Numerical Simulation of the Effect of Combustion Process on Flue Gas Thermal Deviation in 660MW Boiler

Xianbiao Yang1, Yuan Gao1, Shutao Wang1, Renqiang Shi1, Shaohua Liang2 and Rongyue Sun2,*

1 Jiangsu Frontier Electric Power Technology Co., Ltd., Nanjing, China
2 School of Energy and Power Engineering, Nanjing Institute of Technology, Nanjing, China

*Corresponding author email: sunrongyue@njit.edu.cn

Abstract. In order to analyze the effect of the air volume on the combustion side and the non-uniformity of pulverized coal on the temperature distribution of the boiler outlet flue gas, and then analyze the thermal deviation characteristics of the steam heating surface, the following five different working conditions are calculated and analyzed in a 660MW boiler. Results show that the deviation of pulverized coal content of each burner and the deviation of primary air volume are the important factors that cause the temperature deviation of flue gas outlet in the furnace. Therefore, it is an important way to improve the temperature distribution and reduce the thermal deviation of flue gas outlet by improving the uniform combustion and air distribution of the burner in the furnace.

1. Introduction

Four-corner tangential burner is a combustion method commonly used in large-scale electric shovel boilers. Combustion air and coal powder are injected into the furnace from the four corners of the furnace according to a certain ratio and angle. The four-corner airflow is injected in a center tangential circle to form in the furnace [1]. The flow field that rotates and moves upwards makes the furnace flame full and adaptable to coal types [2]. However, due to the effect of the one-way cyclone in the furnace, large flue gas is often generated at the exit of the furnace to participate in the rotation, resulting in the upper panel superheater of the furnace and the convective heating surface of the horizontal flue forming the steam side in the tube due to the deviation of flue gas flow. The heating deviation seriously affects the trouble-free operation of the power station boiler [3]. Relatively speaking, swirling pulverized coal burners generally adopt the front and rear wall opposing arrangement, and the pulverized coal flame is more evenly distributed in the furnace, and there is no overall large-scale cyclone [4]. Therefore, theoretically speaking, for the boiler furnace with swirling pulverized coal burners, the thermal deviation of the outlet flue gas is much smaller than that of the once-through pulverized coal burner boiler. However, in the actual operation process, because the operating conditions of each pulverized coal burner cannot be completely consistent, the pulverized coal volume, air volume and design value of each burner will have different degrees of deviation, which will affect the flow and combustion process and then a certain thermal deviation is generated at the furnace outlet [5].

In order to analyze the influence of the nonuniform distribution of pulverized coal and air volume in the swirling pulverized coal burner on the thermal deviation of the boiler outlet flue gas, this paper uses numerical simulation software Fluent to calculate and analyze the combustion process in a
660MW boiler. Swirl pulverized coal burners affect the combustion in the furnace and the smoke temperature distribution at the furnace outlet under different operating conditions, thereby improving the thermal deviation of the boiler outlet and improving the safety of the boiler.

2. Physical Model
A 660MW coal-fired unit in a power plant was chosen as the research object in this paper. The boiler is designed and manufactured by Dongfang Boiler Factory with ultra-supercritical parameters, variable pressure operation once-through furnace, primary intermediate reheating, single furnace, front and rear wall opposed combustion, tail flue gas baffle adjustment Temperature, balanced ventilation, solid slag discharge Π-type boiler, using three-division warehouse rotary air preheater. The main powerhouse adopts the side coal bunker layout, as shown in Figure 1. The main structural design parameters of the boiler furnace were shown in Table 1.

![Figure 1. Layout and furnace structure drawing of a 660MW ultra-supercritical boiler.](image)

Table 1. Design parameters of 660MW boiler furnace structure

| Items                              | Unit  | Value  |
|-----------------------------------|-------|--------|
| Width of the furnace chamber      | m     | 22162.4|
| Depth of the furnace chamber      | m     | 15.4568|
| Height of the furnace chamber     | m     | 63     |
| Thermal load of furnace section   | MW/m² | 4.48   |
| Volumetric thermal load of furnace| KW/m³ | 80.64  |
| Burner area wall heat load        | MW/m² | 1.68   |
| Flue gas temperature at furnace outlet | °C  | 1007   |
| Distance from upper row burner to bottom of screen | m | 24.3535 |
| Distance from lower exhaust burner to inflection point of cold ash bucket | m | 3.2598 |

3. Numerical Computation Method
Since the research object is the furnace with swirl burners arranged opposite the front and rear walls, the flow in the furnace involves rotating jets. Therefore the model is selected as the Realizable model in the k-e model to correct the influence of rotating airflow on the flow field during the simulation. The combustion procedure of the pulverized coal in the furnace includes various forms of energy transfer such as heat conduction, convection, and radiation. Among them, radiation heat exchange is
the main form. At the same time, part of the energy can also be transferred by convection. Therefore, choosing a suitable radiation heat transfer model is effective for simulating the furnace. The internal heat transfer process is of great significance. This paper chooses the P-1 radiation model, which has a small amount of calculation and can consider the mutual influence of the heat transfer between the gas phase and the solid particles in the furnace [6]. It is suitable for simulating the complex radiation heat transfer process in the coal-fired boiler furnace.

The PDF model is used to simulate the component transport in the furnace combustion process. The PDF method is called the probability density function method (Probability Density Function) [7]. It uses probability and statistics to randomly combine the flow field velocity, temperature, and temperature according to the molecular dynamics theory and the law of two-phase turbulence. The concentration of material components can be calculated to simulate the process of mixing and chemical reaction at the same time. DPM model (Discrete Phase Model) is used to simulate the movement characteristics of pulverized coal particles in the burner and the furnace [8].

The boundary conditions of the model that need to be set up for this subject include primary air nozzles, secondary air nozzles, over-fired air nozzles, furnace outlet, water wall, furnace roof and cold ash hopper boundaries. The boundary conditions used are velocity inlet, pressure outlet and Wall boundary conditions. The horizontal flue exit of the furnace adopts the pressure-outlet boundary condition, and the pressure is set to -50 Pa (gauge pressure).

For the coupling calculation of the swirl burner and the boiler, this paper uses the profile tool in the Fluent software to calculate the flow characteristics of the pulverized coal and combustion air in the swirl pulverized coal burner separately, and use the velocity field at the outlet of the burner as the inlet of the boiler furnace. Use profile to introduce the boundary conditions into the furnace calculation model to complete the coupling calculation of the burner and the furnace.

The calculated fuel adopts the boiler design coal type. The main components of coal and combustion process parameters are shown in Table 2.

| Table 2. The characteristics and main conditions of coal were calculated |
|---------------------------------------------------------------|
| **Elemental analysis /wt %**                                   | **rated power** | **660 MW** |
| Car               | 54.2            | Rated coal consumption | 250 t/h |
| Har               | 3.47            | lower calorific value  | 21040 kJ/kg |
| Oar               | 3.41            | rated power            | 660 MW |
| Nar               | 0.96            | excess air coefficient | 1.18   |
| Sar               | 8.1             | theoretical air requirement | 606.5 kg/s |
| A                 | 28.86           | amount of actual air for combustion | 715.7 kg/s |

4. Results and Discussion

In order to analyze the effect of the air volume on the combustion side and the non-uniformity of pulverized coal on the temperature distribution of the boiler outlet flue gas, and then analyze the thermal deviation characteristics of the steam heating surface, the following 5 different working conditions are calculated and analyzed. Case 1 refers to normal working conditions, in which the design value is adopted, and the air volume and pulverized coal volume of the burner are uniformly distributed. Case 2 refers to the pulverized coal content of front and rear wall burners deviates from the design value +10% and -10% respectively; Case 3 refers to conditions in which the pulverized coal content of front and rear wall burners deviates from the design value -10% and +10% respectively; case 4 refers to the condition that the pulverized coal content of front and rear wall burners deviates from the design value -10% and +10% respectively; case 4 refers to the combustion condition that the pulverized coal content of the left and right burners deviates from the design value -10% and +10% respectively; case 5 refers to the condition that the primary air volume of front and rear wall burners deviates from the design value -10% and +10% respectively. All the other boundary conditions and
initial conditions of the five cases are the same. The calculation of the five cases were further conducted on the Fluent software. The temperature distribution and the flow field at the furnace cross section are shown in Figure 2 and Figure 3 as below.

![Figure 2. Cloud diagram of furnace temperature distribution under various operation conditions.](image1)

![Figure 3. Cloud diagram of furnace flow field distribution under various operation conditions.](image2)

As shown in Figure 2, under the condition of uniform combustion with coal and air distribution, the temperature field inside the furnace is uniformly distributed as to case 1. In this condition, the flame has the highest filling degree and the temperature distribution is more uniform, which will reduce the thermal deviation in the furnace outlet. With the deviation of pulverized coal of each burner, the temperature field inside the furnace also changes obviously. Increasing the coal load in the burner, the temperature increased near the burner, as shown in case 2 and case 3. Changing the primary air volume also affects the temperature distribution in the furnace. It can be indicated that increasing the primary air, the temperature will be improved at the outlet of the burner, as shown in case 5. Therefore, the non uniform feeding and primary air are one of the important factors that cause combustion heat deviation in furnace, which will further increasing the NOx yield as well as increase the risk of overheating of the heating surface.

The flow field distribution in the furnace can directly reflect the combustion characteristics in the furnace under different working, as shown in Figure 3. The difference of the flow field between different cases is not so distinct compared with the temperature distribution. On the whole, the velocity field inside the furnace presents the form of center symmetry. In order to reveal the influence of burner deviation on furnace thermal deviation, it is necessary to study and analyze the flue gas temperature distribution at the outlet section of furnace. The cloud map of outlet temperature distribution is shown in Figure 4 as below.
In Figure 4, the furnace outlets were divided into two sections (left and right section) for each case. The average temperature of the left and right sections is calculated by the average flue gas flow, as shown in Figure 4. The temperature distribution in case 1 is the most uniform among five cases. With introducing coal and air deviation in the burners, the temperature distribution changes significantly. The detailed temperature deviations for these cases were calculated and the results are shown in Table 3 as below.

Table 3. The summarized calculation results of outlet temperature deviation values

| Cases | Temperature Deviation |
|-------|-----------------------|
| Case 1 | 1°C                   |
| Case 2 | 31°C                  |
| Case 3 | 34°C                  |
| Case 4 | 5°C                   |
| Case 5 | 42°C                  |

It can be indicated that the thermal deviation of flue gas temperature at the furnace outlet is the smallest under the design condition, which is about 1°C. When changing the coal load for burners, the temperature deviation increased to 5 - 34°C. Changing the primary air ratio will introduce the largest temperature deviation in the furnace outlet, which reaches 42°C, as shown in case 5.

Through the above calculation and analysis, it can be seen that the deviation of pulverized coal content of each burner and the deviation of primary air volume are the important factors that cause the temperature deviation of flue gas outlet in the furnace. Therefore, it is an important way to improve the temperature distribution and reduce the thermal deviation of flue gas outlet by improving the uniform combustion and air distribution of the burner in the furnace.

5. Conclusions

The thermal deviation of boiler heating surface is an important index affecting the safety of boiler operation. In order to analyze the effect of the air volume on the combustion side and the non-uniformity of pulverized coal on the temperature distribution of the boiler outlet flue gas, and then analyze the thermal deviation characteristics of the steam heating surface, the following five different working conditions are calculated and analyzed in a 660MW boiler. Results show that the thermal deviation of flue gas temperature at the furnace outlet is the smallest under the design condition, which is about 1°C. When changing the coal load for burners, the temperature deviation increased to 5 - 34°C. Changing the primary air ratio will introduce the largest temperature deviation in the furnace outlet, which reaches 42°C. The deviation of pulverized coal content of each burner and the deviation of primary air volume are the important factors that cause the temperature deviation of flue gas outlet in the furnace. Therefore, it is an important way to improve the temperature distribution and reduce the thermal deviation of flue gas outlet by improving the uniform combustion and air distribution of the burner in the furnace.
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