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Numerical simulation of the influence of different oxygen concentration on the combustion characteristics of double tangential boiler at low load

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Abstract—In order to cope with the demand for deep peak regulation of high-parameter coal-fired units, this paper uses numerical simulation methods to systematically explore the influence of different secondary wind oxygen enrichment concentrations on the combustion performance and characteristics of single-furnace double-cut round boilers during low-load operation, so as to provide theoretical support for the actual operation of power plants. The results are as follows: (1) The use of oxygen enriched secondary air combustion during low-load operation of the boiler can improve the overall temperature of the main combustion zone of the furnace and the local temperature of the burner nozzle section, and enhance the combustion stability of pulverized coal in the furnace. (2) When the secondary air oxygen concentration is 35% and 40%, the overall temperature of the main combustion area of the boiler increases the most obviously, and the combustion is the most stable. (3) Oxygen-enriched combustion effectively reduced the NO_x emission concentration in the furnace, and the overall trend of NO_x emission decreases first and then increases with the increasing trend of secondary air oxygen concentration.

1. Introduction

The last five years, the installed size of new energy sources such as hydropower, wind power and photovoltaic power generation has gradually increased, but its random, intermittent, fluctuating, seasonal and other power generation characteristics have brought great pressure to the stable and safe operation of China's power grid, which also puts forward more stringent requirements for the flexible peak shaving capacity of China's thermal power generating units [1,2]. This also means that power plants in some parts of China need low-load operation or long-term medium and low-load operation to adapt to local peak shaving needs. As the load of coal-fired boilers decreases, the combustion stability decreases, the coal consumption rate increases significantly, and the emission of pollutants such as NO_x will also increase greatly. Oxy-fuel combustion has the advantage of significantly improving combustion efficiency during the experiment[3-5], but the current research on the application of oxy-fuel combustion to the low load of ultra-supercritical coal-fired boilers is not perfect.

Therefore, this paper uses numerical simulation method to carry out a numerical simulation test of secondary wind oxygen-enriched combustion of 1000MW double tangential boiler, and the influence of changing the secondary air oxygen concentration of oxygen-enriched combustion on the combustion characteristics of 1000MW double tangential boiler under low load is studied.

2. Model establishment

2.1 Three-dimensional mathematical modeling

The research object of this paper is a single furnace double tangential coal-fired boiler with ultra-supercritical variable pressure operation and secondary intermediate reheat developed by Harbin Boiler Co., Ltd. The full-scale furnace model is established and meshed by ICEM software. The area between the end of the horizontal flue and the cold ash hopper is selected as the calculation domain. From top to bottom, it is divided into five parts : horizontal flue, upper furnace area, SOFA air area, main burner area and cold ash hopper area. The furnace structure and grid division are shown in Figures 1 and 2

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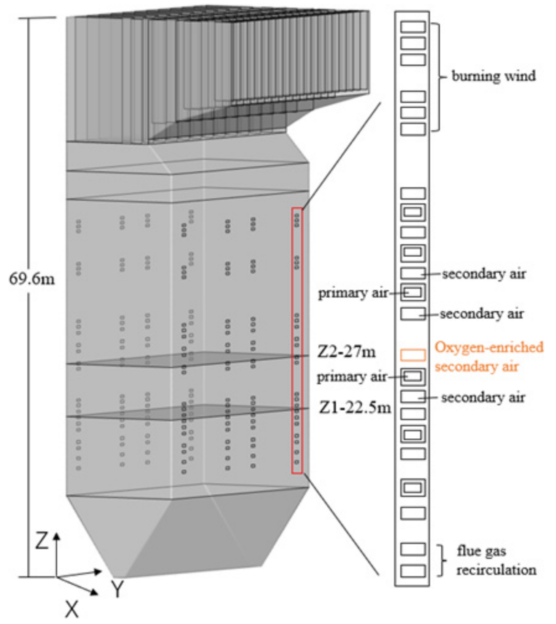

Fig.1 Boiler structure

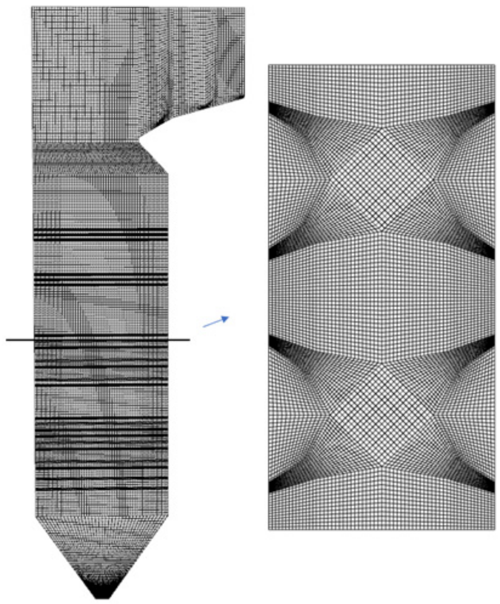

Fig.2 Mesh subdivision

2.2 Mathematical model

In this paper, the Realizable k-ε model is used to describe the turbulent flow of the furnace, and the discrete phase model is used to simulate the movement of pulverized coal particles in the boiler. In order to simulate the combustion process of pulverized coal more accurately, the two-step competitive reaction rate model is applied to simulate the reaction of volatile precipitation in pulverized coal, and the finite-rate /eddy dissipation model in the component transport model is accurately applied to simulate the combustion exothermic process of pulverized coal volatiles. Finally, the P-1 radiation model suitable for pulverized coal combustion is applied to simulate the radiation of heat transfer process in the furnace.

2.3 Boundary conditions and calculation conditions

Each tuyere adopts the velocity inlet boundary condition, the furnace outlet adopts the pressure outlet boundary condition, the pressure is set to -100pa, the temperature of the bottom of the hearth area on the furnace wall is set to 640K, and the temperature of the furnace main combustion area and the burnout area is set to 680K. The SIMPLE algorithm is applied to solve the discrete equations, and the second-order upwind scheme is used. Since the secondary air in this paper uses a mixed gas of O_2/N_2 with different oxygen concentrations, the secondary air oxygen ratio (the ratio of the actual secondary air oxygen flow rate to the oxygen flow rate required for complete combustion of the main combustion zone fuel theory) is used instead of the secondary air ratio to participate in the research. Table 1 describes the detailed operating conditions:

Table 1 Design condition

Condition	Load	Excess air coefficient	Secondary air oxygen concentration	Secondary air oxygen ratio
1	30%	1.25	21%	0.53
2	40%	1.25	21%	0.53
3	60%	1.20	21%	0.53
4	80%	1.15	21%	0.53
5	30%	1.25	27%	0.53
6	30%	1.25	35%	0.53
7	30%	1.25	40%	0.53
8	30%	1.25	46%	0.53

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3. Simulation results and analysis

3.1 Effect of secondary air oxygen concentration on combustion in low load furnace

According to the simulation analysis along the furnace height center section temperature Fig.3, it can be seen that the overall temperature in the furnace of 30% load without oxygen-enriched secondary air transformation is lower and unevenly distributed than other loads. At the same time, the temperature of the central section along the height direction of the main combustion zone in the No.1 working condition without oxygen-enriched transformation fluctuates along the height direction of the main combustion zone, and the overall distribution is about 1400K, and the temperature of the burnout zone decreases faster than other loads, which is prone to combustion instability.

After the secondary air oxygen-enriched transformation of the boiler, the overall temperature inside the furnace has been remarkably improved compared with that before the transformation. It can be seen from the line chart of the temperature distribution of the central section along the height of the furnace that the average temperature of the main combustion zone is basically above 1400K, and the highest temperature can reach 1480K, which can achieve long-term stable combustion. And the center section temperature of the main combustion zone increases first and then decreases with the increase of the secondary air oxygen concentration, and reaches the highest temperature at 40% oxygen concentration. Then when the secondary air oxygen concentration reaches 46%, the overall temperature decreases again, which is basically consistent with the secondary air oxygen concentration of 35%.

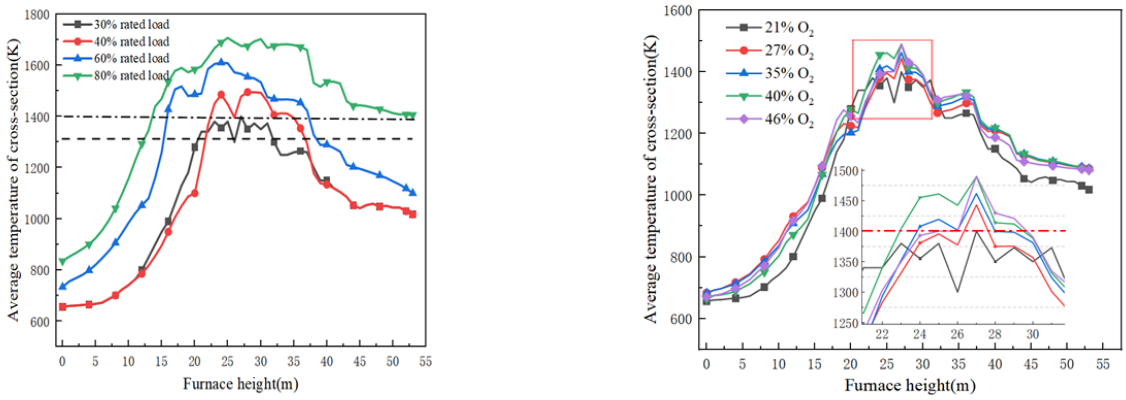

Fig.3 The temperature changes along the height.

It can be seen from Fig.3 that the flame double tangent circle trend in the furnace after the secondary air oxygen enrichment transformation is obvious, the flame distribution on both sides is symmetrical, and the combustion is stable. The flame temperature along the direction of the primary air jet reaches more than 1500K, which can better ignite the pulverized coal airflow, so that the pulverized coal can be continuously and stably burned [6]. With the increase of secondary air oxygen concentration, the flame high temperature zone in the primary air jet direction of the main burner nozzle section also gradually expands, and the region tends to be saturated at 35% and 40% secondary air oxygen concentration.

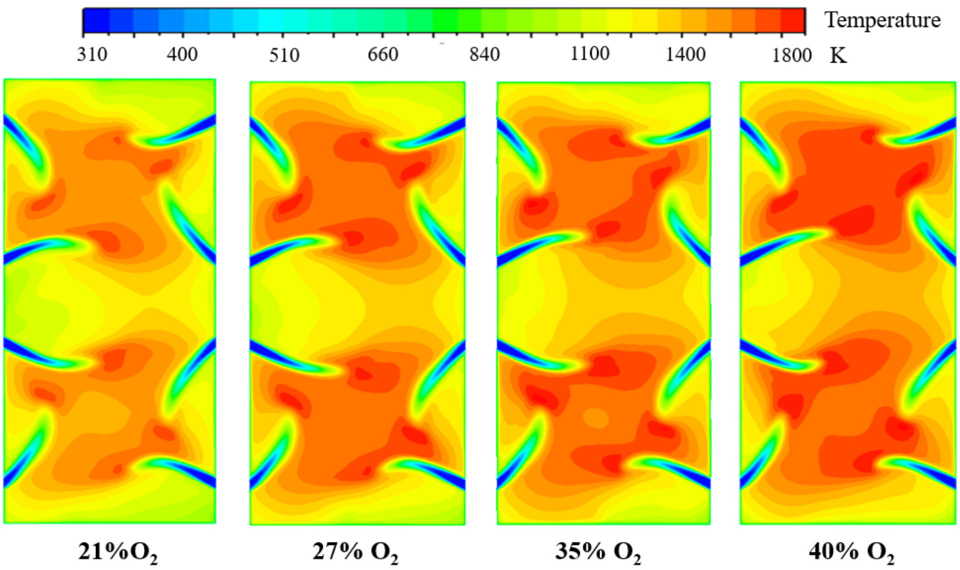

Fig.4 Temperature distribution of main burner nozzle Z2 cross section

3.2 Effect of secondary air oxygen concentration on NO_x emission

From Figure 5, it can be seen that when the secondary air oxygen concentration is in a reasonable range, the NO_x emission concentration in the main combustion area can be reduced. Because the overall combustion state of the secondary air oxygen-enriched condition has been greatly improved compared with that before the transformation, the pulverized coal combustion is more sufficient and stable. Under the condition of high temperature reduction, it is beneficial to promote the formation of CO gas on the surface of coke, inhibit the heterogeneous oxidation reaction of NO_x, and reduce the formation of NO_x [7,8].

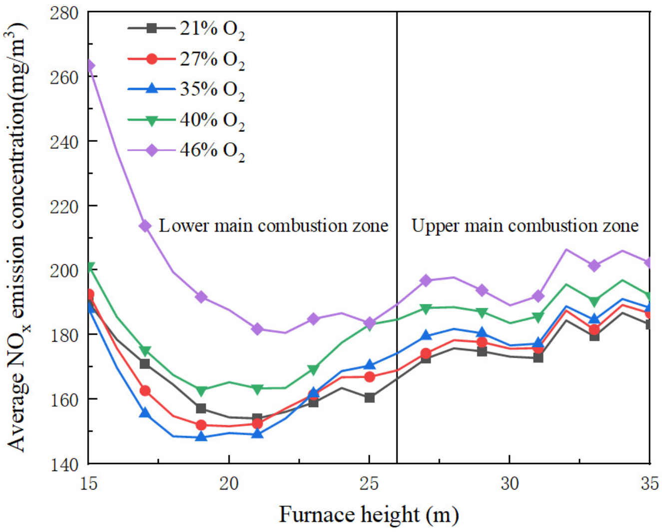

Fig.5 The variation trend of NO_x emission concentration with height

And as the oxygen concentration in the secondary air increase, the NO_x emission concentration of the main burner nozzle section shows a trend of decreasing first and then increasing, which is also consistent with the conclusions drawn by the current researchers through multiple pulverized coal oxy-fuel combustion experiments[9]. The simulation results show that there is a minimum NO_x emission concentration when the secondary air oxygen concentration is 35%, and the minimum NO_x emission concentration is 148mg/m3.

However, when the secondary air oxygen concentration reaches 46%, the NOx emission concentration of the main burner nozzle section increases greatly. This is mainly due to the fact that when the oxygen concentration in the furnace is too high, it will destroy the stability of local pulverized coal combustion to a certain extent. As a result, there is a lack of reducing atmosphere in the main combustion area, which is not conducive to the NO reduction reaction on the surface of pulverized coal particles, which increases pollutant emissions. At the same time, the local high temperature promotes the formation of thermal NO_x, resulting in a significant increase in NO_x pollutant emission concentration. Mainly under the combined influence of the above two reasons, too high secondary air oxygen concentration will greatly increase the emission concentration of pollutants.

4. Conclusion

Based on the above numerical simulation results, the conclusions reached are mainly as follows:

(1) After the transformation of oxygen-enriched secondary air, the overall temperature of the main combustion zone of the furnace and the local temperature of the nozzle section of the burner are improved, which enhances the combustion stability of pulverized coal in the furnace.

(2) When the oxygen concentration of secondary air is 35% and 40%, the overall temperature of the main combustion area of the furnace is the most obvious, and the combustion is the most stable.

(3) When it is located in a reasonable range of secondary air excess oxygen coefficient, the main combustion zone is in a strong reducing atmosphere, and the NOx emission concentration decreases first and then increases rapidly with the increase of secondary air oxygen concentration.

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