NO_x REDUCTIONS VIA OVERFIRE AIR MODIFICATIONS

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Introduction

The reduction of NO_x emissions is an ongoing process for the utility industry in the United States. The purpose of this paper is to describe a project that involved the modification of an existing overfire air (OFA) system which resulted in lower nitrogen oxide (NO_x) and carbon monoxide (CO) emissions. The modifications included partial removal of existing OFA ports and installation of new OFA ports. The design of these modifications was driven by combustion tuning observations and the results of computational fluid dynamics (CFD) modeling.

Background

San Miguel Electric Cooperative, Inc. (SMEC) operates a 440 MWg opposed wall-fired compartmented windbox style boiler that fires south Texas lignite coal. Over the years, SMEC has had to make a number of changes to the boiler to meet the various environmental NO_x regulations. In 2003 the boiler was outfitted with a dual elevation overfire air system. This was Phase I in a two phased approach to comply with the Texas NO_x requirements, which required compliance by May 2005. Each of the two elevations of the OFA system had an OFA port directly above each of the 6 burner columns for a total of 24 OFA ports. The OFA system utilized an out of service gas recirculation duct as the header and is retrofitted with twelve take-off ducts. Each take-off duct feeds two OFA ports.

The OFA header is fed from two riser ducts that connect to the secondary air duct in between the front and rear of the unit. Each of the two OFA riser ducts contains one flow control and an airflow measurement device. The sum of the airflow measured in the two OFA riser ducts is used to control the total flow to the OFA system. There is a total OFA Flow vs. Gross Load curve that was developed via testing. This control curve is based off the boiler O_2 curve and the target lower furnace stoichiometry. This method of control ensures that low NO_x is realized for all normal load conditions.

During Phase II, the boiler was retrofitted with forty-two (42) new low NO_x burners and new secondary air flow measuring devices in 2004. There are four (4) rows of six (6) burners on the rear, and three (3) rows of six (6) burners on the front. The lowest row of burners on the rear is unopposed. To reach full load the boiler is fired with six (6) of the seven (7) pulverizers. After each phase, combustion tuning of the boiler was performed in order to maximize NO_x and CO reductions.

As State and Federal NO_x emissions requirements changed, the need to control NO_x and operate at the lowest possible emission rate becomes a greater priority. SMEC initiated a NO_x strategy evaluation with Burns & McDonnell in 2006 to evaluate the existing technologies available to further reduce NO_x emissions. Multiple options were outlined and several were implemented in 2008 and 2009. These included the addition of OFA port duct flow measuring devices, power operated dampers on each OFA port and a neural network to continually optimize NO_x and CO emissions

SMEC also utilized Reaction Engineering International (REI) to perform a CFD model to investigate the potential for OFA system modifications. Several case studies were evaluated and it was determined that an OFA modification existed that would result in lower CO emissions and up to a 10% reduction in NO_x.

As the NO_x emissions requirements changed further in 2011 (Cross State Air Pollution Rule), further review of the evaluation performed in 2006 suggested that it was an appropriate time to move forward with the OFA modification project.

Discussion

Utilizing OFA systems for NO_x emission reduction is not a new approach. Staging combustion is a time tested method of reducing the overall NO_x formation from the combustion process. Over the last several decades many variations of OFA systems have been designed and installed.

The purpose of an OFA system is to reduce NO_x emissions from the boiler by staging the combustion process. A portion of the secondary air is diverted from the burner front to a series of OFA ports that are located above the burners. As a result, the burners are fired with less than the total amount of air needed for complete combustion. If the amount of air admitted to the burners is less than the amount theoretically required to completely burn the coal, the burners are said to be firing substoichiometrically.

There are several parameters that are typically measured or calculated and used as design points to ensure good combustion under staged conditions. Those parameters involve the fuel and air mixing and the velocities of the primary and secondary streams into the burners.

The addition of OFA reduces the quantity of secondary air delivered to the burners. The OFA system for this boiler is designed to deliver approximately 850 kpph of air to the OFA ports at full load. However the quantity of primary air required for transporting the coal to the furnace will remain constant, regardless of the OFA flow. Therefore the ratio of secondary air to primary air at the burner front will decrease with the increased use of OFA.

The introduction of large quantities of OFA into high temperature regions of the furnace can and will cause NO_x reformation to occur. The injection velocity and mixing of the OFA into the furnace is a critical variable to minimizing the NO_x reformation. Field testing has shown that finding the optimal effective mixing of OFA reduces the amount of NO_x reformation that occurs.

When designing an OFA system, or OFA system modification, the main objectives are to minimize NO_x production and maximize CO burnout. Therefore a compromise must be made between the furnace residence time from the burners to the OFA and the residence time from the OFA to the furnace exit. Maximizing residence time between the burners and the OFA ports will result in lower NO_x formation. However, enough time must remain between the OFA ports and the furnace exit to effectively mix and oxidize the remaining CO prior to the flue gas temperatures dropping below the CO auto-ignition temperature. Longer residence times above OFA ports also results in lower unburned carbon levels. The San Miguel furnace has approximately 2.9 seconds of residence time between the top elevation of burners and the horizontal furnace exit at the arch.

CFD modeling is an ever evolving tool that has become increasingly sophisticated and has allowed for a greater understanding of exactly how the gases are mixing in the furnace. CFD modeling allows for the potential OFA designs to be validated prior to installation. Figure 1, below, shows an example of the penetration and mixing tendencies of OFA ports with different quantities of air flow being introduced into the furnace.

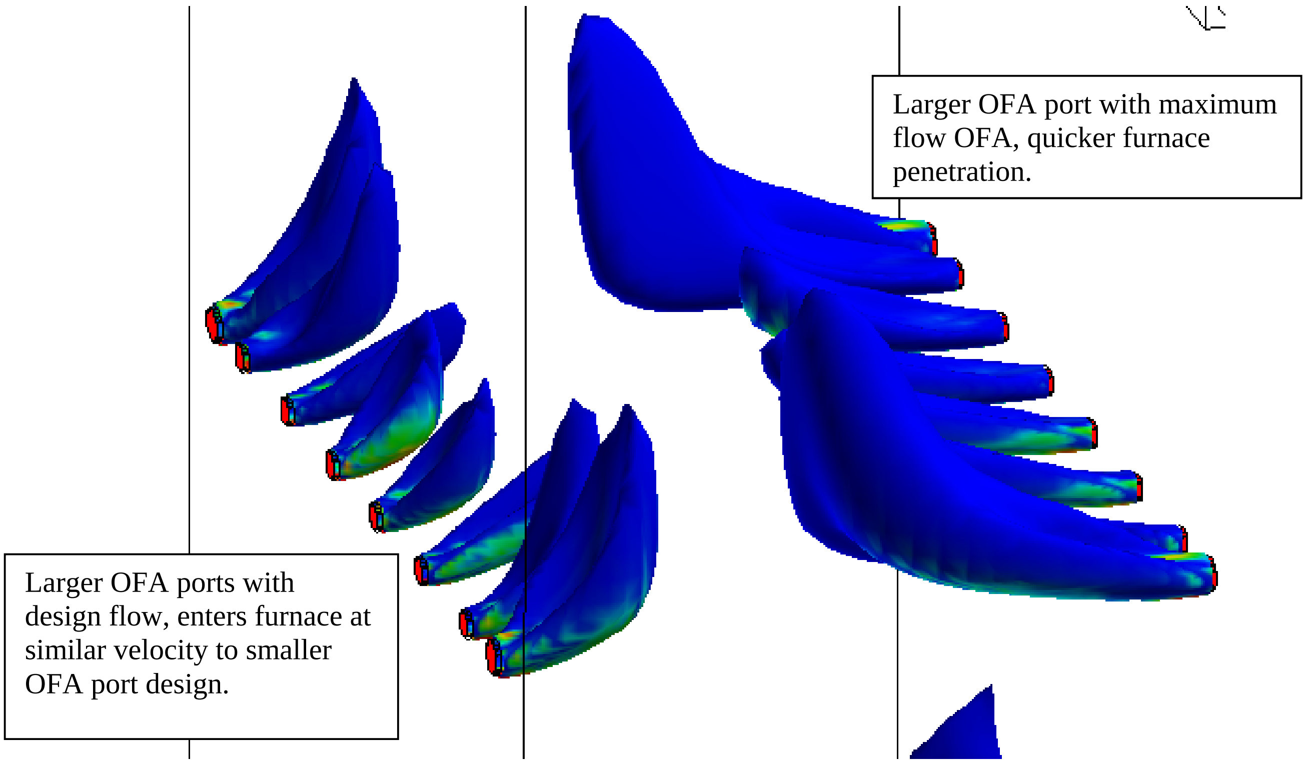

Figure 1: Case 4, 10% O_2 iso-surface depiction

Procedure

As stated above, combustion tuning was performed on the SMEC boiler after each phase of NOx reduction. Combustion tuning at SMEC is performed by utilizing a 66-point economizer flue gas sampling grid. The sampling grid consists of test ports in four individual flue gas ducts. Two flue gas ducts feed individual secondary air heaters. The other two flue gas ducts feed one primary air heater.

The SMEC pulverizers grind 75 – 80 tons of lignite per hour. As the pulverizers wear out, the classifier outlet pipe-to-pipe fuel balance changes. Over time the burners require adjustments to change secondary air in order to more closely match the distribution of the fuel.

After performing combustion tuning on the SMEC boiler multiple times, it became apparent that there was a tendency for pockets of flue gas with high concentrations of CO to run up the four corners of the furnace. With the existing OFA system, it was difficult to get adequate air flow distribution from the OFA ports to burnout the high CO concentrations.

The furnace is 67’ wide by 45’ deep. The distance between the furnace side walls and outer most OFA port was approximately 11 feet. The distance between each burner column is approximately 9 feet. A baseline CFD model was developed and confirmed these higher concentrations of CO in the corners.

There are several important factors to consider in order to optimize NO_x reduction via OFA: optimal mixing rates to minimize NO_x reformation, and overall oxygen distribution to complete combustion burnout. OFA system design begins by determining a lower furnace stoichiometry design point. Combustion calculations then yield total OFA flow rates. Determining placement and injection velocities leads to the sizing of the OFA ports.

On the SMEC boiler, it was estimated that even with the lower elevation OFA ports shut off, approximately 5,000 to 15,000 lb/hr of OFA was leaking by as cooling flow. The objective of the CFD modeling was to determine the effects on combustion, if the lower elevation OFA ports were removed and four new larger OFA ports installed in between the existing upper OFA ports and the furnace sidewall. Figure 2, below, shows one of the four new larger 28” diameter OFA ports. Figure 3, below, shows one of the smaller original 22.5” diameter OFA ports. Multiple CFD modeling cases were evaluated. The results indicated that not only would CO emissions be lower, but that NO_x reductions of ~9-10% could be expected.

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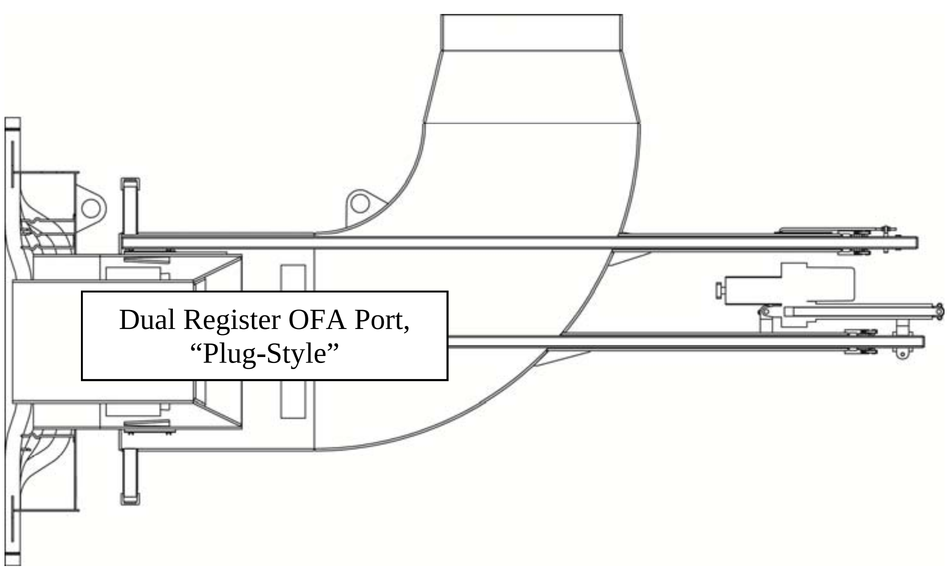

Figure 2: New larger OFA port

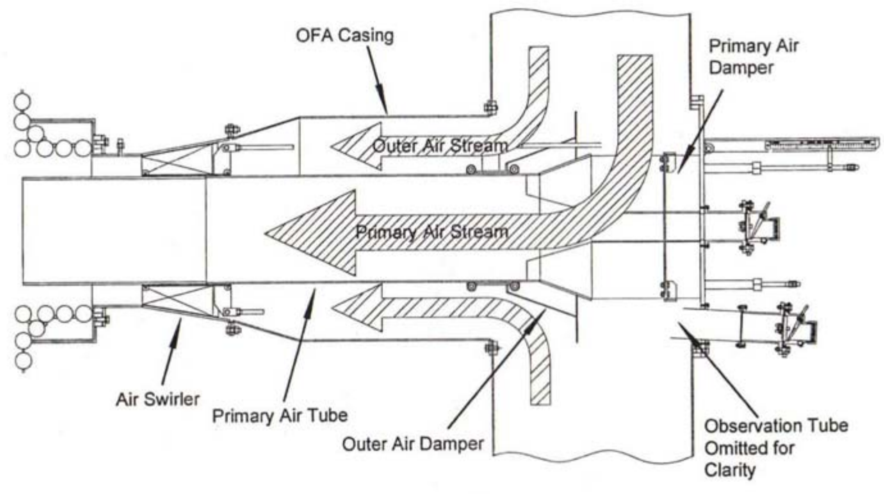

Figure 3: Original smaller OFA port.

In 2011 SMEC retained B&McD to engineer the required retrofit of the OFA system. The retrofit required new bent tube panels, seal can, OFA port, secondary air duct take-off, flow element, expansion joints. To control the new OFA port, beck linear actuators were reused from the demoed OFA ports. After the demolition of the old OFA ports the existing bent tube panels were filled with refractory and sealed off.

Results

The combustion tuning effort of the new OFA system modifications began by putting all burners and OFA ports to a neutral position. In this case all burners were set to identical settings and the OFA ports were to symmetrical settings. San Miguel personnel collected isokinetic coal sampling data from each of the seven pulverizers. Windbox pressure versus secondary compartment airflow measurements was collected and evaluated. Each of the flow elements associated with the overfire air system was calibrated prior to testing.

With the initial setup complete a point by point flue gas sampling grid of data was collected. Then the pulverizer out of service was swapped and another point-by-point flue gas sampling grid was collected. The collected data was then compared to measured pipe-to-pipe fuel balances. Individual burner adjustments were made to identify fuel rich or lean burners. Global adjustments to OFA inner and outer registers were made to identify the best balance between furnace penetration and mixing.

The objective of combustion tuning was to achieve the lowest possible boiler O_2 set point with minimum NO_x and CO emissions for all multiple mill firing configurations. During the combustion tuning effort, a boiler O_2 set point of 2.0% was achieved for all mill configurations. Note that for the B, E and F mill off combinations the average economizer flue gas sampling O_2 were higher than the DCS average of the eight (8) O_2 probes. For SMEC, 2.0% is the lowest permissible set point for O_2. The data collected for the seven mill configurations and full load resulted in the following:

Table 1: Final Results at Economizer Flue Gas Sampling Grid

Date	Configuration	O_2 (%)	CO ppm	NO_x ppm	NO_x lb/mmBtu
18-Aug-12	D-Mill-Off	2.15	106	126	0.166
19-Aug-12	F-Mill-Off	2.49	206	133	0.178
19-Aug-12	B-Mill-Off	2.48	297	131	0.175
20-Aug-12	E-Mill-Off	2.10	119	126	0.165
20-Aug-12	C-Mill-Off	2.49	59	128	0.172
21-Aug-12	A-Mill Off	2.09	137	122	0.160
21-Aug-12	G-Mill-Off	1.99	53	124	0.160
	Average	***2.26***	***140***	***127***	***0.168***

The average NO_x emission rate for all pulverizer combinations was measured at 0.168 lb NO_x/ mmBtu. While the CO emission average was acceptable, two of the seven cases averaged over 200 ppm. For all tests the burner and OFA port position were not adjusted. In contrast, during all other pre-modification combustion tuning efforts some OFA port adjustments were required and different boiler O_2 set points were required for different pulverizer combinations. Continued refinement by the Neural Network has further reduced CO and NO_x emissions.

From 2007 through 2011, SMEC Unit 1 NO_x emission rates have averaged 0.186 lb/mmBtu. Based on the data collected after tuning, the OFA modification has reduced the NO_x emissions by approximately 9.7%. The NO_x reduction is the result of reduced boiler O_2 and less NO_x reformation from the OFA system. It is estimated that up to 200 kpph, (25%) of the OFA airflow was being introduced into the boiler through the lower elevation of the OFA ports that were removed during the OFA modification outage. The lower OFA airflow was required to limit the CO emissions levels. The four new larger OFA ports are adequately limiting the CO emissions and allow for a lower boiler O_2 set point to be achieved.

Conclusion

Increasingly stringent NO_x regulations have resulted in the design and installation of many OFA systems. Some of these systems were not optimally designed and the results of these installations are higher than necessary NO_x and CO emissions and operating boiler O_2.

Through sound engineering practices and observations, OFA modifications were designed for the SMEC boiler that resulted in a combustion improvement and a reduction in NO_x and CO emissions.