Combustion Tempering in Conjunction With SNCR Reduces NO_X Emissions Nearly 60% On a Natural Gas Fired Cyclone Boiler

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ABSTRACT

Middletown Station Unit #3, operated by NRG Middletown Operations, Inc. (NRG), is a Babcock & Wilcox (B&W) #6 oil and natural gas fired cyclone boiler rated at 244 MW. The unit was recently purchased by Middletown Power LLC from the Connecticut light & Power Company. The unit originally fired eastern bituminous coal and was converted to burn #6 oil in the early 1970's. Natural gas firing capability was added in 1997. Subsequent to the natural gas firing addition, the boiler was retrofitted with RJM Corporation's combustion tempering system to reduce the NOx formation in the cyclone burners. Baseline NOx emissions prior to the combustion tempering system installation were 0.45 to 0.5 lb/mmBtu while firing natural gas only. The combustion tempering system reduced the NOx by up to 37.5% with the reduced NOx emissions in the 0.30 to 0.35 lb/mmBtu range. An analysis of the budgeted allowances for the 1999 ozone season indicated a deficiency of allowances and the need to reduce the NOx emissions. The installation of an SNCR system was determined to be the economical choice for NOx reduction. RJM Corporation, a Fuel Tech NOxOUT® licensed implementer, was selected to supply the system because of their prior work on the combustion tempering system and their experience with NOxOUT® systems. The SNCR system operation was initiated on July 26, 1999. After two weeks of optimization, a 35% NOx reduction with emissions to less than 0.21 lb/mmBtu was achieved. Total NOx reductions of nearly 60% were achieved with the SNCR system in conjunction with the previously installed combustion tempering system.

Introduction

Middletown Station Unit #3 is a Babcock & Wilcox (B&W) once-through, universal pressure boiler rated at 244 MW gross. The unit entered service in 1963 burning bituminous coal in five cyclone burners. The cyclones are located on opposing walls with a one over two arrangement on the front wall and two cyclones on the rear wall. The full load steam production is 1,750,000 lb/hr at 2680 psig with 1005° F superheat and 1005° F reheat temperatures. The steam temperatures are controlled using gas tempering and gas recirculation in the upper furnace. The unit is a pressurized furnace with two FD fans, a horizontal shaft Ljungstrom air heater, and an electrostatic precipitator. Unit #3 was converted to #6 oil firing in the early 1970's and continued to burn #6 oil exclusively until 1997 when natural gas firing capability was added. The unit has the ability to fire either fuel exclusively or co-fire #6 oil and natural gas in any number of cyclone combinations.

The NO_x RACT emission rate for Unit #3 is .43 lb/mmBtu when firing either fuel. Prior to the natural gas firing addition the unit could meet its RACT rate without the need of additional NO_x controls. The full load NO_x emission rate while firing natural gas approached .5 lb/mmBtu and a means of reducing the full load NO_x emissions was required. Also, the installation of NO_x controls on Unit #3 was required to comply with a special emissions reduction agreement during the Summer of 1998. The options were evaluated and RJM Corporation's patented Combustion Tempering System was determined to be the most economical control with an expected installed cost of $3/kw. RJM Corporation was also able to meet the extremely fast schedule for a July 15, 1998 in service date. NO_x reductions of 37.5% on natural gas and 15% on #6 oil were achieved.

The ozone season NOx allowance program, starting in May 1999, required substantial reductions in the ozone season NO_x emissions to allow Unit #3 to stay within its NO_x allowance budget. This required additional NOx emission controls or the purchase of NO_x allowances to comply with the budget program. An evaluation determined that SNCR would be an economic alternative for reducing the NO_x emissions. RJM Corporation, a licensed implementer of the Fuel Tech NOxOUT® system was chosen to supply the system. Like the combustion tempering system project, the SNCR system project was a fast track project, requiring good coordination between RJM Corporation, Fuel Tech, and Middletown Station personnel.

The SNCR system start up was initiated on July 26, 1999 and optimized during the following two weeks. NO_x reductions of 35% from the SNCR system were achieved, reducing the full load NO_x emissions to .21 lb/mmBtu in conjunction with the combustion tempering system operation. Ammonia slip was less than 3 ppm as measured at the air heater inlet at this condition. This exceeded the expected 25% NO_x reduction.. The SNCR system is expected to be optimized for #6 oil firing during the Spring of 2000. Unit limitations and operation economics have delayed the oil optimization.

Combustion Tempering System Description

The principle behind combustion tempering is to inject an atomized water spray into the high NO_X production zones within each cyclone. The water spray reduces the temperature in the zone and the reduction in temperature reduces the NO_X production rate within that zone. Thermal NOx doubles for every 190° F above 2780° F provided sufficient oxygen is available to complete the NOx reaction. By cooling the zone of highest temperature and maximum oxygen interface, the thermal NOx is greatly reduced. Since the majority of NO_X produced from combusting natural gas is thermal NO_X, this system is more effective on natural gas than on #6 fuel oil.

The location of the high NO_X production zones in the cyclone were identified through computational fluid dynamics (CFD) modeling performed by RJM Corporation. The CFD model determined that the high NOx production zones were located at the exit of the gas burners and near the re-entrant throat. Figure 1 is a CFD plot of the isometric surface of constant NOx production for the baseline case. Figure 2 is a CFD plot of the isometric surface of constant NOx production for the modified case with the combustion tempering water injected at the natural gas burner exit locations. The tempering water total flow rate used in the model is 7.5 gpm. The plot shows a reduction in the size of the NOx production zones which corresponds to a 38% reduction in the NOx emissions.

A combustion tempering system atomized water injector system was designed to inject water into the high NOx production zones. The injector consists of a header supplying water and air to a number of injector nozzles that atomize the water into very small droplets that are injected into the high NO_X production zones. The droplet size and injector spray characteristics were determined using the CFD model. Service water (a maximum of 10 gpm/cyclone of filtered river water) and service quality compressed air at 100 psig are used as the tempering medium. Two separate injector headers and sets of injectors for each cyclone, one for oil and one for natural gas, are required because the NO_X production zones are different for each fuel. Figure 3 shows the injector system arrangement for natural gas.

The major pieces of equipment that make up the combustion tempering system are:

- **Combustion Tempering Metering Skid** - The skid meters the air and water and controls the water spray flow and droplet size to each cyclone. The controls are automatic and the skid receives information from the Moore controllers to determine if the cyclone is in/out of service, type of fuel and fuel flow and sets the process conditions accordingly. If an injector is out of service but the cyclone is still in service, a minimum flow of air and water is required through the injectors for cooling.

- **Air Compressors** - Two new air compressors (Quincy SWI-750), each rated at 757 scfm @ 110 psig, supply the atomizing air and injector cooling air. The compressors discharge into an air receiver tank through a common header and then through redundant coalescing filters located on the skid elevation. The air compressor control system provided by the manufacturer controls the discharge pressure and balances the compressors loading and output when operated in the parallel mode to maximize compressor efficiency. The plant service air is used to automatically provide back up cooling air in the event that both air compressors fail.

- **Injectors** - Two injector headers, with ten injector nozzles per header, are installed in each cyclone. One set of injectors is used for water injection during natural gas firing and the other set for water injection during #6 fuel oil firing.

- **Moore controllers** - Five new Moore controllers (one per cyclone) the interface with the existing combustion control and burner management systems were installed in the Unit #3 control room and supply the cyclone status information to the metering skid and receive the analog process outputs from the skid.

- **Service water supply** - The primary combustion tempering water supply is from the SNCR system dilution water pressure (DWP) control skid. The back up water supply is from the 110 psig service water system. A duplex strainer is installed on the skid to remove any debris that could plug the injector nozzles.

Combustion Tempering System Operation

The tempering skid operating logic for each of the cyclones is performed in the cabinet located on the skid using an Allen Bradley SLC programmable controller. The skid PLC interfaces with the Moore controllers and the alarm panel in the control room.
The control panel located on the skid contains status-indicating lights allowing the operator to know the condition of the common equipment as well as the status of each individual cyclone. Skid alarm lights are also located on the skid panel.

The system is configured to automatically inject water at the rate of 8 gpm from 74% to 100% fuel input and a linear rate input of 8 gpm to 6 gpm from 74% to 60% fuel input. Below 60% fuel input water is injected at 1 gpm/injector header for cooling purposes. When the cyclone is out of service water injection is not required and the valves will close automatically. The graph of water flow rate vs. fuel flow is shown in Figure 4. The atomizing air pressure is automatically maintained at 5 psi over the water pressure using the constant differential pressure valve for each cyclone located on the skid.

System Performance and Results

The system was installed during the late Spring and early Summer of 1998 and started up of the system was initiated on July 28, 1998. The boiler was operating on natural gas in all five cyclones. Testing and optimization consisted of varying the water flow rate and atomizing air pressure. The water flow rate was increased slowly at first to observe the reaction of the flame scanners and overall combustion process. There was no impact on the flame scanner operation or the combustion process other than the NOx reduction. Various tempering water flow rates were tested and the results showed that 8 gpm of NOx tempering water flow resulted in best NOx reduction. The atomizing air pressure to water pressure differential was also varied and the results indicated that a larger droplet size gave a greater NOx reduction. With the unit operating at 246 Mw and all cyclones firing natural gas, the baseline NOx emissions were .48 lb/mmBtu at 1.2% O_2. A 37.5% NOx reduction, down to .30 lb/mmBtu was achieved with 8 gpm of tempering water flow to each cyclone. The final operating configuration is to use 8 gpm of NOx tempering water per cyclone and 1 gpm of cooling water per injector header.

Long Term System Performance

The system has consistently reduced the NOx since it was first placed into operation. After some initial changes in the operating logic for the control system the overall system performance has been good. Modifications have been made to the cooling air and water supply systems to improve the cooling effect and preserve the injector header tubing and nozzles. The latest modifications are working well and long term system operation with minimal maintenance is expected.

Selective Non-Catalytic Reduction (SNCR) System

Process Description

The NOxOUT® SNCR process is a post combustion NOx reduction method that reduces the NOx on Middletown Unit #3 through the controlled injection of NOxOUT® A reagent into the upper furnace area of the boiler. NOxOUT® A is a 50% urea solution plus a small amount of additives for scale and corrosion control.

The predominant overall reaction for the NOxOUT® SNCR process is described as:

$$CO(NH_2)_2 \quad + \quad 2NO \quad + \quad \frac{1}{2} O_2 \quad ®> \quad 2N_2 \quad + CO_2 \quad + \quad 2H_2O$$

Urea + Nitrogen Oxide + Oxygen ®> Nitrogen + Carbon Dioxide + Water

The two key parameters that affect the process performance are flue gas temperature and NOxOUT® A distribution. The NOx reducing reaction is sensitive to the temperature where the reaction occurs and ammonia will form with concentrations increasing at lower than optimum temperature while chemical utilization and NOx reduction decrease at higher than optimum temperatures. The optimum temperature range is specific to each application and the NOxOUT® A needs to be distributed within the optimum temperature zone to obtain the best performance.

The system design was initiated with high velocity temperature profile and gas composition testing of the Unit #3 furnace at the general elevations of the upper furnace where the injectors were expected to be located. This data was used to validate the computational fluid dynamics and chemical kinetics modeling that was performed to determine the furnace temperature and gas composition profiles through out the furnace.

These models are used to determine the optimum temperature range and injection strategy to distribute the reagent. The injector locations were then modeled with the urea injection parameters to determine the expected NOx reduction. Figure 5 shows the NOxOUT® reagent distribution with the lower level of injectors in service at 240 MW while firing natural gas with the combustion tempering system in service. Figure 6 shows the NOxOUT® reagent distribution with the upper level of injectors in service under the same conditions. The upper level injectors provide additional coverage and increase the reagent concentration in those areas that have a lower concentration of reagent from the lower level of injectors. Figure 7 is the boiler cross section with the elevations of the injectors indicated at Elevation 112' 6" for the lower level and Elevation 136' 6" for the upper level of injectors. The lower level injector arrangement consists of 4 injectors mounted on the front wall and 4 directly opposite on the rear wall. The upper level injector arrangement has 4 injectors along the front wall and one injector on each sidewall.

System Description

The Fuel Tech NOxOUT® SNCR system consists of a NOxOUT® A reagent storage tank, circulation module, two zone metering module, dilution water pressure control module, three distribution modules and 14 retractable lance wall injectors installed on two elevations in the boiler waterwalls.

The 14,000 reagent storage tank is located inside the boiler building on the ground floor. The tank is insulated and also has built in pad heaters for emergency use in case the circulation module cannot maintain a temperature of at least 70° F to keep the reagent from solidifying. The circulation module contains 2 redundant pumps that take suction from the storage tank. The role of the circulation module is to circulate the reagent through the system to the metering module and maintain the required temperature through the use of an in-line heater.

The metering module sets the required flow and pressure of the reagent and dilution water and combines the water and reagent to form a mixed chemical solution for the distribution modules. The metering module for Middletown Unit #3 contains two zones of automatic control valves, flow meters, and pressure gages to supply the mixed chemical to the two levels of injectors. A control panel on the metering module contains a PLC that controls the metering module functions and interfaces with the circulation module, combustion tempering skid, and dilution water pressure control module to integrate the function of those skids into the total system operation. The PLC contains the table of values that determines the system operation and sets the urea flow versus steam flow and fuel flow. The metering module controller also determines the required position of the injectors and inserts or retracts them as required.

A man/machine interface (MMI) is in the control room to provide control function access to the metering module PLC as well as graphically display the system operating status including alarms. The MMI is an industrial grade desk top computer that also stores operating and emission data and displays the data as a historical data logger would. The MMI can be used to access the logic programs stored in the PLC's at the individual skids to provide information and make modifications if required.

The dilution water pressure (DWP) control skid takes water from the stations filtered water system at a pressure of 30 psig and increases the pressure to 200 psig for use by the metering module. The DWP also supplies water to the combustion tempering skid at 125 psig via a pressure reducing station. The DWP control panel has a PLC that controls the DWP skid functions automatically as well as interfacing with the combustion tempering skid for its operation and water supply requirements.

The function of the distribution modules is to control the supply of the mixed chemical and compressed air to the retractable injectors. The module contains chemical flow and air pressure control valves along with a chemical flow meter for each injector. This allows for setting the atomizing air pressure for each zone of injectors and balancing the chemical flow to the individual injectors.

The NOxOUT® A wall injector lances are designed for high temperature spray injection of the reagent with control of flow, droplet size, and spray pattern. The spray nozzle determines the spray pattern and can be changed to suit individual injector and process requirements. The injector lance is inserted and retracted as required using an automatic retract system. The retract mechanism is and air-over spring pneumatic piston and cylinder that inserts the lance when the injector atomizing air is on. When the injector is fully inserted into the boiler a contact arm actuates a spool valve which starts the NOxOUT® A reagent flow to the injector. A local retract control panel provides local or remote control of the retracts and provides indication of the local/remote status along with the injector position status.

System Operation

The SNCR system operation is performed from a workstation in the control room or from the metering module control panel. The normal operating procedure is to place the system in the automatic mode and when the steam flow reaches a set value the required injectors will be placed into service to inject the proper amount of mixed chemical.

The Middletown Unit #3 system is configured to insert the first zone of injectors at a steam flow of 1060 klb/hr, which equals about 160 Mw. The urea flow increases as the steam flow increases to the point where the steam flow equals 1350 klb/hr at approximately 200 Mw and the second zone of injectors is placed into service. Figure 8 is a graph of urea flow versus steam flow for each zone. Natural gas flow is also plotted because that enters into the determination of the urea flow if the unit is co-firing natural gas and #6 oil. The system can be configured to bias the urea flow based on the proportion of natural gas and oil. Those values will be determined once oil optimization is complete.

In addition to maintaining the setpoint of urea flow versus steam and fuel flow, the system can also bias the urea to maintain a NOx setpoint. The configuration table allows a NOx emission rate to be set and along with limits to increase or decrease the urea flow rate to maintain the NOx emission rate setpoint

System Performance Results

The SNCR system was started and optimized during a two-week period. The optimization procedure consisted of first placing the lower zone injectors only into service at 200 Mw and then performing a series of tests where the dilution water flow, injector atomizing air pressure, and urea flow were varied and the resulting effect of each change was identified. The results that were monitored were the NOx reduction, ammonia slip, Normalized Stoichiometric Ratio (NSR), and NOxOUT® A utilization. The NOx removal efficiency and reagent utilization are related by the NSR. The NSR is defined as the ratio of (Actual Molar Ratio of Reagent to Inlet NOx) / (Stoichiometric Molar Ratio of Inlet NOx). The NOxOUT® A utilization is equal to the NOx reduction divided by the NSR.

After the optimum SNCR process conditions were determined for the lower zone at 200 Mw, the procedure was repeated for the lower zone low load point then the mid load and high load points for the upper level injectors. The resulting set points for the steam flow, metering module discharge pressure, and NOxOUT® A were entered into the configuration table and the boiler operated through the load range with the SNCR system in operation. Fine tuning of the NOxOUT® A flow rate was performed to maximize the NOx reduction while minimizing the ammonia slip.

The following table shows the RJM Corporation and Fuel Tech proposed single point performance guarantees for the system along with the actual results on natural gas:

	Guaranteed Values	**Actual Values**
Parameter	**Natural Gas**	**Natural Gas**
Net Heat Input (mmBtu/hr)	2455	2595
Boiler Load (MW net)	240	244
Baseline NOx (lb/mmBtu) w/CTS	0.34	0.325
Controlled NOx (lb/mmBtu) w/CTS	0.255	.210
NOx Reduction (%)	25	35.4
Ammonia Slip (ppm)	<10	2.7
NSR – Expected	1.1	1.1
Expected NOxOUT® Flow Rate (gph)	126	136
Guaranteed NOxOUT® Flow Rate (gph)	145	136

The SNCR system performance exceeded expectations in terms of the resulting NOx reduction and corresponding ammonia slip. The system operates automatically over the required load range and results in a consistent and predictable NOx reduction.

Conclusion

The combination of RJM Corporations Combustion Tempering System and Fuel Techs NOxOUT® SNCR system has provided a 60% NOx reduction on Middletown Unit #3 while firing natural gas and has proved to be a cost effective solution to the Middletown Unit #3 NOx reduction requirements.