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Staged Low NOx Combustion Systems for Coal Fired Boilers and Corrosion

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Abstract

Staged combustion is well known to reduce NOx emissions in coal fired utility boilers. Oxygen has been shown to enhance the benefits of staged combustion producing even lower NOx emissions. Further, oxygen reduces or eliminates other problems associated with deeply staged combustion including higher LOI, reduced combustion stability and waterwall corrosion. This paper discusses the impact of staging on waterwall corrosion. Model results are presented showing that it is possible to go from a system that is unstaged to an oxygen-enhanced deeply staged system without increasing corrosion potential. These results are consistent with performance test results, which have shown that oxygen-enhanced combustion reduces LOI and reduces rear wall impingement by shortening the flames. Both of these factors are consistent with reduced corrosion potential.

Introduction

Staging the lower furnace of a coal fired boiler and utilizing low NOx burners can reduce NOx emissions. However as utilities employed this technology in the 1980's and 1990's, some utilities experienced significant localized increases in waterwall wastage. As a result EPRI conducted extensive research to understand and help utilities mitigate the wastage problem. Praxair's recently developed Oxygen Enhanced Combustion for utility boilers allows even deeper staging for added NOx reductions. Computational Fluid Dynamics (CFD) simulations conducted by Reaction Engineering International (REI) showed that corrosion rates under deeply staged Oxygen Enhanced Combustion conditions are comparable to mildly air staged conditions. This paper summarizes the background information and discusses work performed by REI to study the impact on waterwall corrosion of changing from unstaged to staged combustion with and without oxygen.

Summary of Staging Technology and Benefits

The basic configuration of an overfire air staged combustion system for NOx control is illustrated in Figure 1. In an air staged combustion system, a portion of the combustion air is diverted from the burners to overfire air ports above the burners. The objective is to form a fuel rich flame zone followed by a region where the residual char is burned out. The effect of fuel rich conditions on NOx formation is shown schematically in Figure 2. This figure shows the competition between the formation of NOx and the formation of molecular N_2 from nitrogenous species in the coal[1]. Upon heating coal pyrolizes and forms volatiles and char, each containing bound nitrogen. Oxygen rich conditions drive the competition towards NOx formation. Fuel rich conditions, such as those created in staged combustion, drive the reactions to form N_2. Thus, as shown in Figure 3, by reducing the burner zone stoichiometric ratio the formation of NOx from volatiles is significantly reduced.

One major factor in the effectiveness of staged combustion is the need to form very fuel rich conditions to drive the N_2 forming reactions. Under very fuel rich conditions less combustion takes place, and therefore less heat is released, leading to low flame temperatures. Since the reaction rates driving NOx and fuel nitrogen species to N_2 are strongly dependent on temperature and residence time, there is a competition between the need to create a fuel rich condition and the need to maintain the desired high flame temperature. An additional complicating factor in staged combustion is that the second stage residence time (for burnout) tends to be relatively short. Char burnout is a slow step and NOx formation from char nitrogen is a significant factor in a low NOx coal combustion process. Therefore if the coal is only partially oxidized in the first, fuel rich, stage, significant NOx may form from char oxidation and there may not be sufficient residence time to burnout the residual carbon, – leading to high unburned carbon in the ash[2].

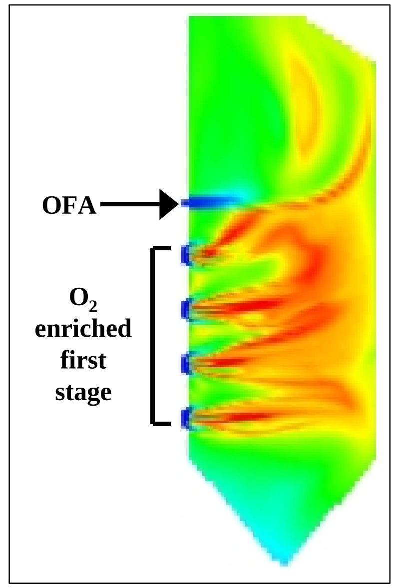

Figure 1. Schematic of Staged Combustion

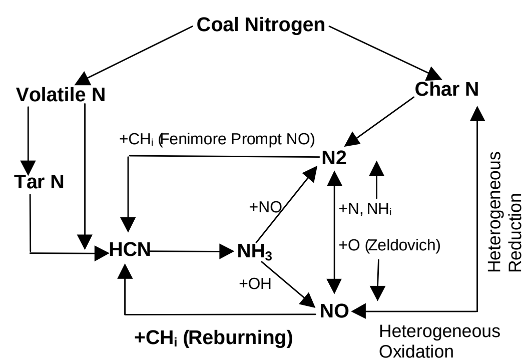

Figure 2. NOx production pathways in coal combustion[1]

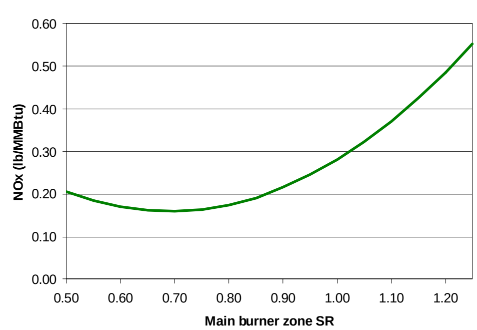

Figure 3. Typical effect of main burner zone SR on NOx – air only

Waterwall Corrosion in Low NOx Combustion Systems

In 1999 Bakker, et al published a paper based on the substantial work sponsored by EPRI looking at the impact of low NOx coal combustion systems on waterwall tube wastage[3]. Some of the conclusions from that work are as follows.

- Survey work indicated that there was no significant correlation between coal sulfur content and corrosion rates. Previously, it was commonly believed that gas-phase H_2S produced from coal sulfur under reducing conditions was responsible for the observed corrosion.

- Further survey work indicated that the corrosion rates in subcritical boilers were much less than those in supercritical boilers. This was attributed to the higher wall temperatures in the supercritical units. (Tube wall temperatures in subcritical units are less than 700F)
- Experimental, modeling, and field test work demonstrated that the corrosion rates could not be attributed to H_2S alone.
- An additional conclusion was that the root cause of the high corrosion rates was the presence of FeS rich deposits which decompose to provide corrosive reduced sulfur species near the waterwall tubes, leading to severe sulfidation of the waterwall tubes. The FeS comes from partially combusted pyrite (FeS_2) contained in many coals. The work also showed that higher tube wall temperatures found in supercritical boilers can significantly increase the corrosion rate.
- In test work conducted by EPRI, at wall temperatures of 700F and H_2S concentrations as high as 600 ppm, H_2S based corrosion rates are predicted to be less than 3 mils/yr (mpy) while FeS deposition related corrosion rates greater than 30 mils/yr (mpy) are predicted at nearly identical temperatures. This suggests that while H_2S corrosion is expected to be low for subcritical boilers, FeS based corrosion needs to be addressed even for subcritical units[5].
- Comparing modeling predictions with actual furnace corrosion experience, REI showed a good correlation between the model predicted and actual areas of severe corrosion. The model studies further showed that high unburned coal fractions in the deposits were predicted in areas experiencing high corrosion rates. The model suggested modifications to corrosion conditions that could reduce impingement and resulting corrosion[4].

In their work at CONSOL Energy, Hanson and Abbot concluded that gas-phase composition has little impact on wastage. They concluded that the incident radiation coupled with the deposition were the cause of high wastage. They further concluded that one of the keys to minimizing waterwall wastage was managing ash deposition and the properties of the deposits formed[6].

Chlorine has also been shown to contribute to boiler corrosion for coals with high chlorine content in Great Britain. This mechanism will not be addressed here as most domestic coals have relatively low chlorine contents.

REI has published the results of the work demonstrating the ability of their computational fluid dynamics (CFD) software (GLACIER) to predict waterwall wastage in coal fired boilers. In 2001 Praxair engaged REI to study the impact of oxygen combined with deep staging on NOx emissions, LOI and waterwall wastage.

Impact of Oxygen on Waterwall Wastage

The impact of oxygen on staged combustion has been demonstrated in single burner and full scale boiler testing. These results have been correlated with CFD simulations conducted by REI. For staged conditions both predicted and actual NOx reductions have been in the range of 35-50%. Going from unstaged to oxygen-enhanced staged operation, NOx reductions of approximately 70% have been achieved. Further actual boiler test results have shown that LOI under staged conditions with oxygen can be brought back to levels comparable to unstaged conditions. FeS deposition is driven by particle impingement on waterwall surfaces. This improved combustion performance suggests that oxygen may reduce FeS deposition under staged conditions. In order to understand this better, REI conducted a series of furnace simulations comparing staged and unstaged operation with and without oxygen in two subcritical boilers. Simulations were completed for a boiler with minimal corrosion problems going from unstaged to staged operation and one that experienced a significant increase in wastage when it was converted to staged low-NOx firing. The first boiler is a 44 MW front wall fired unit burning low sulfur bituminous coal. The results are as follows:

- This subcritical boiler experienced minimal corrosion under unstaged conditions.
- The simulations predict that the H_2S, average FeS and Maximum FeS based corrosion rates will be virtually unchanged for this unit going from the unstaged baseline condition to deeply staged conditions. (Figure 4) This result is consistent with the operator's experience under staged low NOx operation. The predicted unstaged corrosion rates are not zero because the model still predicts some deposition.

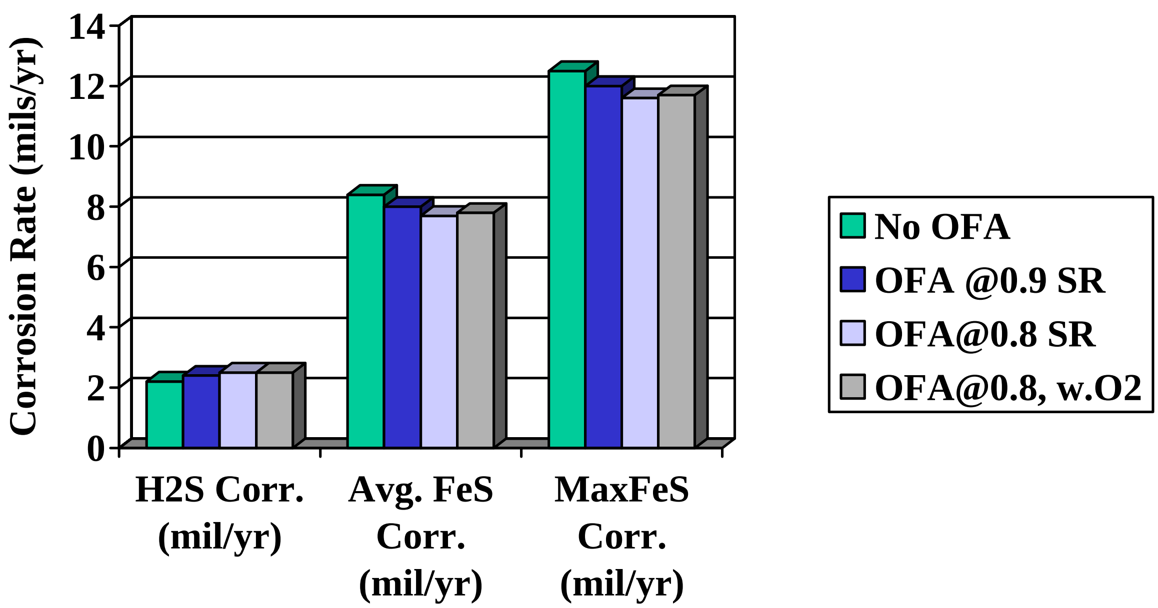

Figure 4: Predicted corrosion rates under staged and unstaged conditions.

- In this boiler the predicted waterwall areas subject to corrosion were very small and also little changed from staged to unstaged conditions, as seen in Figure 5.
- Based on periodic ultrasonic tube wall measurements, this boiler has experienced minimal corrosion both under staged and unstaged operation. The actual corrosion rates were much less than the predicted rates.

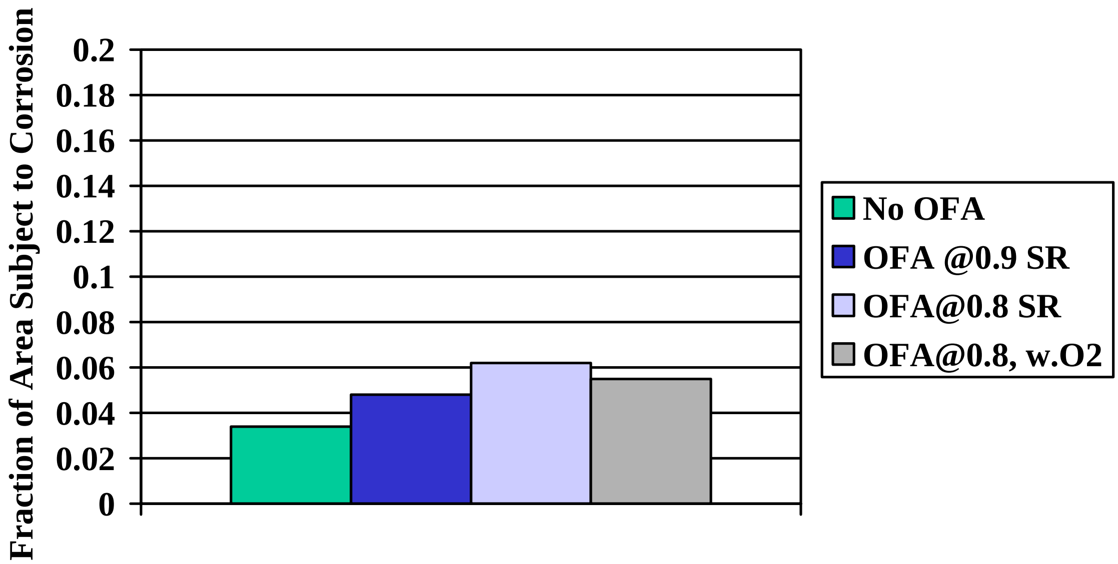

Figure 5: Predicted area of corrosion under staged and unstaged

The second boiler is a 180 MW front wall fired unit; the unit has experienced corrosion under staged low NOx operation. Simulation results for this boiler were presented at the EUEC and Clearwater Conferences. The following conclusions were reached[7]:

- Predicted corrosion rates due to H_2S varied very little between the mildly staged and deeply staged cases. In any case, these corrosion rates did not exceed 5 mils /yr.
- Predicted average FeS based corrosion rates for mildly staged combustion without oxygen were ~ 30 mils/yr. These were noted as being high for a subcritical boiler but consistent with actual plant observations for this unit.
- The predictions indicated that the average corrosion rates for all cases were comparable but in the oxygen enhanced cases the area susceptible to FeS based attack is significantly reduced even when compared to the mildly staged air cases. Thus they concluded that oxygen enhancement is predicted to lead to a significant reduction in the waterwall area susceptible to the highest rates of FeS based corrosion. They also noted that this is consistent with the

predicted increase in volatile yield and reduced unburned carbon due to oxygen enhancement. Field observations (on a different unit) support this conclusion. LOI levels under oxygen-enhanced conditions were comparable to those of an unstaged boiler, and the addition of oxygen substantially shortened the flame length, thereby reducing impingement and potential deposition on the rear wall of the furnace.

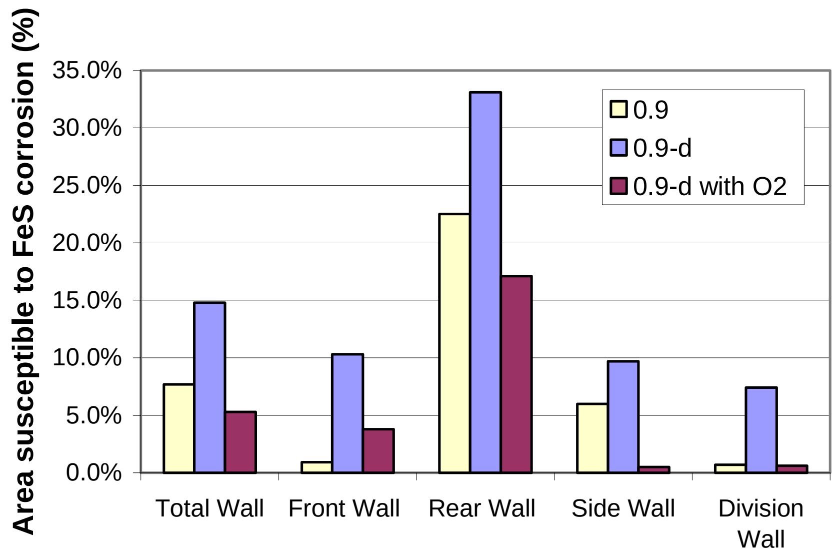

Figure 6: Total waterwall surface area below the OFA ports predicted to be susceptible to FeS based corrosion for cases 1 (0.9,air), 2 (0.9-d, air), and 4 (0.9-d, O2). Overall, oxygen reduces the area susceptible to corrosion.

In further work, REI conducted additional modeling to compare the corrosion rates of the unstaged boiler with the staged boiler with and without oxygen. A summary of the results is as follows:

- Tube wall temperatures under staged conditions with oxygen showed a nominal 18F increase compared to the unstaged conditions.
- In the area above the hopper to the OFA, the predicted corrosion rate due to H2S was below 5 mils/yr (mpy) for all cases. The increase between the unstaged case and the deeply staged oxygen enhanced case was ~ 1.5 mils/yr (mpy).
- Going from unstaged to staged conditions **without oxygen**, the area on the rear wall between the hopper and OFA subject to FeS corrosion increases from less than 1% to as high as 33%. Even mildly staged, the area subject to FeS corrosion increases to 22% on the rear wall. Under deeply staged conditions simulations predict that with oxygen the area subject to corrosion is 17%. In all cases the rear wall represented the area subject to the greatest corrosion rate.

- Even under unstaged conditions, the maximum corrosion rate for this unit is predicted to be ~ 30 mpy; this rate is comparable to the maximum rate with oxygen deeply staged.

Figure 7 shows the maximum corrosion rate on the right wall under different conditions.

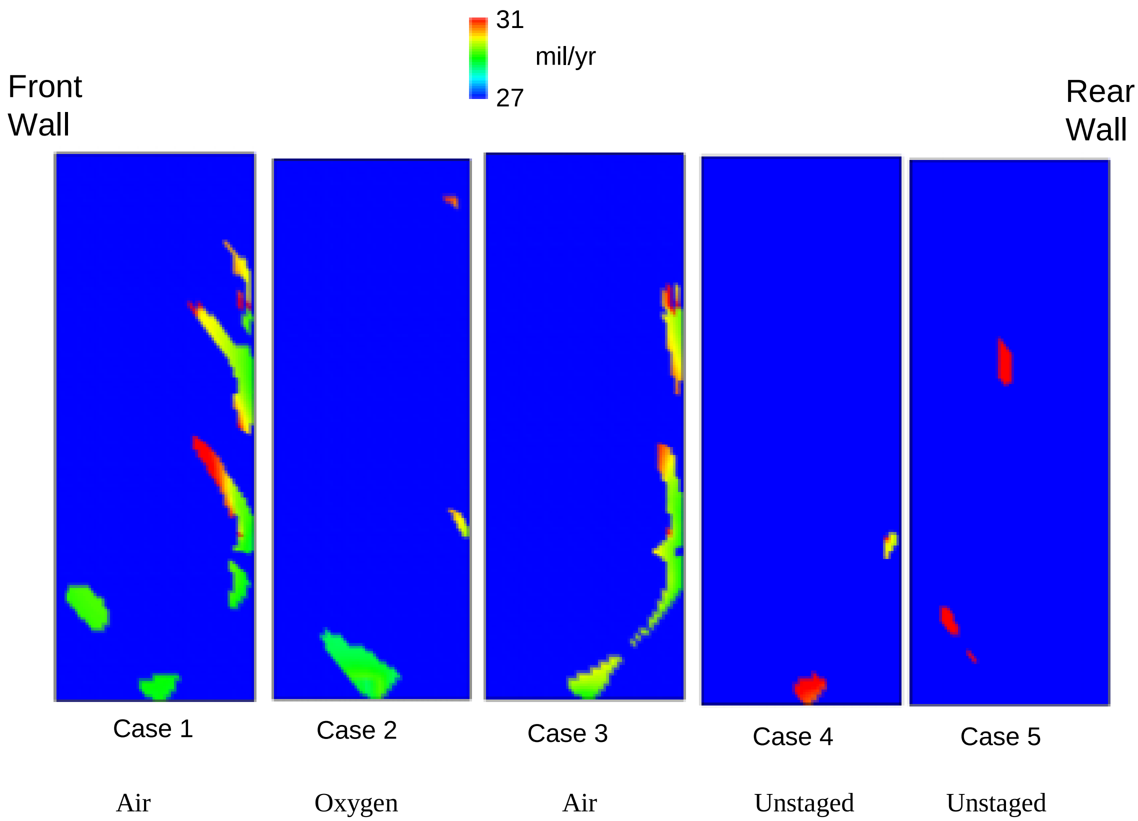

Figure 7: Predicted rate of corrosion due to FeS on the right side wall for cases 1(Burner SR=0.9-d, air), 2(Burner SR=0.9-d, oxygen), 3(Burner SR=0.9, air), 4(Burner SR=1.18, air, boundary air), Case 5(Burner SR=1.18, air)

Conclusions

- The NOx reduction benefits of Oxygen Enhanced Combustion can be achieved with minimal impact on waterwall wastage. The area of the boiler subject to FeS based corrosion under air staged conditions can be reduced by using oxygen.
- In the case of a boiler going from a mildly staged to a deeply staged condition, the area subject to corrosion can increase. However, oxygen significantly reduces the area subject to corrosion.
- Simulation results and experience have shown that it is possible to go from unstaged to staged operation in a coal fired boiler without increasing waterwall wastage. In cases where there is a predicted increase in corrosion, oxygen has been shown to reduce the area subject to corrosion.

- In tests, oxygen has been shown to improve boiler combustion performance, and by reducing LOI, and shortening the flames to reduce rear wall particulate impingement and the potential for FeS deposition[8]. Boilers with less deposition potential also have less corrosion potential, and thus can be staged with minimal corrosion impact. Coals with low pyrite content are also unlikely to produce FeS.
- Modeling is probably warranted in most cases to identify any areas that might be subject to flame impingement and corrosion.
- During the start-up and tuning of the Oxygen Enhanced Combustion system, the system needs to be checked and tuned to insure that there is minimal rear wall flame impingement to minimize the potential for any FeS based corrosion.

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