CARDINAL UNIT 1
LARGE SCALE SELECTIVE NON-CATALYTIC REDUCTION DEMONSTRATION PROJECT

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Abstract:

In late 1997, American Electric Power, Fuel Tech, and EPRI decided to perform a full-scale demonstration of a Urea-based **S**elective **N**on-**C**atalytic **R**eduction (SNCR) system. The demonstration was set to be installed at Cardinal Plant Unit 1. It is expected that multiple power plant operators will be allowed to average the emissions for their system in order to develop the most cost effective system-wide emissions reduction plan. SNCR is a promising technology likely to be utilized in achieving this goal. When SNCR is coupled with LNB's a level of NO_x reduction in the range of 65% can be achieved at a moderate expense.

The primary objective for the project was to demonstrate that Urea-based SNCR technology can be applied to a 600MW steam generator. The specific operational goal for the project is to reduce NOx emissions by 30%, beyond the level achieved through the use of Low NOx Burners, while minimizing ammonia slip at or below 5ppm. The unit is cell-fired with baseline, (post-LNB) NOx emissions of 0.75 lb/MMBtu at full load.

Introduction:

Cardinal Unit 1 is a Babcock & Wilcox opposed-wall cell fired dry bottom pulverized coal boiler which began service in February, 1967. The Cardinal Plant is located in Brilliant, Jefferson County, Ohio. Cardinal Unit 1 was retrofit with Low NOx Burners (LNB's) during its fall 1998 outage. Fuel Tech installed the outage related SNCR equipment concurrently, with the remaining equipment being installed following the outage.

A consortium of EPRI member utilities, AEP, the Ohio Coal Development Office within the Ohio Department of Development, the U.S. Department of Energy, and FuelTech worked together to complete the project. The project is significant in that it is one of the largest domestic installations of the kind burning a relatively high sulfur coal.

The consortium has demonstrated that SNCR technology can be successfully applied to a large-scale high sulfur coal burning utility steam generator. To date, this technology has been applied to smaller industrial and utility boilers burning an assortment of different fuels, but not to any domestic coal combustor larger than 321MW. The specific technical objective for this project was to reduce the NOx emissions from Cardinal Unit 1 by 30% beyond the level achieved by LNB's, while maintaining a maximum of 5ppm ammonia slip.

Title IV of the Clean Air Act requires that utilities comply with maximum allowable NOx emission rates by the year 2000. The NOx limit is 0.68 lbm/MMBtu on an annual basis for Cardinal Unit 1. AEP installed Low NOx Burners at Cardinal 1 during the fall 1998 outage, and have reduced NOx emissions allowing the unit to meet Title IV requirements. Figure 1 shows NOx performance as a function of load.

The consortium intended to demonstrate that SNCR technology when successfully coupled with LNB's can provide an additional level of NOx reduction exceeding the mandates legislated by Title IV. The very nature of SNCR technology will allow the system to be utilized as needed, thus reducing the annualized operating expense of this emissions control methodology. The system was intended to achieve a 30% reduction in NOx emissions with the SNCR. This reduction when coupled with the reduction from the LNB's is estimated to provide an overall reduction from pre-LNB baseline of 65%.

The SNCR process is a post-combustion NOx reduction method that reduces NOx through the controlled injection of reagent, in this case urea, into the combustion products of fossil-fired boilers. Conceptually, the SNCR process is simple. A nitrogen-based reagent, is injected into and mixed with the combustion products. The chemical reacts selectively in the presence of oxygen to reduce the oxides of nitrogen (NOx) primarily to molecular nitrogen (N_2) and water (H_2O). The reaction between urea and NOx occurs within a specific range of temperature, known as the temperature window. If the temperature is too low, reaction rates are too slow and byproduct emissions can become excessive. At high temperatures, NOx reduction and chemical utilization are low. This optimum temperature window is specific to each application. In addition to temperature, residence time within the temperature window, flue gas velocity and directions, and baseline NOx affect the process performance.

<u>Project Development:</u>

Unit Survey:

The first step in designing an SNCR system, consisted of completing a unit survey report. This report identifies the characteristics specific to the unit that will impact the design and operation of the installed system. Steam generator design information, coal analyses, operating information, and emissions data are assembled and provided to the process design team. This information becomes the basis for the development of the computer model. The SNCR process is designed using computational fluid dynamics (CFD) and chemical kinetic modeling (CKM) via results from field tests. The CFD model simulates flue gas flows and temperatures inside a unit while the CKM model calculates the reaction between urea and NOx based on temperature and flow information from the CFD model. A combination of these two models determines the optimum temperature region and the optimum injection strategy for distributing the reagent relative to unit load.

Initial Process Engineering:

Field data acquisition and computer modeling are required to identify the existing combustion, and physical parameters that will affect the reagent injection, amounts, concentrations, and locations. A test crew visits the subject unit and identifies the temperature profile and gas species of the combustion products across the unit in as many physical locations as are accessible. This is done under a number of "normal" unit load points, and under a variety of operating variations. Operating variations such as mill loading patterns, soot-blower operation, etc., are manipulated to obtain as much actual background information as is economically reasonable to develop a working computer model of the unit.

Cardinal 1 was scheduled to have Low NOx Burners installed simultaneously with the installation of the SNCR system. The operation of the LNB's would provide a different combustion pattern than that provided by the original burner arrangement. To address this issue Fuel Tech tested Muskingum River 5, a sister unit, which had already been outfitted with LNB's. The Muskingum River 5 data in conjunction with the Cardinal 1 data provided a very good representation of the combustion process that could be expected on Cardinal 1, after LNB's were installed. The number, type, and location of the reagent injection devices, as well as the injection rates relative to injection location and unit load were preliminarily determined during this stage of the project.

System Description:

The system consists of the following equipment:

Reagent Storage Tanks - FRP tanks sized to provide a 10day supply of reagent. The tanks are heated and insulated to keep the reagent in solution.

Reagent Circulation Module- this module consists of a high head, high flow delivery system designed to supply filtered reagent to the Injection Zone Metering Module.

Injection Zone Metering Module- used to precisely meter and independently control the concentration of the reagent to each zone of injection. This module automatically adjusts reagent flows, activates or deactivates injection zones, or controls zone mass flows in response to changes in NO_x level, boiler load, or firing configuration once the system is optimized.

Reagent Distribution Modules- these are used as a guide and check for proper injector performance.

Injector Assemblies - The unit required three separate zones of injectors. Two are wall mounted injectors located in the upper furnace. The lower set of injectors are retractable allowing them to be removed from the furnace as load is increased, and temperatures exceed that in which the injector could survive. The upper level of injectors are fixed. Six multi-nozzle lances (MNL's) were installed which can be inserted and withdrawn from the first opening in the convection pass. Each MNL is water cooled, and has controllable sub-zones.

An Operator Interface- this device is located in the control room and provides the operators with the ability to monitor and control the operation of the SNCR.

Dilution Water Pressure Control System- this is a self-contained high flow, high head pressure control and delivery system designed to supply filtered process dilution water to the Injection Zone Metering Module.

Condensate Pressure Control Station- this station regulates the cooling water pressure for the MNL's in order to maintain the proper flow rate and temperature.
Temperature Monitoring System- this is a continuous optical device designed to monitor the furnace flue gas temperature. The temperature sensed by the monitor is utilized in determining the proper zone of injection for the process. By properly selecting the zone of injection based on the flue gas temperature, the process can be optimized with regard to NO_x reduction, chemical flows, and ammonia slip.

Summary of Parametric Testing:

Parametric testing to optimize the SNCR system for Unit #1 was performed between March 16 and April 27, 1999. Data was collected by both Fuel Tech, Inc. and FERCO. The testing was completed across the applicable load range of 620 MWg (100% MCR) to 340 MWg (55% MCR) and the preliminary control tables for automatic operation were completed.

The objective of 30% NOx reduction with less than 5 ppm NH3 slip was achieved at the tested loads. To avoid air heater fouling, ammonia slips were carefully measured, the pressure drop across the air heaters monitored, and the testing proceeded conservatively to limit ammonia slip. Throughout the entire testing, the air heater pressure drop at the tested loads remained relatively constant, indicating no evidence of air pre-heater fouling.

The testing at full load was performed first to determine the proper configuration of the upper furnace injection zone (Zone 2) and the multiple nozzle lances (Zone 3.) Each test lasted between 30 minutes to several hours while holding constant SNCR and boiler operations. The boiler and SNCR system operating parameters, NOx, CO, O2, NH_3 and other flue gas species were measured and recorded. Spray patterns were adjusted to evaluate the effectiveness of injection at relatively low chemical flow rates. The resulting chemical utilization and ammonia slip were used to determine the optimum strategy for treatment at higher chemical flow rates. The lance nozzles were configured to maximize the effectiveness of the fine convective pass spray patterns in the high temperature gas at the furnace exit. Droplet size distribution from Zone 2 wall injectors was increased to maximize the reagent distribution in the appropriate temperature zone in the upper furnace. The lower level of wall injectors (Zone 1) was tested and, as expected, was not effective at full load.

At full load, the maximum NOx reduction of 31% was achieved with 5 ppm slip, based on the recorded CEMS data. The level of achievable NOx reduction at full load varied with the apparent baseline NOx and the upper furnace temperature. For example, NOx reduction decreased to ~25% when the upper furnace temperature approached or exceeded 2600 °F (100 F° higher than typical.) Subsequent soot blowing lowered the temperature and improved the NOx reduction.

Optimization at lower loads focused on determining the load point at which Zone 1 injectors could be used effectively and the point at which the lances in Zone 3 should be removed from service. The rear wall injectors in Zone 1 were found to be most effective below 500 MWg, the remainder of Zone 1 was inserted below 410 MWg, the point at which Zone 3 was removed. Similar to full load tests, injection parameters were varied while carefully monitoring ammonia slip.

Higher reductions were achieved at reduced loads. More than 34% reduction was achieved at 450 MWg (75% MCR) with less than 5 ppm slip. At minimum load (340 MWg) as much as 42% reduction was achieved, also with less than 5 ppm ammonia slip. Lower upper furnace temperature and higher residence time than at full load improved the process performance at these reduced loads.

Summary of Long Term Testing:

The Long Term testing was completed between September 20 and November 19, 1999. During this time period the unit was held at various load points during the day. This was done to verify that the SNCR system would perform adequately at the full, intermediate, and minimum load points, in addition to providing stable operating conditions during which specific data could be gathered. When not held at the various load points the unit was under normal dispatch conditions. The system successfully provided approximately 30% reduction in NOx emissions across the load range while maintaining slip near 5ppm, (see fig. 1).

The most significant balance of plant concern was air heater pluggage due to ammonium bisulphate formation. The air heater differential was monitored throughout the long term testing and was observed to increase by approximately 1.5" w.c. We continued to monitor the air heater differential after the SNCR was taken out of service and the differential was observed to decline somewhat, (see fig. 2). This is thought to be a function of the scouring action of the flyash.

Fig. 1

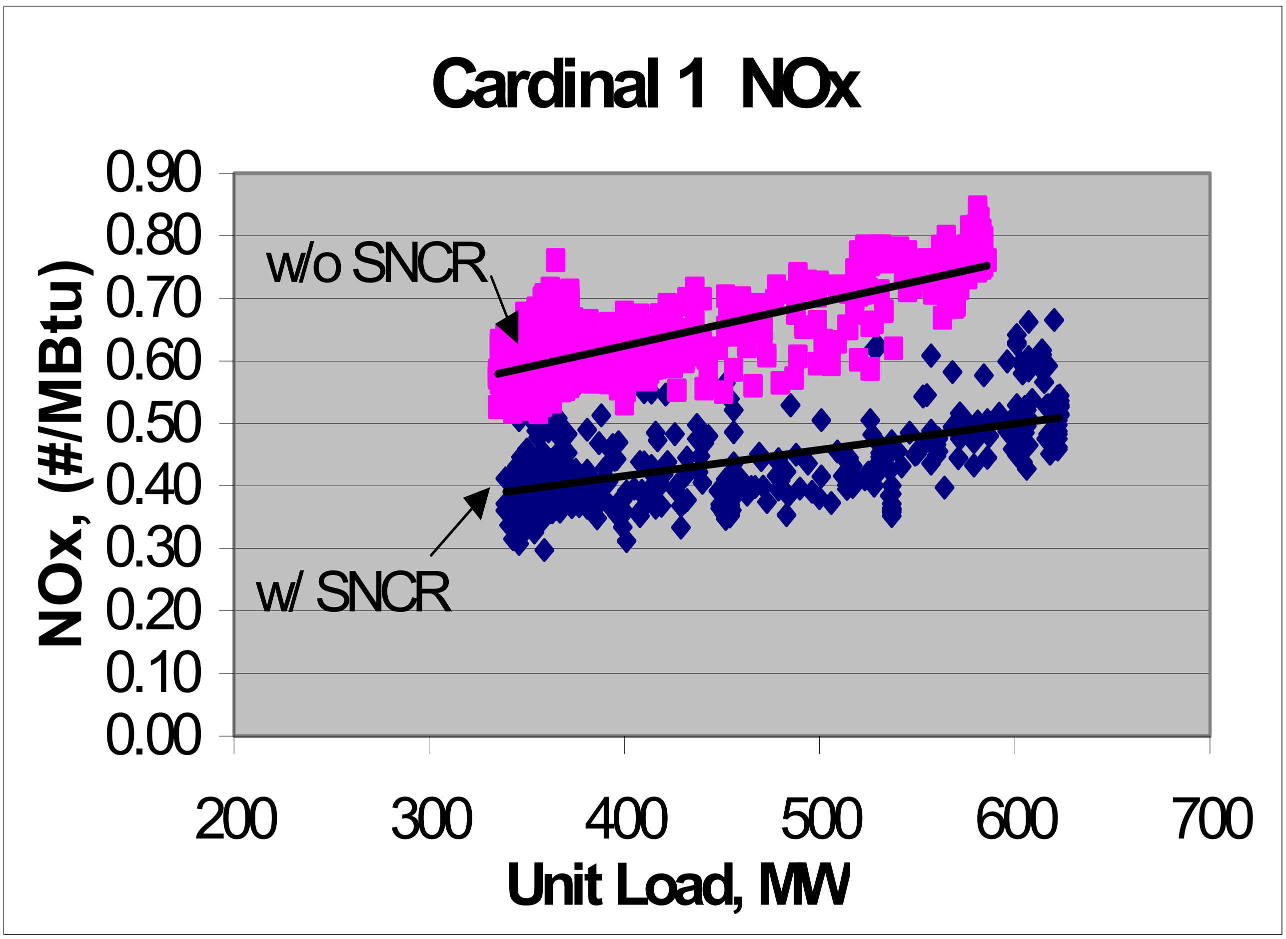
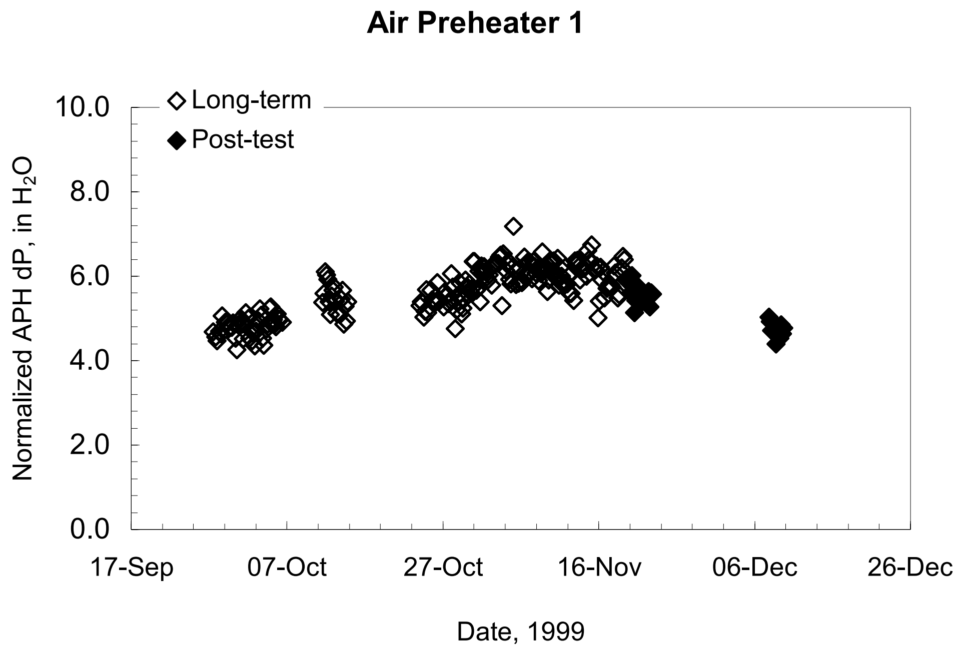
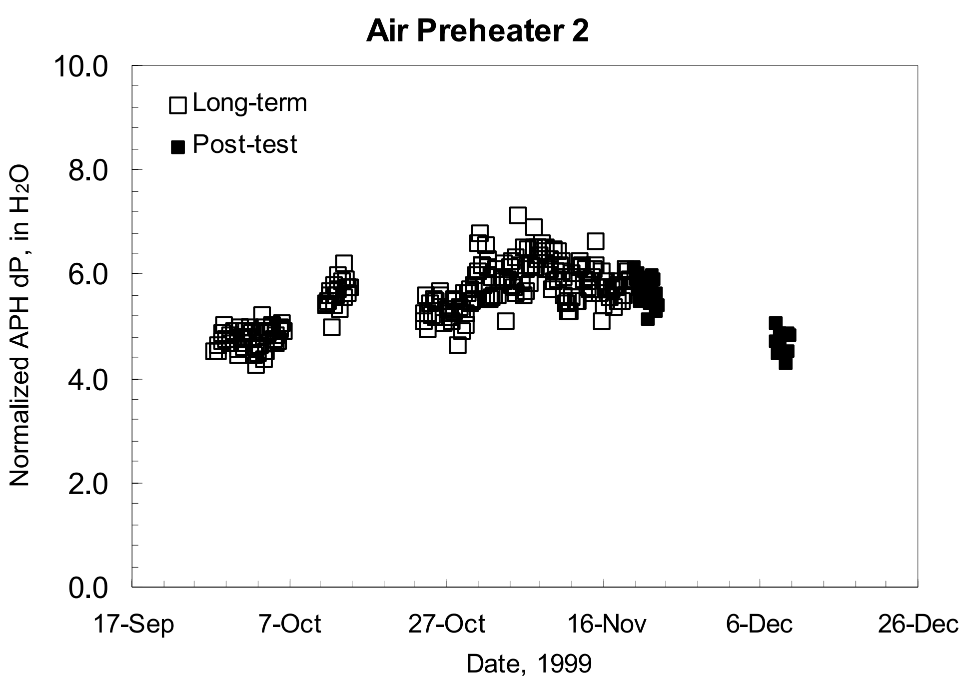


Fig. 2


Air Preheater 1
Long-term
Post-test
Normalized APH dP, in H_2O
10.0
8.0
6.0
4.0
2.0
0.0
17-Sep
07-Oct
27-Oct
16-Nov
06-Dec
26-Dec
Date, 1999


Air Preheater 2
Long-term
Post-test
Normalized APH dP, in H_2O
10.0
8.0
6.0
4.0
2.0
0.0
17-Sep
7-Oct
27-Oct
16-Nov
6-Dec
26-Dec
Date, 1999

Conclusion:

Few difficulties were experienced during the systems operation. Two of the six MNL's developed leaks in their cooling water jackets as a result of a manufacturing defect, not related to the operation of the system. Each device was taken out of service, weld repaired, and returned to operation.

The system has been able to obtain a fair level of NOx reduction as installed. Overall, the unit experienced very few operational problems. This technology combined with Low NOx Burners can obtain a significant reduction in emissions at a comparatively lower installed cost than for other post combustion controls.

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