NOx Control Options and Integration for US Coal Fired Boilers

Quarterly Progress Report

Reporting Period Start Date: October 1, 2000
Reporting Period End Date: December 31, 2000

Mike Bockelie, REI
Marc Cremer, REI
Kevin Davis, REI
Bob Hurt, Brown University
Eric Eddings, University of Utah

January 31, 2001

DOE Cooperative Agreement No: DE-FC26-00NT40753

Reaction Engineering International
77 West 200 South, Suite 210
Salt Lake City, UT 84101

Disclaimer

Abstract

This is the second Quarterly Technical Report for DOE Cooperative Agreement No: DE-FC26-00NT40753. The goal of the project is to develop cost effective analysis tools and techniques for demonstrating and evaluating low NOx control strategies and their possible impact on boiler performance for firing US coals.

The focus of our efforts during the last three months have been on:

- Completion of a long term field test for Rich Reagent Injection (RRI) at the Conectiv BL England Station Unit #1, a 130 MW Cyclone fired boiler;
- Extending our Computational Fluid Dynamics (CFD) based NOx model to accommodate the chemistry for RRI in PC fired boilers;
- Design improvements and calibration tests of the corrosion probe; and
- Investigations on ammonia adsorption mechanisms and removal processes for Fly Ash.

Each of these topics is discussed in the following sections. The topic discussions are grouped by the corresponding task from the detailed work plan presented in the proposal.

Table of Contents

1

Introduction

The work to be conducted in this project received funding from the Department of Energy under Cooperative Agreement No: DE-FC26-00NT40753. This project has a period of performance that started February 14, 2000 and continues through February 13, 2002.

2

Experimental Methods

Within this section we present in order, brief discussions on the many tasks that are contained within this program. For simplicity, the discussion items are presented in the order of the Tasks as outlined in our original proposal.

Task 1 Program Management

Industry Involvement

On December 12, 2000, REI met with EPRI senior staff members Tony Facchiano (EPRI Target Manager, Boiler Performance and NOx Control) and Dave O'Connor (EPRI Project Manager, Combustion Performance). The purpose of the meeting was to provide EPRI with an update on the work being performed on this project in order to identify pathways to quickly transfer promising technologies to the utility industry. Of particular interest was the recent progress on developing an improved NOx model targeted for simulating Rich Reagent Injection (RRI) in a PC fired Boiler (see Task 2). Action items from the meeting included:

(1) if RRI modeling continues to show promise, O'Connor and Facchiano will follow-up with EPRI members from the utility industry that use oil or gas firing systems to determine their interest in providing funds to conduct computer simulations of RRI for their boiler.

(2) O'Connor and Facchiano will assist in arranging follow-up meetings (or conference telephone calls) with EPRI technical personnel and program managers. The purpose of the meetings is to provide targeted EPRI personnel with detailed de-briefs on the work being performed in order to help provide industry input to our program and to help transfer our findings to industry as quickly as possible. In addition, REI will travel to EPRI (~March, 2001) to hold follow-up meetings on this program.

(3) REI and EPRI will work together to identify appropriate EPRI and utility personnel to participate in a DOE Program Review meeting to be held at REI in 2001.

(4) REI and EPRI will work together to identify a well characterized PC utility boiler for investigating the impact/benefit of operating a boiler without a Low NOx Firing System (LNFS) under deeply staged conditions. The combination of deeply staged firing conditions, OFA and RRI could provide a very cost effective means to achieve low emissions. If the modeling proves successful, EPRI will attempt to locate an appropriate boiler for a field test of this concept and to procure additional funds to support the field test.

Preliminary negotiations were held with EPRI (Contact: Dave O'Connor) to create a team to commercialize the RRI technology. The commercialization team will include REI, EPRI and one or more equipment vendors with expertise in SNCR installation. In addition, negotiations are in-progress to create a license agreement for RRI between EPRI and REI. It is our intention to finalize the license agreement and commercialization team early in 2001.

Task 2 - NOx Control – LNFS/SNCR/Reburning

Integrated System Design Analysis

The focus of this sub-task is the application of REI's CFD modeling capability to the design of RRI injector systems for a full-scale boiler. The previous quarterly report discussed the application of REI's CFD tools to the design and assessment of an RRI injection system at Conectiv's B.L. England plant. The model based design was installed in Unit 1 and tested as part of the field verification testing that was conducted from July through October, 2000. An update on this is provided in the discussion of Task 6 progress.

The next scheduled field test is planned for spring, 2001 at Ameren's Sioux plant. Sioux Unit 1 is a 488 MW opposed wall fired cyclone furnace equipped with ten 10-ft. diameter cyclone barrels firing a blend of Powder River Basin (PRB) and eastern bituminous coals. Unit 2, which is a sister to unit 1, was the first cyclone fired furnace to be equipped with in-furnace overfire air (OFA). REI recently completed a model based design (under a contract with Ameren) of an overfire air system for Unit 1, which is planned for installation during spring, 2001.

REI is also now under contract with Ameren to assess performance of RRI and SNCR in combination with RRI within Sioux Unit 1. Since the application of RRI is so boiler specific, there are a number of differences between B.L. England Unit 1 and Sioux Unit 1 that will require significant differences between RRI injection systems. Among these are:

1. Sioux unit 1 is opposed wall fired, B.L. England Unit 1 is front wall fired - the optimal regions for release of urea in the lower furnaces are significantly different
2. Sioux unit 1 is much larger in size than B.L. England Unit 1, requiring that the injection system be designed to spread reagent over greater much greater cross-section areas to optimize NOx reduction
3. Sioux unit 1 is equipped with FGR in the lower furnace which contains roughly 3% O2 - releasing reagent into these gases under the high temperatures in the lower furnace will oxidize the reagent to produce NOx rather than reduce NOx
4. The flue gas residence time from the top of the top row of cyclone barrels to the OFA ports for B.L. England Unit 1 and Sioux Unit 1 are approximately 0.25 and 0.5 sec., respectively. More residence time in this region equates to more time to inject, release, mix, and react reagent in the flue gas, favoring the application of RRI in Sioux Unit 1 over B.L. England Unit 1.

The CFD simulations of preliminary designs of RRI in Sioux Unit 1 indicate that NOx removals in this unit could be comparable to those previously predicted and later achieved through the field tests at B.L. England Unit 1. This work is still under progress. It is expected that the information gained in the Sioux Unit 1 RRI modeling program with Ameren will be utilized within this DOE program to move forward in performing the planned field testing at the Sioux plant this spring.

More fundamental RRI modeling studies have been performed in parallel under this DOE program during the last quarter to support the process design of an RRI system in Sioux Unit 1. This work has been aimed at gaining greater understanding concerning impact of flue gas temperature, flue gas stoichiometric ratio, normalized stoichiometric ratio (NSR), as well as reagent distribution on RRI performance. Figure 2.1 shows the calculated effect of local flue gas temperature and reagent NSR on NOx reduction under suitable RRI conditions. These calculations were performed utilizing our detailed chemical kinetic mechanism within plug flow reactor (PFR) simulations using CHEMKIN. As the flue gas temperature increases above 1800 K, the optimal NSR increases and the overall NOx reduction decreases. Although not plotted here, Figure 2.1 suggests that reagent utilization begins to significantly decrease for NSR>2, particularly for temperatures less than 1900 K. Figure 2.1 also suggests that for temperatures greater than 1900 K, low concentrations of reagent will lead to significant levels of NOx formation. This is in contrast to conventional SNCR in which small amounts of reagent will lead to NOx reductions for conditions over a suitable temperature window.

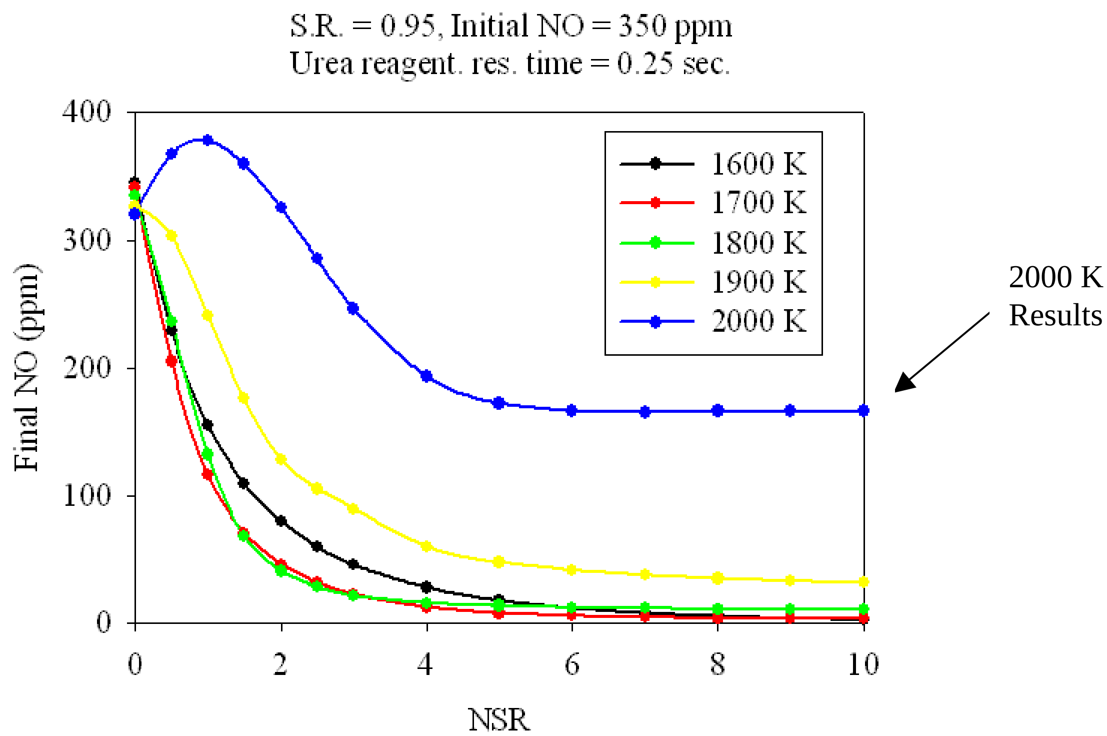

Figure 2.1: Detailed chemical kinetic calculations in a plug flow reactor geometry to investigate the effect of normalized stoichiometric ratio (NSR) and flue gas temperature on NOx reduction under fuel rich conditions.

A range of CFD simulations for a single aqueous urea spray injecting into an otherwise homogeneous flue gas flow was carried out to investigate effects of nozzle flow rate and droplet size over a range of flue gas temperatures. The results of these simulations, along with detailed chemistry results from simple reactors similar to those shown in Fig. 2.1, are useful in terms of establishing design guidelines for full scale boiler applications. Figure 2.2 shows the computed

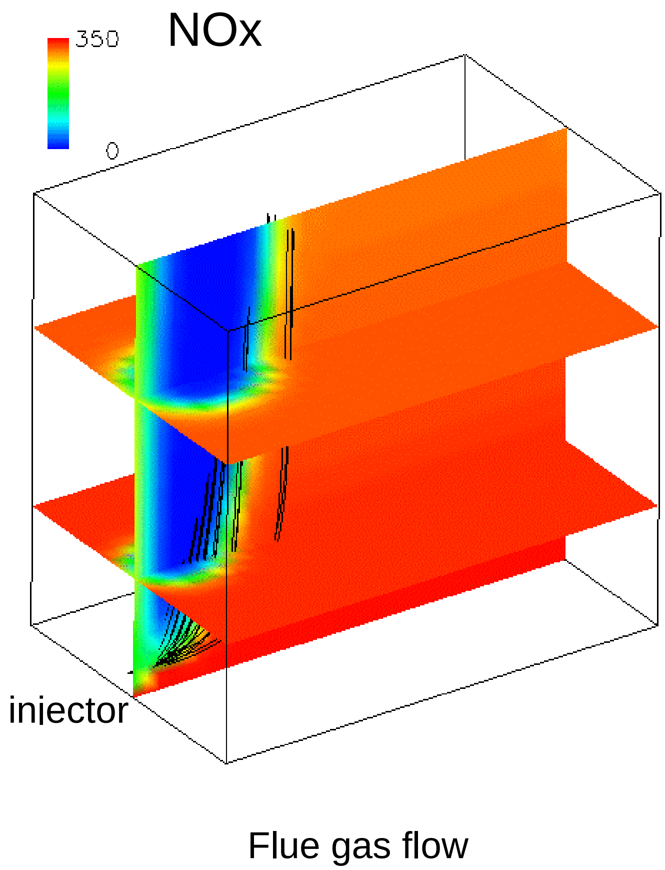

Figure 2.2: Simple CFD model of a single aqueous urea injector spraying into a cross-flow of flue gas at a uniform velocity and gas temperature.

distribution of NOx resulting from the injection of an aqueous urea spray into flue gas typical of products of coal combustion. Typical results of these simulations are shown in Figs. 2.3 and 2.4, which indicate the predicted NOx reduction and NH_3 slip over a range of flue gas temperatures (1800, 1900, 2000K), mean droplet sizes (50 and 300 µm Sauter Mean Diameter), and injector flow rates (2 and 4 gpm). A few overall conclusions from these simple investigations include:

- Better performance (i.e., high NOx reduction, low ammonia slip) is achieved utilizing two 2 gpm injectors rather than one 4 gpm injector, but the difference decreases with increasing temperatures;
- For the temperatures and residence times chosen, performance is best for 150 µm SMD droplets; and
- Performance decreases with increasing flue gas temperatures.

Figures 2.3 and 2.4 suggest that these investigations need to be performed over a wider range of droplet sizes, flue gas temperatures, and nozzle flow rates to gain a better understanding of effects of these parameters which will serve useful for design. This work is planned for next quarter.

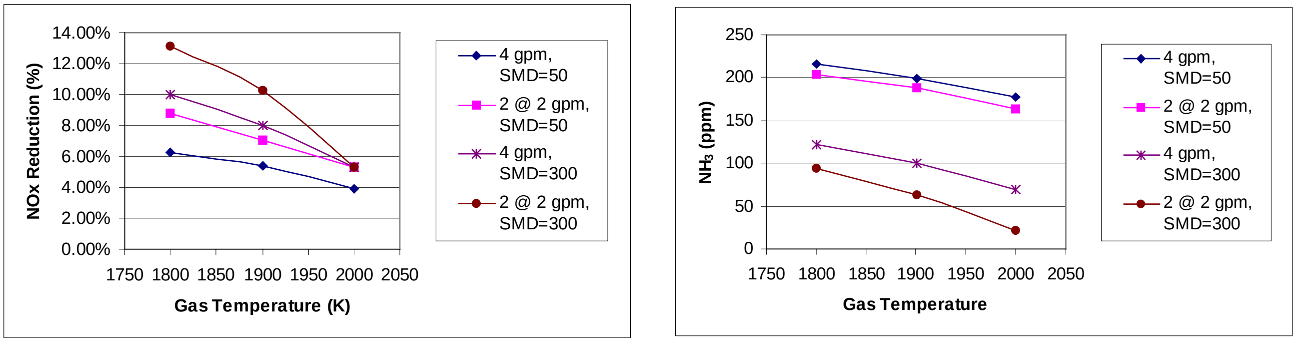

Figure 2.3: Results of geometrically simple simulations of reagent injection in cross flow (see Fig. 2.2) over of range of RRI conditions. Predictions are shown for NOx reduction and NH_3 slip showing the effect of gas temperature and nozzle size on performance at different flow rates.

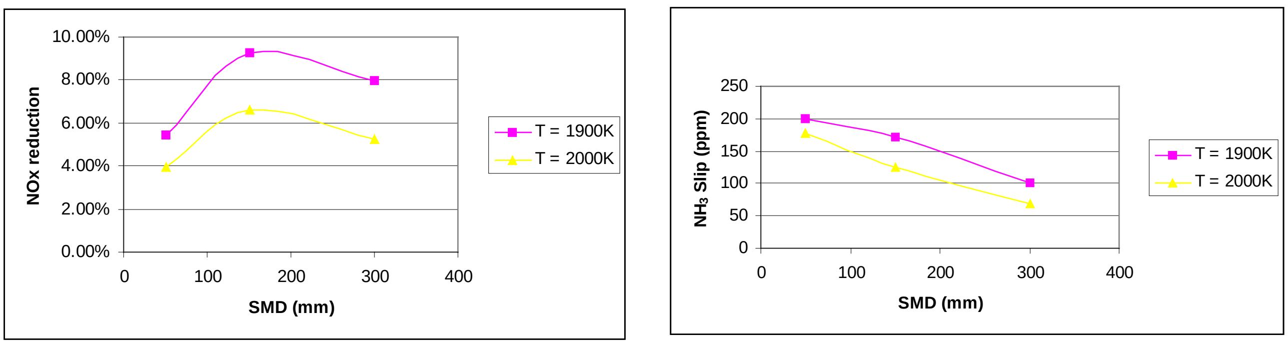

Figure 2.4: Results of geometrically simple simulations of reagent injection in cross flow (see Fig. 2.2) over of range of RRI conditions. Predictions are shown for NOx reduction and NH_3 slip showing the effect of droplet size and gas temperature on performance.

Evaluation of Other NOx Control Options

There is substantial interest within the utility industry to investigate the performance of RRI in a PC fired boiler, as a result of the RRI field testing previously conducted at B.L. England Station. At issue is whether RRI in a PC unit could provide NOx reductions similar to what has been predicted and measured at B.L. England (e.g., ~30%). PC fired boilers make up approximately 80% of the generating capacity associated with coal firing in utility boilers, so the potential payoff is quite large if RRI can be successfully demonstrated in a PC fired boiler.

In order to assess performance of RRI in a PC fired boiler using our CFD model, a number of developments were necessary. The most significant development concerned how to account for the products of devolatilization and char oxidation within our post process, reduced mechanism NOx model. The modeling of RRI in cyclone fired furnaces did not need to address this issue since it was assumed that all of the coal was combusted in the cyclone barrel and only rich gas phase products were emitted into the furnace. In addition, refinements to the reduced chemistry used in the cyclone furnace simulations were required in order to handle NOx precursor species, such as HCN, that were not included in the reduced chemistry for the cyclone furnaces. For this implementation, two different reduced mechanisms were developed, one designed for conditions where the flue gas stoichiometry has an equivalence ratio (ER) greater than unity (i.e. fuel rich), and the other for ER less than unity (i.e. fuel lean). These mechanisms were implemented into the NOx model post processor and results were compared with those obtained utilizing the detailed chemistry in CHEMKIN over a wide range of conditions including stoichiometry, gas temperature, and normalized stoichiometric ratio. Figs. 2.5 and 2.6 show comparisons between the reduced chemistry implemented into the CFD model with the detailed chemistry in CHEMKIN for a plug flow reactor geometry. The fuel lean mechanism (Rei97_11) compares with the detailed chemistry very well under fuel lean conditions while the fuel rich mechanism (Rei97_12) compares very well with the detailed chemistry under fuel rich conditions.

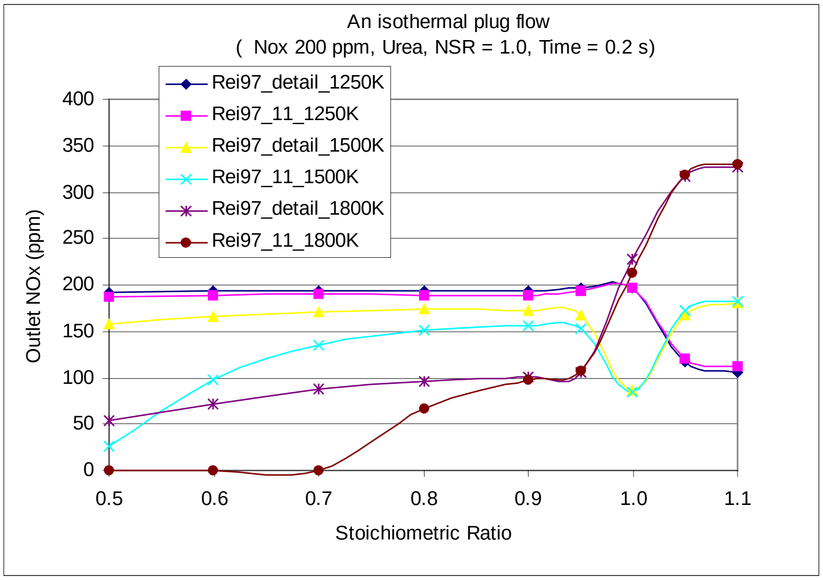

Figure 2.5: Comparisons between new reduced NOx model implemented into a CFD model with results of plug flow reactor simulations using detailed chemistry in CHEMKIN. Comparisons show calculated outlet NOx versus flue gas stoichiometric ratio. The reduced mechanism (Rei97_11) was developed for fuel lean conditions, and the results show that the comparison with the detailed chemistry is very good for SR > 1.

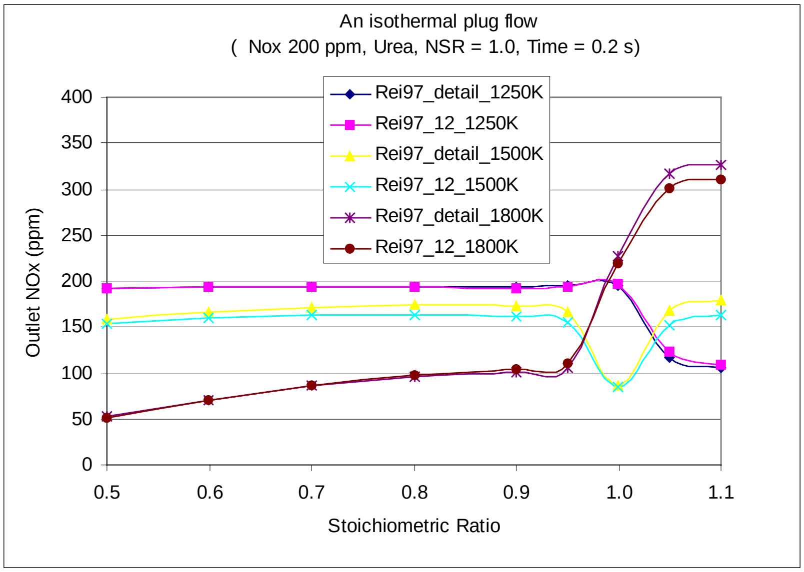

Figure 2.6: Comparisons between new reduced NOx model implemented into CFD model with results of plug flow reactor simulations using detailed chemistry in CHEMKIN. Comparisons show calculated outlet NOx versus flue gas stoichiometric ratio. The reduced mechanism (Rei97_12) was developed for fuel rich conditions, and the results show that the comparison with the detailed chemistry is very good for SR < 1.

After the reduced chemistry was verified by comparison with detailed chemistry over a wide range of conditions relevant to the environment in the lower and upper furnace of a PC fired furnace, the new model was applied to the problem of predicting the NOx emissions from a 500 MW twin, tangentially fired PC boiler. This boiler was operated over a range of conditions involving significant variation in staging by adjustment of air flow through the separated over fire air (SOFA) ports. The boiler was previously modeled by REI under this set of conditions and predictions of NOx emissions were made utilizing the new reduced chemistry as well as REI's commercially used global NOx model (these conditions do not include reagent injection). The comparisons of the predictions with the data from the continuous emissions monitor are shown in Fig. 2.7. These results indicate that the NOx predictions utilizing the new reduced chemistry, in the absence of reagent injection, compare quite favorably with the data and even indicate an improvement over the previous estimates utilizing global mechanisms for NOx formation/destruction. This comparison gives confidence that the newly implemented reduced chemistry is able to accurately describe the mechanisms of NOx formation/destruction in a PC fired boiler in the absence of reagent injection.

Investigations are now in progress to predict the NOx reduction performance using the newly developed model in another boiler previously modeled by REI. This particular boiler is a 180 MW Babcock and Wilcox front wall PC fired boiler equipped with over fire air and SNCR. It is expected that results of this analysis will be available for the next quarterly report.

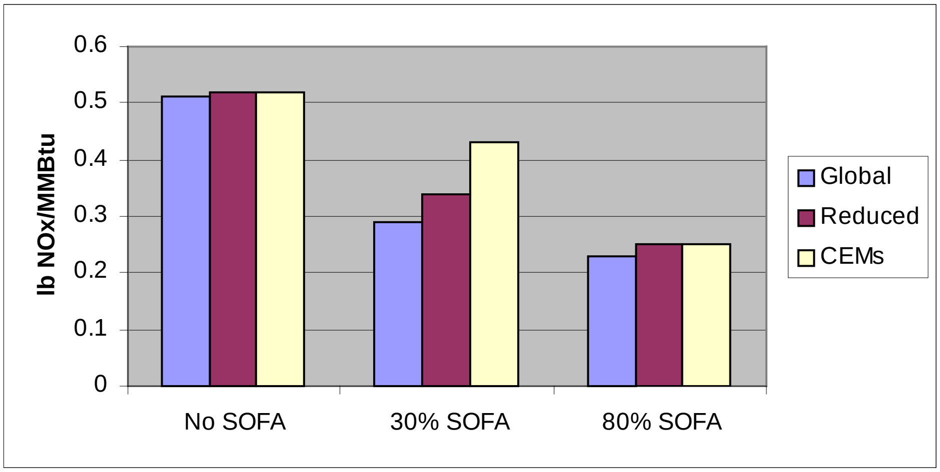

Figure 2.7: Comparison of measured NOx data from CEMs for 500 MW twin tangentially fired PC boiler with CFD model predictions utilizing a global mechanism for NOx formation and predictions utilizing a new reduced mechanism NOx model developed for application to RRI in PC boilers. The comparisons indicate that the new NOx model results compare favorably with the CEMs data and suggest an improvement over the global chemistry model. For this boiler, the agreement between the model predictions and CEMs data is better than expected.

Task 3 – Minimization of Impacts

Waterwall Wastage

Progress was made on three fronts this quarter.

(1) The remaining analyses of results from the October field tests were completed.
(2) An approach was developed for calibration of the corrosion probe using lab scale testing under a range of conditions.
(3) Probe redesign efforts were begun for tests at a pulverized coal fired boiler experiencing sulfur-related corrosion and a cyclone fired boiler experiencing chlorine related corrosion.

Field Testing at BL England Station
Data reduction for the October testing at BL England Station in New Jersey was completed this quarter. As discussed in the previous quarterly report, the signal was consistent during periods of steady operation with corrosion rates varying from 3 to 8 mils/yr. Completion of this analysis and comparison of the data with test logs illustrates the feasibility of this technology over an extended period – 12 days in this field test. Practical issues arose that served to point out specific installation requirements when using this equipment.

An existing view port was used for this testing. The port door was modified for insertion of the probe and the probe was located immediately across the furnace from one of the three cyclone barrels in this unit. The probe face was made flush with the waterwall surface. After a period of a few hours, analysis of the heat transfer occurring at the sensor face indicates the formation of a slag layer. The condition of the sensor at this stage is representative of that of the surrounding waterwall. However, because (1) the inside diameter of the port is significantly larger than the outside diameter of the probe and (2) cyclone fired furnaces have flowing slag on the lower furnace walls (particularly at wall locations opposite the barrels), molten ash will drip from the top of the port onto the probe. Therefore, it is often difficult to relate changes in corrosion rate with operating conditions since changes in the slag layer at the surface of the probe lead to significant changes in the composition and temperature of the material on the sensor. Although this test served as a valuable opportunity to verify the operability of the system in a plant environment, the location of the probe during this test was dictated largely by the existence of access ports. Future tests will target areas of high corrosion and are unlikely to involve flowing slag, making comparisons between operating conditions and corrosion rates more meaningful.

Corrosion Probe Calibration

The technology used in REI's approach to corrosion monitoring relies upon the use of electrochemical noise (ECN) signals. The physics used to describe this process involve analogies drawn from linear polarization theory. These developments are accepted less because of their rigorous fundamental basis than from experimental evidence validating their usefulness. For this reason, confirmation of the quantitative accuracy of this approach for a range of potential corrosion mechanisms and temperature ranges is necessary to provide confidence in the technology's use for the spectrum of useful applications in the high temperature, multiphase environment encountered in the furnace of a coal-fired boiler. For example, although theoretically this approach should work for corrosion of boiler tubes related to gas-phase sulfur and chlorine chemistry, there has been little substantiation based upon careful testing.

In order to provide confidence in the probe for all likely corrosion mechanisms, a set of carefully controlled laboratory experiments have been planned for a range of stoichiometries, sulfur concentrations, chlorine concentrations, and temperatures. These experiments will use a tube furnace, gas mixtures, and flow controllers to create an environment typical of the lower furnace of a coal-fired boiler. The system is designed to control CO_2, H_2O, CO, H_2S, and HCl concentrations for a range of temperatures.

The challenging aspect of this effort is to devise an accurate calibration that can be performed in a timely manner. The approach that has been developed will rely upon measurement of the volume of material lost by the actual sensor elements during the tests. As the tests are performed the ECN signals are recorded as a function of time. The corrosion rate can then be integrated as a function of time to determine the volume of material removed based upon the actual corrosion related reactions occurring. This can then be compared with the actual amount of material removed from the elements. The key feature of this approach is the volumetric measurement. In order to accomplish this the following procedure is used:

- The border of the sensor elements (1/64 in.) are sputtered with nickel in order to form a protective layer that will remain unchanged in comparison with the stainless steel surface during corrosion testing. The effectiveness of this approach was verified in a recent PowerGen/EPRI study (2000). Figure 3.1 illustrates the masking of the sensor face prior to the nickel sputtering.

- The sensor elements are then characterized using a profilometer. The profilometer uses a stylus with a tip a few microns in size. The stylus traces the surface of the element in 20 micron steps and records the height every 20 microns. (i.e., a height is recorded at every point on a 20 micron by 20 micron grid.) Figure 3.2 illustrates the profilometer interface and the video image of the stylus.
- Corrosion tests on the order of eight hours are performed for a specific set of conditions. The probe is then disassembled and the sensor elements are again characterized using the profilometer.
- Software written specifically for this purpose is then used to define a basis plane and determine the volume of surface material removed during the test.
- A surface of the element is machined flat, resputtered, and reinserted for the next set of conditions.

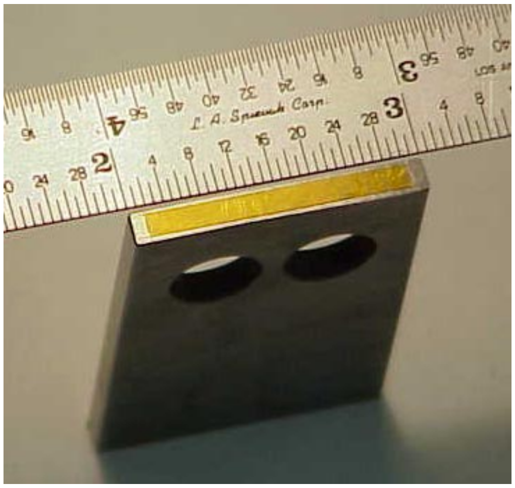

Figure 3.1 Sensor element face after masking prior to nickel sputtering

The amount of material removed by corrosion during an eight hour test is extremely small. Conventional efforts using corrosion coupons require periods of months or longer to obtain accurate determinations of a corrosion rate. The use of a high resolution profilometer, careful techniques for mounting the piece to be analyzed, and software designed to compare the sensor element surface before and after testing, has the potential to quantify material loss to depths of less than a nanometer. This distance is more than two orders of magnitude smaller than should be necessary for the proposed tests.

The development and verification of this procedure are underway and the calibration tests should be completed during the next quarter. Profilometers are commonly used for chip wafer analysis and standard equipment for sample mounting is designed for thin circular shapes. Therefore initial efforts focused on the construction of a jig for mounting of the sensor element. (See Figure 3.3).

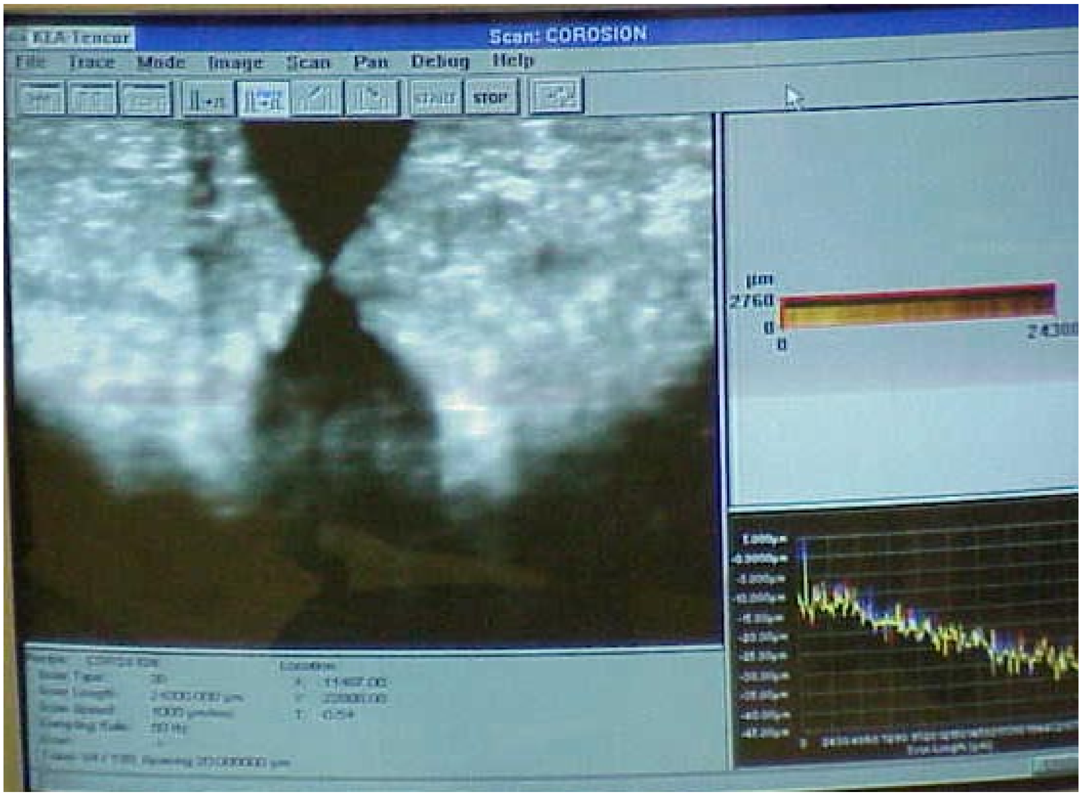

Figure 3.2 Profilometer software interface.

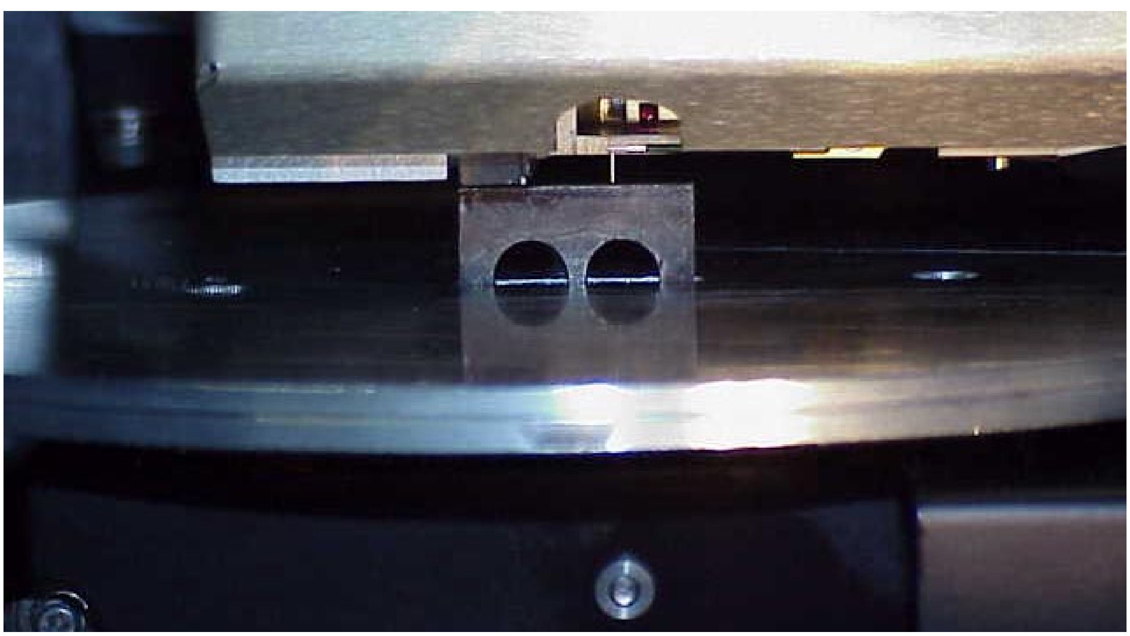

Figure 3.3 Jig used to position sensor element in profilometer.

Corrosion Probe Design Improvements

The improvement of the existing design of the corrosion monitoring system is an important part of this program. The initial design, although extensively tested in aqueous applications and low temperature environments downstream of furnaces, can be significantly improved for application to a coal-fired boiler. There are a number of unique challenges for this application:

- High temperatures and heat fluxes
- Potential outdoor use (water, wind, traffic)
- Less than 3 inch distance between tubes
- Ductwork interferences including windbox and FGR

In addition, the current design has room for improvement in terms of ease of use and maintainability. Efforts this quarter focused on modifications to the existing probe. The following improvements have been implemented:

- Interior wiring has been replaced with finer, better insulated conductors
- Thermocouple sleeving has been installed to prevent interferences with signal carrying lines
- Interior bolts used to hold the sensor elements have been replaced with anti-seize bolts
- Military-type connectors have been installed to prevent damage to the wiring as they exit the probe and to improve ease of installation while reducing the chance of miswiring.

During the next quarter more significant design changes and the construction of a new system will be undertaken with an emphasis on reducing the cross section of the probe for water wall/windbox penetration. In addition water cooling will not be required as the boiler waterwall will help cooling (as opposed to a refractory lined test furnace).

Future Field Testing

Scheduling and facility requirements are currently being determined for tests at two locations:

- Sioux Unit #1 - This is a 550 MW supercritical cyclone-fired unit that was recently modified to operate under staged conditions with overfire air. Initial indications were that post-modification corrosion rates in a similar unit (#2) were manageable. However, following recent changes in fuel composition (low sulfur and high chlorine), corrosion rates increased dramatically (over 100 mils/yr in certain locations). CFD modeling of unit #1, including analyses of specific areas that are potentially problematic, will be performed during February. Based upon these results, the location of a windbox penetration will be determined. Ductwork will be inserted and tubes will be bent to allow probe access. Discussions with Ameren to finalize the field tests, should be completed in early, 2001.
- Eastlake – This is a pulverized coal fired unit that uses high sulfur Ohio coal and has experienced corrosion related maintenance difficulties. FirstEnergy has committed to funding an extended field test of the corrosion monitoring system. A plant visit will be conducted this quarter to determine the ideal location of the probe based upon existing port locations and the likelihood of encountering corrosive conditions.

Both of these installations will require a redesign of the existing probe in order to insert the probe through the wrap around windboxes on these units. Improvements to the probe design are currently being implemented (see above) along with the modifications required for use in these units.

Task 4 - SCR Catalyst Testing

The objective of this task is to develop inexpensive SCR catalyst testing/evaluation techniques. The principle concerns are possible poisoning of the catalyst. This task will build upon earlier work performed by REI and the University of Utah for the EPA and NASA on catalyst testing.
Augmentation of this task has been under negotiation with DOE this quarter. Additional sub-tasks of interest to DOE/NETL personnel have been identified and the possible inclusion of Prof. Larry Baxter (Brigham Young University) to the program team is being discussed. The arrangements with Prof. Baxter and the modified task plan will be finalized next quarter.

Task 5 - Fly Ash Management/Disposal

This task deals with the undesirable adsorption of ammonia on fly ash associated with the operation of advanced NOx control technologies such as selective catalytic reduction. The task examines the fundamentals of the adsorption process as well as the fundamental process underlying potential techniques for post-combustion removal of adsorbed ammonia. Some of the topics covered below were briefly mentioned in the last quarterly report. The discussion here provides more details on these efforts.

Ammonia Adsorption Mechanisms

This subtask examines the fundamental mechanism leading to the initial adsorption, and seeks to understand the effect of temperature, ammonia slip level, flue gas composition, and ash type on ammonia contamination levels. In the first phase of the project we have:

a) retrofited our existing automated vapor adsorption workstation (Autosorb) to accommodate ammonia as an adsorbate. This device measures complete adsorption and desorption isotherms for captive samples by programmed changes in partial pressure in a static cell. The Autosorb device has never been used for ammonia, so a retrofit package with new valve gaskets was obtained through discussion with the vendor and installed. We also carried out non-ideal gas calculations to relate the pressure changes to adsorbed moles (and supplied this data to the vendor for widespread use).

b) We measured complete adsorption and desorption isotherms for one of our standard fly ash samples (class F ash from bituminous coal combustion at Brayton Pt. station in Somerset, MA) in pure, dry ammonia. The same measurements were carried out on the mineral portion of the ash after carbon removal by air oxidation. An example result is shown in Fig. 5.1. In this figure, the difference between the adsorption branch and the desorption branch, the "hysteresis loop," suggests some irreversible adsorption. It is likely that a portion of the ammonia is strongly adsorbed or even destroyed on acidic functional groups. Fig. 5.1 also shows that most of the adsorption potential can be removed by oxidation of the carbon component (here about 6 wt-% in the as-received sample).

The data suggests that ammonia adsorption is dominated by the carbon component, <u>under these experimental conditions</u>. This data range extends, however, to partial pressures much higher than those found in the post-SCR region of boilers. Examination of the very low pressure region in the data shows an adsorption amount that is less than the 100 - 1000 ppm observed in field samples. It is likely that other components of the flue gas stream influence the adsorption, such as sulfur oxides whose adsorption can lead to the presence of strong acidic adsorption sites. These data suggest that adsorption on a small number of acidic sites may dominate at low partial pressures, but the adsorption on carbon will play an increasing role as partial pressure increases, consistent with the very large surface area of carbon relative to the mineral portion of the fly ash.

c) to pursue the idea discussed above, we have begun to develop the experimental capability to study ammonia adsorption in the presence of ppm quantities of sulfur oxides. We have begun co-adsorption work in a closed static environment and have ordered precision gas delivery systems for flow experiments. This system will be assembled and tested in the next period.

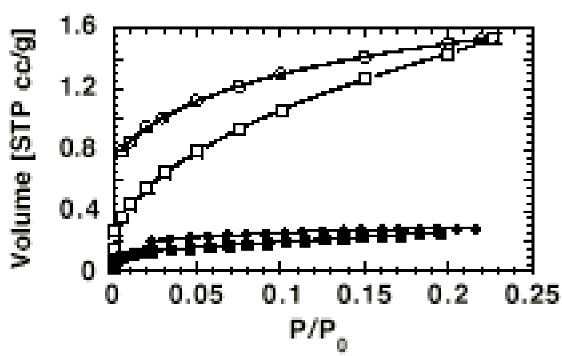

Figure 5.1. Ammonia adsorption isotherms on standard class F fly ash. Open points are for the whole fly ash. Closed points are for the mineral portion after carbon removal. Squares represent the adsorption branch and circles the desorption branch.

Ash Post Processing

A number of ash beneficiation processes are currently under development that employ heat, moisture, basic additives, air stripping, or some combination of these techniques to make salable ash. The goal of this subtask is to carry out fundamental work on the mechanisms of ammonia release from containing ashes in response to temperature, moisture, and/or basic additives in support of these various industrial development efforts. In the first phase of this project we have:

a) identified the technical specifications and placed an order for a vapor phase ammonia analyzer for dynamic desorption experiments, and a controlled humidity chamber for work in the presence of ammonia and water vapor.

b) We have begun time-resolved experiments to measure the rate of the ammonia release process as a function of moisture, air flow, and pH. Both dynamic experiments and modeling are planned to help identify the optimal conditions for release of ammonia, with the current emphasis on processes operating at or near room temperature.

Task 6 – Field Validation of Integrated Systems

BL England Station Field Test

Field tests of RRI have been completed at the Conectiv BL England Station Unit #1 (Atlantic City, NJ). This unit is a 130 MW, three-barrel cyclone furnace that had been previously retrofitted with OFA and SNCR. This site was chosen for the field testing for a number of economical and scientific reasons. This choice was a good one economically since it was already equipped with over fire air, which is necessary for RRI, and it has an existing SNCR system. The existing SNCR system provided the infrastructure which could be easily modified to perform the RRI testing. In terms of scientific reasons, this boiler was a good choice because it provided a stringent test of the RRI technology. The residence time of the flue gas from the top of the cyclone barrels to the overfire air ports, is relatively short (0.25 sec). Longer residence times in this region increase the time available to inject and release the reagent, mix it into the flue gas, and chemically react prior to reaching the oxidizing conditions near the overfire air ports. Thus, a successful test in this unit translates to the probability of a successful test in most other units.

As reported in the previous quarterly report, the results of the first two sets of short term tests were very favorable, with NOx reductions from RRI alone from 25 to 30%, with less than 1 ppm NH_3 slip. These measurements were consistent with the early CFD model predictions.

Longer term testing was conducted during the past quarter. In these tests, reagent was injected for time periods of at least eight hours in order to assess the performance of RRI during typical boiler operation involving normal variations over an 8 hour span. Tests were conducted over a range of loads from 33% of maximum capacity to 100% capacity. These tests confirmed the performance observed during the short term tests and were unable to identify any boiler performance impacts due to RRI.

The overall conclusions from the testing at B.L. England are:

- Typical NOx reduction due to RRI at full load are 25-30% with NSR=2;
- NH3 slip resulting from RRI at NSR=2 was measured to be less than 1 ppm;

- The combination of RRI with SNCR provided over 50% NOx reduction with less than 5 ppm NH_3 slip; and
- Overall, the CFD model predictions and the field measurements were in very good agreement.

Future Field Tests

Plans for field testing of RRI at Ameren's Sioux Unit #1 are still ongoing. It is currently planned that these tests will commence following the Sioux plant's spring outage at which time both overfire air and the temporary RRI system will be installed. Sioux Unit 1 is a 488 MW, ten barrel cyclone furnace with opposed wall firing, which is much larger in size than B.L. England Unit 1. This unit is not currently equipped with SNCR, as was B.L. England, complicating the installation of the temporary RRI system. REI is currently under contract by Ameren to perform the CFD modeling necessary for development of the RRI design.

Results and Discussion

Our recent results on RRI have been quite encouraging. The long term field tests completed at BL England have confirmed previous tests that for a cyclone fired furnace: (1) RRI can provide 25-30% reductions in NOx; (2) combining RRI and SNCR can produce over 50% NOx reduction. Furthermore, the long term and short term tests have also demonstrated that our CFD tools can be used to design a RRI injector system for a utility scale cyclone-fired furnace. Our efforts to design a RRI system for Sioux Unit #1, which is a much larger furnace than is BL England, has proven more difficult. The combination of a larger furnace, more complex flow field and fewer restrictions on the lower furnace injector locations has resulted in more challenging design problem. Model predictions for our current design indicates that RRI could provide NOx reductions comparable to those obtained at BL England.

Substantial progress has been made on evaluating RRI for PC coal fired units. As described above (see Task 2), an improved NOx model for RRI chemistry for PC fuel has been developed and validated against detailed chemistry calculations. The new NOx model has been implemented into our CFD model and verified on non-RRI simulations for idealized reactor problems and a full scale utility boiler with OFA. The new NOx model results for the utility boiler showed the new NOx model provided better agreement with field measured values. Simulations for RRI application in a utility boiler will be performed during the first quarter of 2001.

The interest of industry in RRI remains quite high. Negotiations are on-going to establish a license agreement and create a team to commercialize the RRI technology.

Fundamental development work is continuing on the corrosion probe for monitoring waterwall wastage. The experience and data from the field test at BL England has continued to show dividends by highlighting features to improve in the original probe design and how to operate the probe in the field. Calibration tests of the probe are currently being performed at the University of Utah Combustion Research Laboratory facilities. It is our plan to complete these tests and the re-design effort during the next quarter before the next set of field tests are performed.

The Fly Ash study being performed by Prof. Hurt at Brown University has provided useful data on the adsorption of ammonia onto fly ash in the absence of sulfur. Tests for including sulfur in the simulated flue gas will be performed next. In addition, good progress is continuing on investigations of novel methods for ammonia removal from fly ash.

Conclusions

Important progress has been made in the last three months. Long term field tests of RRI in a cyclone fired furnace have confirmed the predicted NOx reductions of 25-30%. Furthermore, the field tests demonstrated that RRI can be “layered” with other technologies to achieve substantially greater NOx reductions for cyclone applications. A CFD model has been developed for RRI applications in PC fired units and is being used to develop a RRI design for a front wall fired unit. If RRI will provide as large of NOx reductions in PC units as have been witnessed for cyclone units has yet to be determined.

Plans for the next quarter will focus on: developing a potential RRI design for a PC boiler; simulations to support the upcoming RRI field test at Ameren’s Sioux 1; calibration and design improvements of the corrosion probe; and studies of the impact of ammonia on fly ash.

Literature References

Paul James, Len Pender, Arun Mehta, Ian Wright, "Effects Of Fuel Composition And Combustion Parameters On Furnace Call Fireside Corrosion In Pf-Fired Boilers," United Engineering Foundation Conference on the Effects Of Coal Quality On Power Plant Management:Ash Problems, Management and Solutions, Park City, Utah, May 8 - 11, 2000.