THE APPLICATION OF GAS CONDITIONING TECHNOLOGY FOR NOx REDUCTION ON FIVE WATERTUBE BOILERS©

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Abstract

The reduction of emission through the design and implementation of the appropriate combustion system is the key to offering maximum operational benefits. The ability to offer emissions reduction through the use of the latest combustion technology gives a method to achieve maximum emissions reduction, while avoiding the cost and complexity of back-end cleanup systems. Choosing the right system based on the operating conditions, furnace design, fuel supplies, and other mitigating factors is critical to implementing a successfully operating system. By addressing all the aspects of the combustion process, the entire combustion system can be optimized to produce the lowest possible emissions.

The Chevron refinery in Richmond, California needed to reduce their total plant NOx emissions to come into compliance with new local air quality regulations. An initial baseline survey of NOx emissions at the refinery indicated that the five utility boilers in their Power Plant #1 contributed about 25% of the total refinery NOx emissions, with observed NOx emission levels ranging from 250 to 450 ppm. New regulations required them to reduce the NOx emissions on these boilers to less than 27 ppm. Initial planning called for the use of Selective Catalytic Reduction (SCR) systems to meet these requirements. Close cooperation between Chevron's NOx Reduction Project Team, consultants, and equipment suppliers resulted in an alternate solution using new burners equipped with gas conditioning technology. After initial testing on one unit it was demonstrated that the required NOx levels could be met without the addition of SCR's, and the remaining units were subsequently converted. Successful application of this technology on all five boilers resulted in over 90% NOx reduction, allowing all the boilers to meet the targeted limit and resulting in substantial cost savings.

Project Background

The California Clean Air Act, signed into law in 1988, called for the installation of the "Best Available Control Technology" on existing facilities that produce ozone-causing emissions such as Nitrous Oxides (NOx) and Volatile Organic Compounds (VOC). As part of its compliance with this act, the Bay Area Air Quality Management District (BAAQMD) developed regulations in 1994 that targeted NOx and VOC emissions in the San Francisco Bay Area. Regulation 9, Rule 10, was designed to limit NOx emissions from combustion sources in local refineries by requiring NOx control systems to be retrofitted on existing (1994 & prior) furnaces and boilers.

At Chevron's Richmond Refinery, the daily average emission rate had to be reduced to less than 0.033 pounds NOx per million Btu's of fuel burned, equivalent to about 27 ppm NOx, (corrected to 3% O2). Chevron's NOx Reduction Project was initiated in 1997 when Chevron assembled a team of company personnel and consultants to evaluate, recommend, and implement NOx reduction technologies that would allow the refinery to achieve its compliance goals in a timely and cost-effective manner. An initial baseline survey was conducted and revealed that three major fired systems produced over 50% of the total NOx emissions in the refinery. The Hydrogen Reformers, Power Boilers, and Crude Heaters were found to be the major NOx producers. It therefore made sense to get these major sources as low as possible first, in order to lower the plant-wide average and potentially eliminate NOx reduction requirements for many other sources.

The Power Boilers

The NOx emissions from the five boilers in Chevron's Richmond Power Plant #1 produced average NOx emissions of between 250 and 450 ppm, which would require reductions of 89% to 94% bring them into compliance with the new daily average emission rate. The power plant utilizes four D.B. Riley water-tube boilers (units 1, 3, 4 & 5) each rated at 140,000 lb/hr, along with one Babcock & Wilcox water-tube boiler (unit 7) rated at 180,000 lb/hr, of 850 PSIG steam. Boilers #1 and #3 were built in 1936, boilers #4 and #5 were built in 1941, and boiler #7 was built in 1953. Each boiler was equipped with the original boiler manufacturer's burners, operated on refinery gas fuel with approximately 25% hydrogen by volume, and had combustion air preheat levels of between 400 and 500 degrees Fahrenheit. The Riley boilers each utilized five burners, with rated capacities of 40 million BTU's per hour each, while the B&W boiler had four burners, each with a capacity rating of 70 million BTU's per hour.

Due to the refinery fuel being burned, the level of air preheat, and the design of these old boilers, an off-the-shelf burner was not available to meet their NOx requirements without requiring significant and costly modifications to the existing combustion air system. Therefore an initial study projected using Selective Catalytic Reduction (SCR) technology to obtain the maximum NOx reduction. SCR's use a nitrogenous agent, such as ammonia, and a catalyst to remove NOx from flue gases. These systems have demonstrated the ability to achieve NOx reductions of greater than 90%, however at a very high installed cost and high annual operating expenses. Additionally, the use of chemicals like ammonia within the process poses a threat of leakage, or “slip”, into the atmosphere, thereby creating additional harmful air pollution.

After looking at the logistics of using SCR’s for NOx reduction on the boilers, it was found that Chevron would be required to install two SCR systems behind the boiler house. In addition to the equipment required, substantial earth moving would be required to the hill behind the boiler house just to provide the space to install them. It would also involve bringing the exhaust from all five boilers to the remote-located SCR systems using a fan requiring over 2,500 HP and a complicated network of ducts. Since the capital cost for this project would have been over $20 million, and annual operating costs would have increased by as much as $1.5 million, it made sense to look at other NOx reduction methods.

Technology Selection

Chevron contacted Jerry Lang Combustion Consulting (“JLCC”) to help evaluate the various options and alternatives. JLCC recommended that Chevron develop burners using a gas conditioning technology that had been successfully applied previously at other Chevron locations. Since the properties of the fuel being burned have a direct impact on the emissions of the combustion system, gas conditioning results in substantially reduced emissions. The gas conditioning involves a fuel dilution process whereby boiler flue gases are induced and mixed with the existing refinery gas fuel to generate a low BTU gas. The fuel dilution reduces thermal NOx by reducing the flame temperature and lowering the local oxygen concentration. Since it also increases the fuel mass flow, it improves fuel-air mixing, reduces the residence time under NOx forming conditions, and homogenizes the flame, which serves to further lower the peak flame temperature. Fuel dilution technology also reduces the carbon radical concentrations in the combustion zone and thereby reduces prompt NOx formation.

Conventional flue gas recirculation (FGR) returns some flue gas to the air-side of the combustion zone. This air-side dilution acts to reduce thermal NOx by reducing available oxygen and lower the mix temperature in the combustion zone. However, FGR does not increase the fuel mass flow or significantly improve the fuel-air mixing, so it is not as effective in reducing thermal NOx as fuel dilution. Since FGR does not affect the fuel side of the combustion, it also has no significant effect in reducing prompt NOx. This has resulted in the ability to achieve higher NOx reductions with fuel dilution, than with conventional flue gas recirculation system using the same mass flow of flue gases. Since FGR also requires fans to transport the flue gases, it results in accompanying power usage. Gas conditioning uses the motive force of the fuel to transport the flue gases, which results in lower operating costs. In this application, where the desire was to re-use the existing combustion air fans, inducing large volumes of flue gas was not an option due to fan capacity limitations. Fuel dilution therefore offered a method of flue gas addition without requiring modification, replacement, or addition of fans.

Chevron had good experience using fuel dilution for NOx reduction at several of their other sites prior to this project. In 1994-95, at Chevron’s El Segundo refinery, a similar capacity single-burner rental boiler had been fitted with fuel dilution technology and had operated at below 9 ppm NOx for approximately five months. In another installation, at Chevron's Shandon pumping station, several old 1920-30's vintage boilers had been successfully converted to fuel dilution technology and ran at less than 20 ppm for over two years. Fuel dilution technology was also added to a 300,000 lb/hr boiler at the ChevronPhillips Chemical Plant in St. James, Louisiana. This modification allowed the unit to increase capacity by 20% and reduce NOx emissions from 60 ppm down to less than 30 ppm. Additionally, over thirty steam flood boilers in Chevron's oil fields in the Bakersfield area have used fuel dilution to reduce NOx on the existing burners to between 15 and 30 ppm.

Burner Development

One luxury that Chevron had, as long as the refinery's co-generation plant and other steam producers were operating, was excess steam capacity. This left one of the Riley boilers available as a spare and provided an ideal situation for prototype testing. It was decided to dedicate boiler #5 for experimental purposes to demonstrate a workable low NOx system. To accomplish this JLCC designed, fabricated, and installed five prototype fuel dilution burners. The burners utilize multiple gas nozzles and available fuel pressure to induce flue gases from an integral flue gas plenum. The system design included the fuel dilution burners, ducting to transport the flue gases from the stack to the burners, a small amount of induced FGR supplied to the existing fan, and a steam injection sparger in the fuel dilution line. At the same time, in order to provide optimum safety and reliability, a new burner management system was also installed on the unit. The only restriction imposed on the design was that the original burner openings in the windbox and boiler front wall had to remain unaltered, in order to facilitate reinstallation of the original burners if the experiments failed.

Baseline NOx emissions for this unit prior to this retrofit ranged as high as 400 ppm. The initial installation on boiler #5 was completed in July 1998, and at initial start-up 70-80 ppm NOx levels were achieved with a good flame patterns and no instability problems. After testing and evaluation, it was concluded that additional flue gas was needed in the fuel, along with a more efficient steam sparging system. A flue gas booster fan was installed to help introduce more flue gas into the fuel and a new steam sparger was designed to provide higher steam flows. After installing and testing these items, it was determined that the problem was actually in the burner mix nozzles. Since they had been designed to fit into the existing burner openings, the restriction resulted in a plug flow condition. It was decided to replace the burner drawer assemblies with ones including larger diameter mix nozzles. This change was done in early 1999, and allowed the removal of the flue gas booster fan from the system. After testing using the re-designed burners and steam sparging system, this boiler consistently produced NOx numbers of 15-20 ppm (corrected to 3% O2).

Burner Supply

The results of the testing on boiler # 5 clearly indicated that fuel dilution technology was a viable solution for all the units. At this point Chevron and JLCC jointly decided that a burner company needed to be involved in the process in order to facilitate the retrofit of the remaining boilers. JLCC contacted John Zink Company ("Zink") in Tulsa, Oklahoma to finalize the design and supply production burners for the remaining boilers. Zink has been involved with fuel dilution technology since its development in the early 1990's, and had used it to develop their CMR burner. Based on the initial prototypes tested on boiler #5, and working with both Chevron and JLCC, Zink developed the LCF burner. LCF burners were shipped to Chevron to retrofit the four remaining boilers, and Chevron also purchased production LCF burners to replace the prototypes on boiler #5.

As part of the "system" solution to ensure optimum burner performance, the TODD Combustion Group of John Zink ("TODD") provided an air distribution study of the windboxes and combustion air systems, using their in-house modeling facilities. Long-term experience in the application of oil and gas firing equipment to a wide range of boiler designs led to the conclusion that it was required to add baffles to the windboxes. This is used as a means of balancing airflow, in order to assure stable flame formation without combustion induced boiler vibration, and to minimize excess air levels and boiler emissions. For this purpose, TODD has developed over the past fifteen years the COOL*flow* modeling technique, a scale model test facility which allows for full observation and photographic recording of the air flows within scale model versions of existing ductwork and windbox/burner configurations.

The actual models were constructed from plastic and sized so that the velocity heads were representative for analysis, using analog methods, of full scale flow conditions. The scale model was specially fitted with miniature pitot tubes and other flow measurement devices to obtain the velocity heads. This information was then plotted on polar diagrams from which bulk flow rates were computed using graphical and numerical surface integration. As part of the testing, baffles were added to the model only as required to balance airflow to each burner. Based on these results, a drawing showing recommended baffles for the actual windboxes was provided so that the result was a configuration that assured balanced air flow and optimum burner performance.

Any recycling of flue gases increases mass flow through the boiler, increasing convective section velocities and superheat temperatures. Since gas conditioning is more effective in reducing NOx than conventional flue gas recirculation, it requires less flue gas for the same amount of NOx reduction and results in a much lower impact to the boiler operation. Baffle modifications to reduce superheat temperatures were done in all boilers except boiler #7. Boiler #7 historically had lower steam superheat temperatures than the maximum design superheater outlet temperature, so the change to superheat temperature ended up within the operating limits of the boiler. Modifications to boilers #1, #3, #4 and #5 included adjustments to lengths of convection section baffles above and below the superheat tubes. The original boiler manufacturer, DB Riley, modeled the boilers in order to determine which baffles would require modification and to what extent they would need to be modified. These changes allowed the units to meet the NOx reduction limits without requiring the addition of any steam superheat control equipment.

Final Results

Installation work on the four remaining boilers began in February 2000 and was completed by mid-July 2000. Along with the burner retrofit, Chevron elected to perform boiler repair work, re-certification where applicable, control system modifications, and the addition of a Continuous Emissions Monitoring System (CEMS). The prototype burners on boiler #5 were replaced with the new LCF burners in May 2001. The normal fuel gas header pressure available in the boiler house is 38 PSIG. The gas pressure at the burners is about 25 PSIG at 120,000 lb/hr steam production and 30 PSIG at 165,000 lb/hr of steam. To ensure that the firing rate is not lowered beyond the point of flame stability a low-pressure alarm is set at 2 PSIG and a shutdown is initiated at 1 PSIG.

The boilers all operate on a 24 hour a day, 7 day per week, basis and NOx emissions are consistently maintained at or below 25 ppm (corrected to 3% O2). Chevron has also demonstrated the ability for these units to achieve NOx levels of less than 7 ppm, with the use of additional sparging, while maintaining excellent flame stability. In cases where a source of excess low pressure steam is available the additional NOx reduction to single digit levels comes with almost no additional operating expense. However, since this plant has to let down 850 PSIG steam for sparging it can result in a considerable ongoing operating expense. For this reason the steam injection rate is controlled only to the amount required for the boilers to stay comfortably below their permitted NOx levels. To control the steam injection rates to the burners, Chevron implemented a fuel gas cascade control scheme. This control minimizes the need for the boiler operators to adjust steam injection rates as boiler firing rates are varied, which is done automatically as steam demand changes in the refinery.

Conclusion

The result of this cooperative venture between Chevron's NOx Reduction Project Team, Jerry Lang Combustion Consulting, and the John Zink Company was an innovative and cost-effective solution to a tough emissions reduction application. The LCF burners developed as part of this project have demonstrated the ability to provide over 90% NOx reduction and maintain safe reliable combustion performance. In addition, with the use of additional steam sparging, the burners are capable of reaching Ultra Low NOx levels of less than 7ppm. As a result of taking this innovative approach to finding a solution to their NOx problem, Chevron has seen a savings of over $7 million for the cost of the project and avoided an additional $1 million to $1.5 million a year in operating expenses.