INSTALLATION OF THE POWER INDUSTRY’S FIRST COMMERCIAL ALTA SYSTEM FOR NO$_X$ CONTROL AT AMEREN’S SIOUX PLANT

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ABSTRACT

In 1996 Ameren was the first US utility to employ overfire air on a coal-fired cyclone boiler for NOx control at their Sioux plant. Since that time, a number of further enhancements have been made to both 540 MW boilers at Sioux Plant in order to optimize operation of the OFA systems to achieve very low NOx emission levels while achieving extremely high capacity factors. During 2005, Reaction Engineering International (REI) led a DOE-NETL sponsored program to combine deep staging with rich reagent injection (RRI) and SNCR in Sioux Unit 1 to demonstrate full load NOx emissions below 0.15 lb/MBtu. This layered approach to NOx reduction is termed the Advanced Layered Technology Approach (ALTA). The results of the DOE-NETL program were presented at the 2006 Clearwater Conference. The success of that program prompted Ameren to discontinue previous plans for SCR installation at Sioux Plant in favor of commercial ALTA systems in both units at Sioux Plant, representing the first commercial installation of its kind. This paper provides a description of the ALTA systems that were recently installed at Sioux Plant as well as performance results from startup and optimization testing.

INTRODUCTION

Cyclone fired boilers have historically been characterized as high NOx emitting units due to the very high combustion temperatures that are produced in the primary combustion zone. Uncontrolled NOx emissions ranging from 0.8 to 1.9 lb/MBtu have been typical. Due to the design characteristics of cyclone fired units, they are not conducive to the application of conventional low NOx burner technology. Prior to 1997, the conventional wisdom was that cyclone fired boilers could not be practically operated under two stage combustion conditions due to concerns about the reducing conditions in the cyclone barrel leading to corrosion. Gas reburn technology and SCR were considered to be the technologies of choice in cyclone units for NOx reduction (Stultz, 1992).

Starting in 1995 Reaction Engineering International (REI) participated with EPRI and their Cyclone NOx Control Interest Group (CNCIG) to evaluate cost-effective approaches for NOx reduction in cyclone units. There were three significant outcomes of this work: 1) Development of a CFD based model of cyclone barrel combustion for evaluation of cost-effective options for NOx reduction (Adams, 1997), 2) Demonstration of two stage combustion in cyclone boilers as a cost-effective NOx reduction strategy (Smith, 1997), and 3) Demonstration of Rich Reagent Injection (RRI) in combination with OFA for significant additional NOx reduction in cyclone boilers (Cremer, 2001, 2002). The successes of the CNCIG group led to the installation of OFA in the majority of cyclone boilers currently operating in the United States allowing them to meet the Title IV NOx limit of 0.86 lb/MBtu at capital and operating costs significantly lower than that of gas reburn or SCR.

Subsequent field tests led by REI and EPRI and funded by CNCIG and DOE showed that OFA could be combined with RRI and SNCR to further reduce NOx emissions from cyclone boilers. The culmination of these efforts was the successful testing of the Advanced Layered Technology Approach (ALTA) in Ameren's Sioux Unit 1 during summer 2005. This DOE-NETL funded program demonstrated full load NOx emissions well below 0.15 lb/MBtu were achievable with ALTA at levelized operating costs well below those of SCR. As a result of these efforts, in late 2005 Ameren chose to discontinue SCR engineering efforts at Sioux Plant in favor of the installation of ALTA systems. The installation and startup of the ALTA systems were recently completed in time for initiation of full-time operation during the 2007 ozone system. This paper describes the installation and results of ALTA start-up testing at Sioux.

APPROACH

Plant Description

Ameren's Sioux Power Plant consists of two 540 MW generating units located on the Mississippi River approximately 20 miles north of St. Louis, MO. The steam generators are supercritical, universal pressure, once through, cyclone-fired with balanced draft. The cyclone barrels are 10 feet diameter with five each on the front and rear walls in a two over three arrangement on each wall. The cyclones are equipped with radial burners that utilize primary and tertiary air. Secondary air is supplied to the cyclones from a common windbox, and control and shutoff dampers control the air to each cyclone. Each unit also incorporates a flue gas recirculation system for steam temperature control. Although the steam generators were designed for Illinois No. 6 high sulfur coal, both units currently fire a blend of approximately 85% Powder River Basin (PRB) and 15% Illinois No. 6 to achieve net outputs of approximately 440 MW. Both units are equipped with fine grind crushers, allowing them to burn high percentages of PRB. Higher percentages of Illinois coal can be burned in the event full unit capability is needed to meet system demands.

During April-May 1997, Ameren installed a temporary OFA system on Sioux Unit 2. This system was designed to inject secondary combustion air into the furnace through the ten existing gas recirculation ports located above the top row of cyclones. Due to the success of the temporary OFA system, Ameren subsequently converted the temporary system into a permanent installation. During spring 2001, Ameren installed OFA on Unit 1. In this case, however, Ameren elected to locate the OFA ports at a higher elevation in the boiler to accommodate the future installation of RRI technology as well as to achieve the higher levels of NOx reduction with the OFA system, predicted with CFD modeling. During the spring 2001 outage, 20 ports were also installed in unit 1 below the OFA elevation and above the cyclone barrels to accommodate RRI. In addition, stainless steel weld overlay was installed in both units in the waterwall region extending from the studline to just above the OFA elevation as a preventative measure for mitigation of waterwall corrosion. Subsequent RRI and ALTA tests were performed in Unit 1, culminating with the DOE-NETL sponsored ALTA test program during spring 2005 (Cremer, 2005).

Project Team

During Fall 2006, Ameren contracted Fuel Tech Inc. (FTI) for the RRI and NOxOUT SNCR equipment supply and for the RRI and SNCR start-up and optimization testing in both units at Sioux Plant. FTI had previously supplied the temporary reagent injection equipment and testing personnel during the 2005 DOE-NETL ALTA field tests at Sioux Plant and is also one of two RRI system implementers. REI was contracted to provide CFD modeling to support the process design of the RRI and SNCR systems as well as to support the OFA system modifications in unit 2. REI was also contracted to provide support of the start-up and optimization testing of the RRI systems. Ameren contracted Benham Companies for management of the system construction and Sega for distributed control system (DCS) programming.

ALTA Process Design

Starting in 1995 (see Figure 1), REI began work with Ameren to use CFD modeling to guide the design of the overfire air system that was subsequently installed in 1997. Since that time, further modeling has been used to guide the design of the OFA system, and the temporary RRI and SNCR systems that were subsequently tested in unit 1. Many of these efforts were reported in the literature (Boll, 2002; Cremer, 2004; Cremer, 2005).

OFA Arrangement

Following the ALTA test program in unit 1, carried out during spring 2005, and Ameren's decision to move forward with the commercial installation of ALTA systems in both units at Sioux Plant, REI commenced with additional CFD modeling to guide the OFA modifications and the location of RRI and SNCR injectors in unit 2. The OFA system that was originally installed in unit 2 required modifications involving relocation of the OFA ports to a higher elevation to accommodate the RRI process (see Figure 2). CFD modeling showed that the 10-port staggered, opposed wall OFA arrangement could effectively limit CO concentrations at the furnace exit even when relocating the ports to an elevation five feet higher than in unit 1. The model results showed that the higher OFA elevation would provide additional residence time under fuel-rich conditions, potentially leading to lower NOx emissions following application of RRI. Since the predicted CO concentrations and average gas temperature were not predicted to

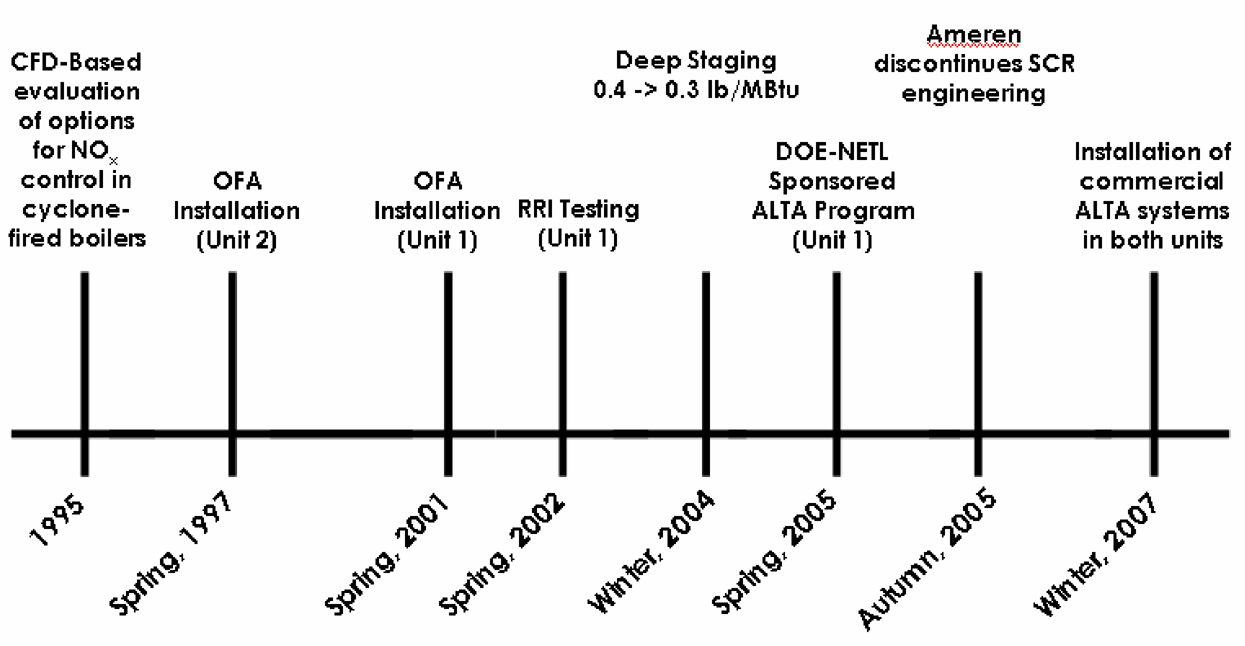

Figure 1. Timeline of NOx Control Efforts at Ameren's Sioux Plant

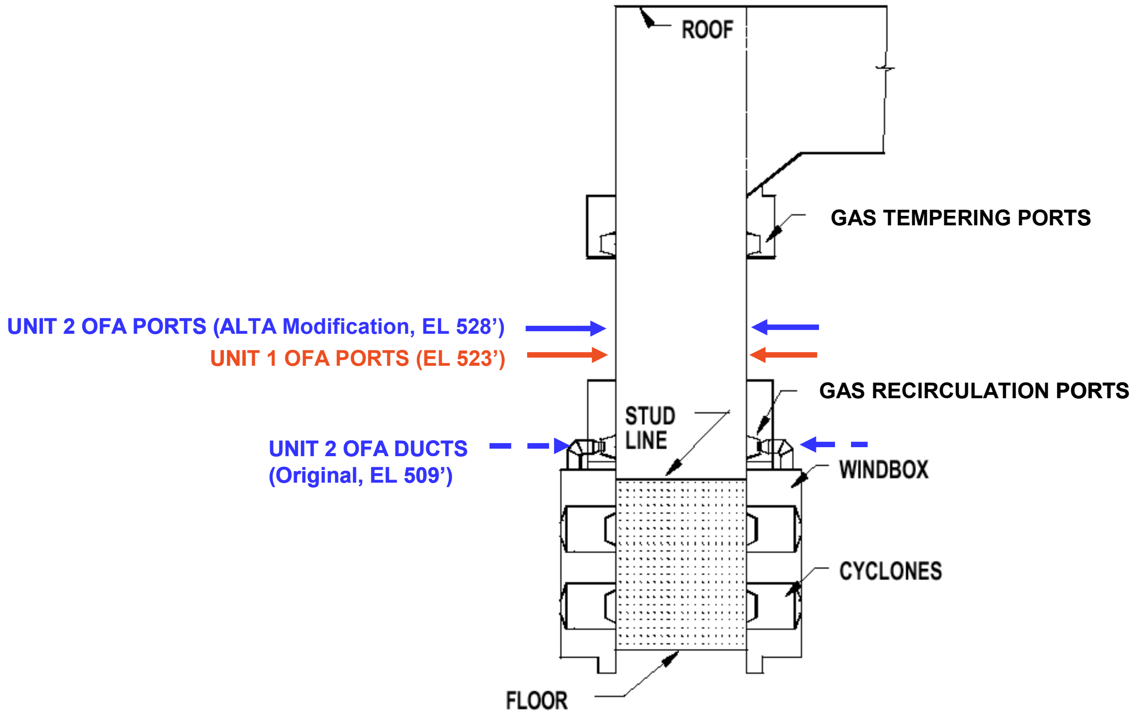

Figure 2. OFA arrangements in Sioux Units 1 and 2 to accommodate installation of ALTA process.

increase significantly at the furnace exit, SNCR performance was not predicted to be negatively impacted.

RRI Arrangement

The RRI arrangement that was installed in unit 2 was based on the results of modeling the application of RRI in this unit as well as the results of the RRI test programs that were previously completed in unit 1. This arrangement included a total of twenty (20) injector locations with eight (8) locations on the front and rear walls and twelve (12) locations on the side walls. CFD modeling conducted prior to the 2005 ALTA tests in unit 1 showed that locating the front and rear wall ports seven feet below the locations that were originally installed in unit 1 would lead to a significant improvement in RRI performance (Figure 3). The improved performance was subsequently verified in the 2005 tests (Cremer, 2005). The front and rear wall ports were installed only at the lower elevation in unit 2.

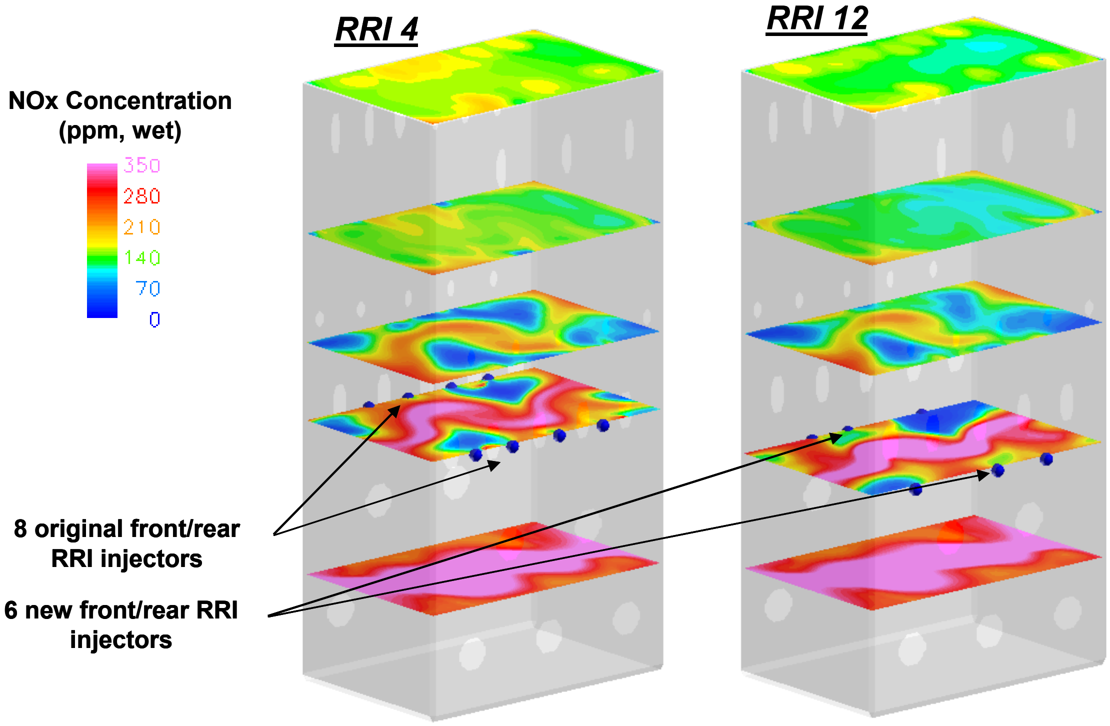

Figure 3. CFD model predictions showed the benefit of relocating the front and rear wall RRI injectors seven feet lower than those originally installed in unit 1.

SNCR Arrangement

The SNCR injector arrangement that was installed on unit 2 was based on CFD modeling completed by REI as well as on the results of the ALTA field testing completed summer 2005. The arrangement includes thirteen (13) injectors located at two elevations on the front wall as well as two (2) additional injectors located on the side walls.

Equipment

The ALTA system at Sioux Plant was designed for use with aqueous urea. The common reagent between the RRI and SNCR systems allows for common use of the reagent storage tank, pumps, and skids. Figure 4 shows the 400,000 gallon aqueous urea supply tank and adjacent pump enclosure which were constructed for the ALTA system. The insulated tank, as well as all urea piping, are constructed of stainless steel. Urea is continuously recirculated between the tank and the pump building passing through electrical heaters to ensure that the urea temperature stays well above the saltation temperature. A FTI high flow delivery (HFD) pump (Figure 5) supplies undiluted reagent from the tank up to the FTI injection zone modules (IZM) inside the boiler house (Figure 6). For each unit at Sioux plant, a single IZM delivers mixed urea to four injection zones: 2 RRI zones and 2 SNCR zones. For each unit, the liquid and air pressures to injectors within each injection zone are controlled from four distribution modules. Pressurized air and mixed reagent are supplied to each individual RRI and NOxOUT SNCR injector (Figure 7).

Figure 4. 400,000 gallon aqueous urea supply tank and adjacent pump house for the ALTA system at Sioux Plant.

The RRI and NOxOUT SNCR injectors at Sioux Plant are manually inserted and retracted. In general, the RRI and NOxOUT SNCR injectors will remain inserted except when maintenance is required. The RRI injectors can remain inserted even when chemical is not flowing since they are water-jacketed and are equipped with high temperature alarms to notify when overheating of the coolant water is occurring. The SNCR injectors, located where the average flue gas temperature is significantly lower than where the RRI injectors are located, are air-cooled. Air-cooling is sufficient to protect them when chemical is not flowing.

Figure 5. FTI's High flow delivery (HFD) pumps (center) and recirculation pumps (left) located inside the pump house adjacent to the urea storage tank.

Figure 6. One of two FTI injection zone modules (IZM) where dilution water and aqueous urea are metered and mixed.

Figure 7. Two side-wall RRI injectors installed in Sioux Unit 2.

RESULTS

Following the initial startup of the ALTA system in unit 2 during winter 2007, the system was run continuously over a 1-week period. Figure 8 shows the associated plant traces over that time period, showing gross load (MW), NOx emission rate (lb/MBtu), 50% urea flow rate for RRI (gpm), and 50% urea flow rate for SNCR (gpm). Over this time period, the gross load during the daylight hours was approximately 470 MW, and the gross load during the evening hours was approximately 330 MW. This load curve is relatively typical for both units at Sioux Plant except during the hot summer months when the peak load can increase to a maximum turbine output of 540 MW. The trace shows that over this time frame, NOx varied from 0.08 – 0.14 lb/MBtu. The NOx trace shows that the NOx emission is strongly related to the gross load, with the lowest NOx emissions corresponding to the time periods when the unit is at reduced load. Figure 9 shows the NOx emission rate during this 1-week time-frame when the gross load was 470 MW and Figure 10 shows the NOx emission rate when the gross load was 330 MW. The average NOx emission rate at 470 MW was approximately 0.13 lb/MBtu and the average at 330 MW was 0.09 lb/MBtu, well below the current ozone season limit of 0.15 lb/MBtu. Extractive ammonia measurements as well as continuous tunable diode laser measurements taken over the range of loads have shown typical levels to be less than 5 ppm.

A 1-day trace showing the incremental NOx reductions achieved with RRI and with RRI+SNCR is shown in Figure 11. For this time-period, the gross load was steady at approximately 445

Figure 8. 1-week trace following the start-up of the ALTA system in Sioux Unit 2 showing load, NOx emission rate, and RRI and SNCR urea flow rates.

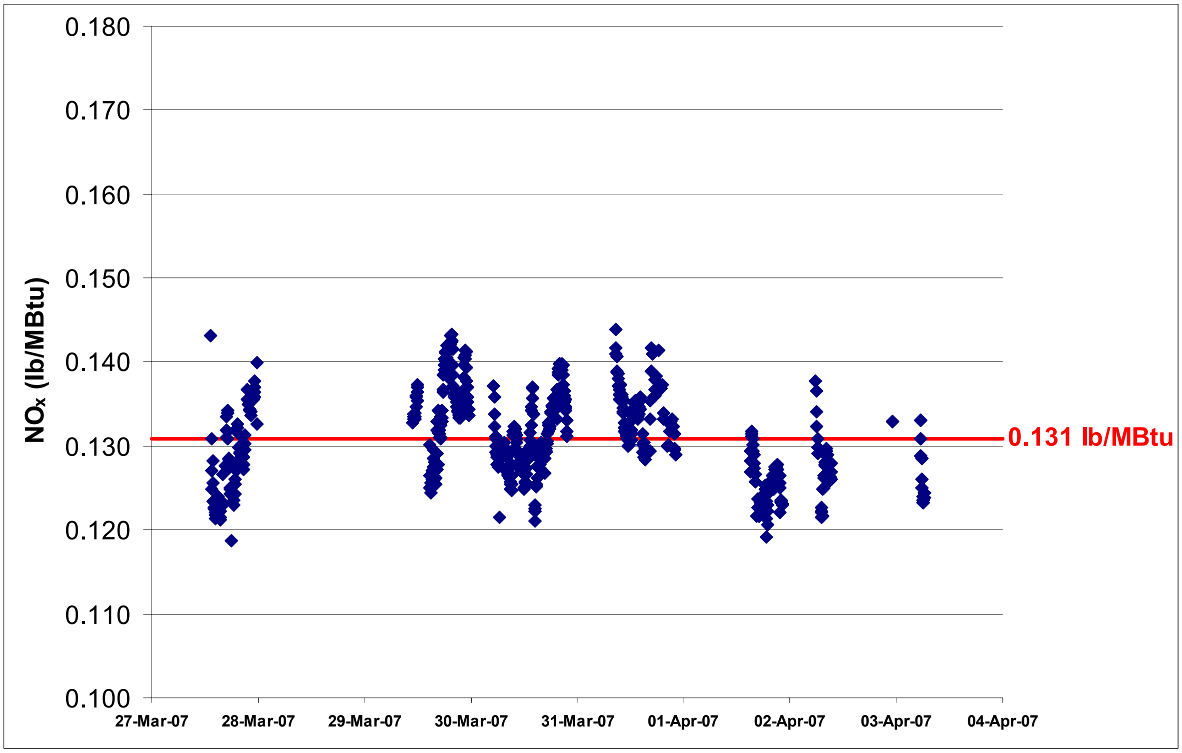

Figure 9. 470 MW data taken from Figure 8.

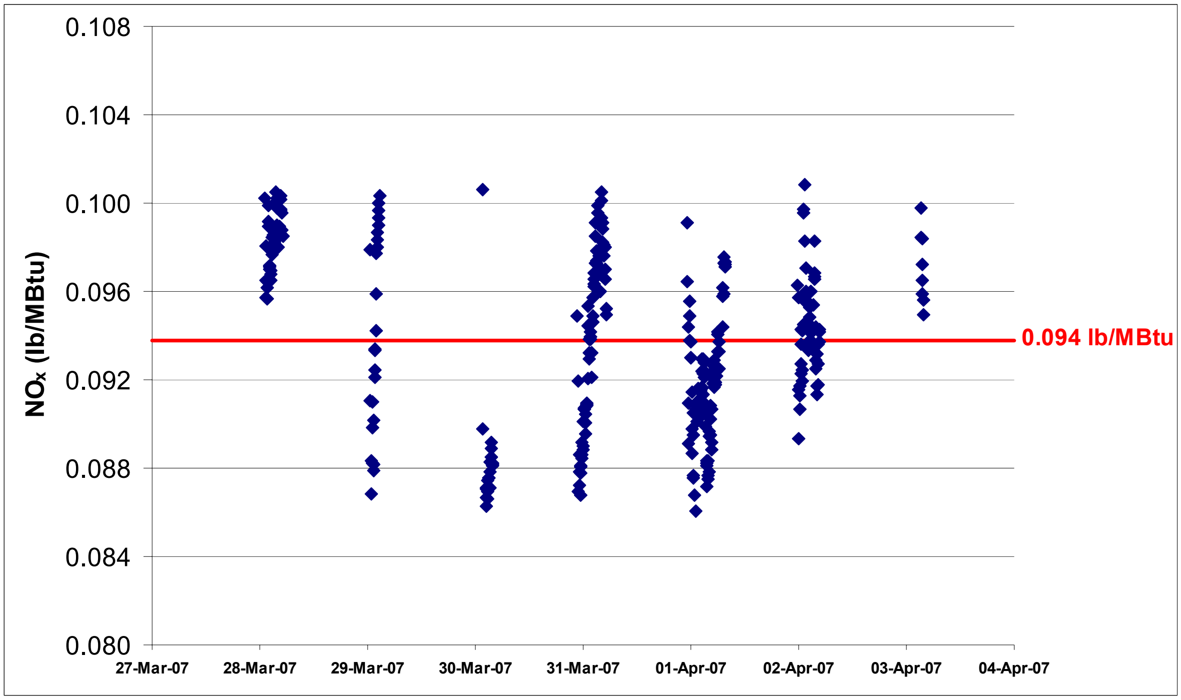

Figure 10. 330 MW data taken from Figure 8.

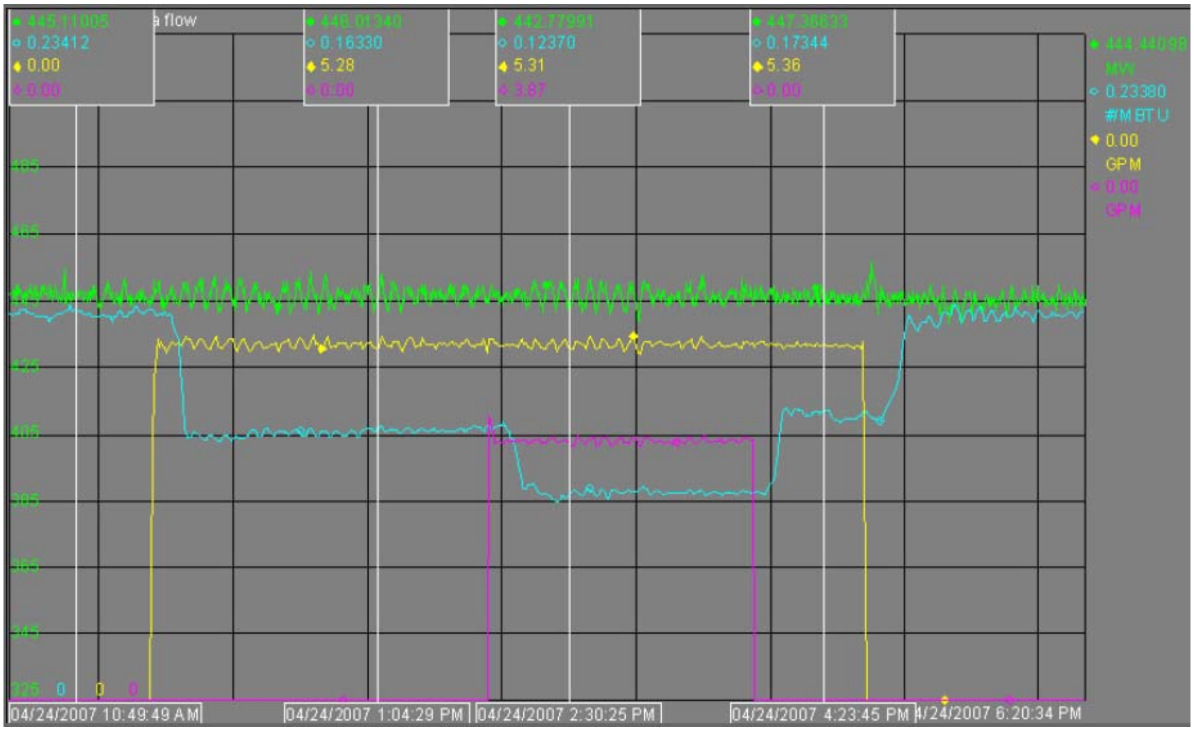

Figure 11. 1-day trace following the startup of the ALTA system in Sioux Unit 2 showing the separate contributions of OFA, RRI, and SNCR on overall NOx reduction due to ALTA.

MW. Prior to RRI or SNCR injection, the NOx emissions were approximately 0.234 lb/MBtu. Emissions dropped to approximately 0.163 lb/MBtu with RRI injection (30% reduction). The addition of SNCR reduced the emissions to approximately 0.124 lb/MBtu (47% reduction). Emissions returned to approximately 0.234 lb/MBtu when the urea flow to the RRI and SNCR systems were turned off. This trace is consistent with data obtained during the 2005 ALTA testing in unit 1 (Cremer, 2005).

Results have shown that the NOx emissions achieved with ALTA under reduced load conditions (e.g. 330 MW) are significantly lower than those achieved under max load conditions. This is expected and is attributable to several factors that improve the performance of OFA, RRI, and SNCR. The reduced flue gas flow rate in the lower furnace leads to an increase in residence time under fuel-rich conditions at reduced load. The increased residence time is favorable for improving NOx reduction under fuel-rich conditions as well as for improving RRI performance through both improved reagent distribution and increased rich zone reaction time. In addition, the lower furnace gas temperatures decrease somewhat under reduced load, which is also predicted to improve RRI performance in the Sioux boilers. The increased residence time at the furnace exit as well as the reduced furnace exit gas temperatures at reduced load are also expected to yield improved SNCR performance. The result is NOx emissions well below 0.10 lb/MBtu at reduced load.

The ALTA control strategy that has been adopted thus far at Sioux Plant includes the following elements:

- OFA dampers are adjusted based on a load curve to achieve desired NOx emission of approximately 0.23 lb/MBtu
- Urea flow for RRI is a function of load; NSR increases with load
- Urea flow for SNCR is a function of load; NSR increases with load

It is expected that this control strategy will be modified over time to improve overall performance across the load range. Flexibility of the RRI and SNCR systems allow for adjustment of total urea flow, biasing of reagent between the injectors, as well as adjustment of the injector air pressure to control the droplet size distribution. Ameren anticipates future integration of the ALTA system in neural networks that are planned for both units at Sioux Plant.

Potential balance of plant issues associated with the ALTA system at Sioux Plant include: 1) increased LOI, 2) degradation of barrel tapping performance, 3) waterwall wastage, and 3) air heater pluggage due to ammonia slip. Sioux plant has been operating with OFA in unit 2 since 1997 and in unit 1 since 2001. Over that time frame, there have been occurrences of high LOI, and poor tapping performance, and isolated occurrences of accelerated waterwall wastage. Regarding LOI, observations have shown that it is sensitive to a number of operational parameters (e.g., coal moisture, air temperature, coal grind). However, for the current barrel stoichiometries, data have not yet shown a significant trend of increasing LOI with degree of staging (Cremer, 2004). Similarly for barrel tapping performance. Both units are equipped with weld overlay to mitigate waterwall wastage, which has been experienced with certain high chlorine Illinois coals. Regarding potential air heater pluggage due to ammonium bisulphate (ABS) deposition, ammonia slip measurements show that sub 5 ppm levels are characteristic of the ALTA system. Given the low sulfur content of the PRB/Illinois blend along with the use of tubular air heaters, it is believed that these slip levels will not result in any significant air heater fouling.

SUMMARY AND CONCLUSIONS

Commercial ALTA systems were recently installed in both cyclone-fired boilers at Ameren's Sioux Plant. These systems were placed into full time operation for the 2007 ozone season which began May 1. Startup testing has shown that typical full load NOx emissions during week-long operation of the system were approximately 0.13 lb/MBtu, well below the 0.15 lb/MBtu limit. Average NOx emissions under minimum load of 330 MW were 0.09 lb/MBtu. Ammonia slip measurements at the economizer exit show typical levels less than 5 ppm. Ameren plans to integrate the ALTA systems within neural network systems on both units at Sioux Plant, which could lead to further improvements in performance. Current plans are to use the ALTA systems during the 2007 and 2008 ozone systems and then to use them annually during 2009 and beyond.

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