of the reburning fuel increases, advantage of using N-agent becomes less prominent.

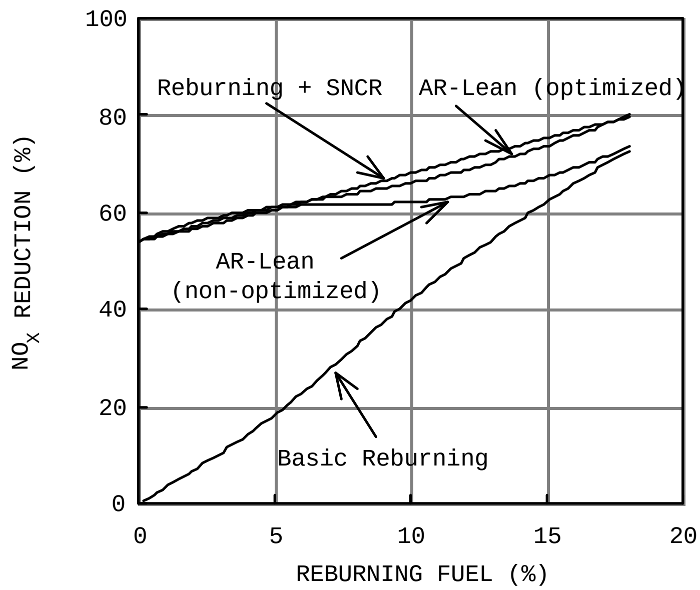

Figure 4. Predicted performances of basic reburning, AR-Lean and Reburning + SNCR. Temperatures of flue gas at the point of N-agent injection and droplet evaporation times are optimized for the best AR-Lean and Reburning + SNCR performances. NSR = 0.7.

4.0 Conclusions

1. The model describes major trends of AR-Lean and can be used for the process optimization. Mixing and thermal parameters in the model can be adjusted depending on characteristics of the combustion facility.
2. The following parameters are identified by modeling to be important in AR-Lean: amounts of the reburning fuel and N-agent, temperature of flue gas at the point of OFA/N-agent injection, and evaporation time of N-agent.
3. The optimum efficiency of AR-Lean depends on the efficiency of SNCR at similar conditions. For a highly effective mixing process with corresponding high efficiency of SNCR, the AR-Lean process is most effective at small heat inputs of the reburning fuel. For conditions when efficiency of SNCR is limited to 50% NO_x reduction, the optimum conditions depend on evaporation time of N-agent. For evaporation times shorter than the OFA mixing time, AR-Lean is most effective at 3-6% reburning. For evaporation times longer than OFA mixing time, the efficiency of AR-Lean increases as the amount of the reburning fuel increases.
4. Modeling results suggest that for conditions at which efficiency of SNCR is limited to 50%, the highest levels of NO_x reduction are achieved at large heat

inputs of the reburning fuel. The maximum predicted NO_x reduction for 18% reburning fuel is about 80%.

5.0 Future Work

Modeling predicted that N-agent evaporation time affects efficiency of AR-Lean. Future activities will include an assessment of the effect of the N-Agent injection parameters (droplet size and angle of injection) on evaporations of N-agent. Evaporation of single droplet in reactive flow will be evaluated using CFD modeling.

6.0 Reference

1. Zamansky, V.M., Lissianski, V.V., and Maly, P.M. (1998) Second Generation Advanced Reburning for High Efficiency NO_x Control. *Quarterly Report No. 7, DOE Contract No. DE-AC22-95PC95251.*