The Reducing Ambience Analysis under the Low Nitrogen Mode Operation of a Boiler

Baixiang Xiang, Jun Huang, Yan Li and Binqiao Han
Shenhua Guohua (Beijing) Electric Power Research Institute Co., Ltd., Beijing, China
Email: 20035058@chnenergy.com.cn

Abstract. In 2014, the electricity industry boilers are required to meet the ultra-low emissions standard. Specifically, the dust, SO$_2$, NOx are required to reach 5, 35, 50 mg/m$^3$, respectively. Hence, the boiler operated under lean oxygen will be widely and long-term existed. In this paper, the distributions of velocity, temperature and flue gas composition were simulated under different air distribution modes. The numerical simulations demonstrated that both the CO and H$_2$S contents in the major burner zone increased with the SOFA rate increasing. However, there is almost no CO and H$_2$S in the burnout zone due to the increase of SOFA. Besides, as the SOFA rate increasing, NO in the burnout zone slightly increased, but the NO in the main combustion zone significantly reduced.

Keywords. Lean oxygen operation; reducing ambience; air stage; NOx.

1. Introduction
As the environmental policy being stricter, the NOx emission is forced to meet the ultra-low emission standard. The newest policy required the enterprise to control the NOx emission below 50 mg/m$^3$ (referred to 6% O$_2$ content, same below) [1]. Hence, various methods are adopted to reduce the NOx emission. Li, et al. adopted the deep air-staged combustion in a 20 kW down flame furnace to control the NOx emission [2]. Kang et al. tested the effect of staged combustion on an oil boiler [3]. Frassoldati et al. developed a nitrogen mechanism to predict the NOx formation [4]. To further investigate the atmosphere distribution near the main combustion area, a 300 MW boiler was selected as the simulation object. The H$_2$S and CO et al. atmosphere and the temperature distribution were calculated at different excess air ratios, different location of the SOFA air etc. conditions.

2. Boiler introduction and simulation method
The boiler is 300 MW of capacity, π shape furnace structure, tangential burners, as shown in figure 1a. The specified burner details can be seen in figure 1b. The primary air burner nozzle is arranged with staged layers. A, B, C, D, E, F a total of six layer. The secondary air burner nozzle is AA, AB, BC, CC, CD, DE, EE, EF, FF nine auxiliary air layers. The others are AB, CD, EF three oil guns and I, J, K, L four air SOFAs.

The tangential combustion boiler has wide fuel adaptation [5-7]. The most commonly used fuel is bituminous coal. Very fewer tangential boiler burns anthracite. To meet the ultra low emission standards, the air staged technology is used. The SOFA layout is to assure the carbon burnout. Generally, the carbon in the fly ash can be controlled under 5%. For the anthracite fuel, the carbon in the fly ash is a little higher, above 10%. The distance between the SOFA and the main burner area is the reduction area.
2.1. Simulation Method

2.1.1. Mesh Strategy. The total grid number is one million. In the main combustion area, the mesh was refined to 500 thousand. The detailed grid information can be seen in figure 2. Meanwhile, the area of burner exit was also refined and the center area was sparse. After a careful grid independence check, the current grid set can satisfy the calculation requirement.

2.1.2. Simulation Condition. The calculation conditions include the excess air rate, the SOFA rate, the locations of SOFA nozzle, the coal types of different sulfur and nitrogen content. The specified conditions can be seen in table 1. There are 10 calculation conditions. The first three only changes the excess air rate. The next three conditions change the SOFA air rate. The case 7 and case 8 changes the location of the SOFA nozzles. The case 9 and case 10 represent two different coal types. The coal particle size ranges from 10 to 200 μm. The coal proximate analysis and ultimate analysis can be seen in table 2. The burner is designed with rich-lean separation device. The interior pulverized coal concentration is higher than that of outside. The volatile is 29.18% (dry ash free). It is a typical bituminous coal. The sulfur content is 1.51%. It is a medium content coal. The nitrogen is 0.71%.
Table 1. Ten groups of calculation conditions.

| NO. | Excess air ratio | Coal feeder | Primary air rate | secondary air rate | OFA air rate | SOFA air rate |
|-----|------------------|-------------|------------------|-------------------|--------------|--------------|
| 1   | 1.273            | 40          | 22               | 50                | 8            | 20           |
| 2   | 1.2              | 40          | 22               | 50                | 8            | 20           |
| 3   | 1.355            | 40          | 22               | 50                | 8            | 20           |
| 4   | 1.273            | 40          | 22               | 70                | 8            | 0            |
| 5   | 1.273            | 40          | 22               | 60                | 8            | 10           |
| 6   | 1.273            | 40          | 22               | 40                | 8            | 30           |
| 7   | 1.273            | 40          | 22               | 50                | 8            | 20 (up)      |
| 8   | 1.273            | 40          | 22               | 50                | 8            | 20 (down)    |
| 9   | 1.273            | 40          | 22               | 50                | 8            | 20           |
| 10  | 1.273            | 40          | 22               | 50                | 8            | 20           |

Note: The case 9 is a high sulfur and low nitrogen condition. The case 10 is a low sulfur and high nitrogen condition.

Table 2. The proximate and ultimate analysis of coal.

| Proximate Analysis of Coal (wt.%) | Ultimate Analysis (wt.%) |
|-----------------------------------|--------------------------|
| $V_{daf}$                        | $V_{ar}$                 | $A_{ar}$ | $M_{ar}$ | $FC_{ar}$ | $C_{ar}$ | $H_{ar}$ | $O_{ar}$ | $N_{ar}$ | $S_{ar}$ |
| 29.18                            | 17.90                    | 26.66    | 12.00    | 43.44     | 50.99    | 3.36     | 4.77     | 0.71     | 1.51     |

2.1.3. The Simulation Mode Chose. The real boiler combustion process is really complicated. Some useful methods and modes are adopted. For example, the finite volume method (FVM) [8, 9], the standard $k$-$\varepsilon$ model were used in this paper [10-13].

2.2. Results

2.2.1 Velocity Field. Figure 3 gave out the velocity distribution of the longitudinal furnace cross section along with furnace height direction. The SOFA nozzle was not operated. The excess air ratio was 1.273. The largest velocity is 26 m/s, mainly focused on the main burner area. The nozzle velocity from layer A to F was relatively larger than that of other areas. In the symmetrical axis area, the wind velocity is little. Below the burner area is the ash hopper. In this area, there is no wind injected in, hence, the wind velocity is also little. Above the burner area, is the reduction area. The wind velocity is 10-20 m/s, furtherly, in the flame horn area, the wind velocity is 8 m/s. Figure 4 supplies the velocity distributions of furnace cross section of layer A and layer F. The combustion tangential circle is formed by the pulverized coal flow flame from the four corners. The layer A circle is not an ideal circle. Two corners primary wind velocity is too large, the flame direction is oblique. On the contrary, the layer F is a perfect circle. The primary wind velocity is 26 m/s.
Figure 3. The longitudinally symmetrical cross-section velocity (m·s\(^{-1}\)).

Figure 4. The A-layer and F-layer burner sections velocity (m·s\(^{-1}\)).

2.2.2 Temperature Field. Figure 5 gave out the cross section temperature distributions of layer A and layer F. As mentioned above, the two corners coal flow are oblique. The largest temperature is 1900 K. Three isolated high temperature area is formed. It is noticed that the there are four cold temperature (blue area). This is the cold pulverized flow. Generally, the ignition distance is 0.5-1.0 meter. The cold pulverized coal heated rapidly by the convection and radiant heat. Thus, it released a large amount of volatiles. These volatiles are easier to ignite. In the center area of the furnace, the temperature is relatively lower, 1200-1400 K. Conversely, the F-layer burner section temperature is more uniform than that of the layer A section. Likewise, the largest temperature is also 1900 K while the lowest the temperature is only 900 K. In the center area, the temperature is more uniform, with a value of 1600 K. The high temperature is located in the coal flow area. When the coal encountered the oxygen, the ignition is started and the combustion is rather fierce. the temperature increased with the height increasing; however, a decreasing trend was observed at higher height.
2.2.3 Concentration Field. Figure 6 showed the distributions of O\textsubscript{2} and CO content on A-layer and F-layer burner sections. As shown in figure 6, the concentration of O\textsubscript{2} reached the highest on F-layer burner section, whereas CO content was rare. Due to the release and the combustion of volatile matter, the concentration of O\textsubscript{2} decreased significantly with the height increasing. Different to the distribution of O\textsubscript{2} concentration, CO content increased significantly with the height increasing, however, a decreasing trend was showed at higher height.

Figure 7 demonstrated the distributions of O\textsubscript{2}, CO and H\textsubscript{2}S content on A-layer burner section, and the region ranging from the front wall to left wall. As shown in figure 7, the O\textsubscript{2} concentration was relatively low. The CO concentration showed an increasing trend with the height increasing in the height direction, however, a decreasing trend was observed at higher height. In particular, the concentration of CO decreased significantly after OFA, and it almost disappeared after SOFA. Similar to the CO content distribution, the concentration of H\textsubscript{2}S was relatively high at the main burner area; however, it was obviously reduced due to the introduce of oxygen after OFA. In particular, it almost disappeared after SOFA, which was good agreement with the field measurement results. The aforementioned distributions in the height direction mainly depends on the excess air coefficient. That is mainly because that the oxygen is insufficient. However, the reducing atmosphere was badly affected due to the supply of enough oxygen. In addition, the distributions in the circumferential direction mainly depended on the tangential combustion, which can result in the whole flow field rotating.

**Figure 5.** The temperature distributions (K).
Figure 6. The distributions of O$_2$ and CO content.

According to the concentration distributions of CO and H$_2$S, the high temperature corrosion in the main burner area was the most serious in the height direction. However, due to the introduce of sufficient oxygen, the corrosion was significantly reduced after SOFA as the reducing atmosphere was badly affected. H$_2$S is a strong corrosive gas and its concentration is in direct proportion to the CO concentration. The higher the CO concentration, the higher the H$_2$S. The H$_2$S can react with the iron...
oxide to shape FeS. The iron oxide covered outer the tube is a protective film, which can prevent the oxygen oxidation. But this film layer can not stop the corrosion by H$_2$S. Some plants with severe high temperature corrosion, the tube thickness can be thinned by 0.8-1 mm per year.

3. Conclusion
(1) With the excess air rate increasing, both the flame center and outlet temperature of boiler decreased. The overall temperature, CO and H$_2$S concentrations showed a decreasing trend at higher excess air ratio, however, O$_2$ and NO content increased.

(2) The CO and H$_2$S content in the main burner zone increased obviously with the SOFA rate increasing. However, there was almost no CO and H$_2$S in the burnout zone due to the supplement of SOFA. In addition, though NO in the burnout zone slightly increased that in the main combustion zone significantly reduced with the SOFA rate increasing.

(3) H$_2$S is a strong corrosive gas and its concentration is in direct proportion to the CO concentration.

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