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Numerical Study on Heat Transfer and Combustion Characteristics of Gas-fired Boiler under Different Loads

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ABSTRACT

Gas-fired boiler has received wide attention with the advantages of simple structure and low pollutant emission. In this study, the combustion characteristics and heat flux distribution of gas-fired boiler were investigated numerically under four different loads (30%, 50%, 75%, 100% load). The heat flux distributions of thermal calculation and numerical simulation results have significant difference due to different calculating method. Results show that the temperature in the furnace increases as the increment of boiler loads. The temperature of furnace outlet can reach 1573 K at 100% load. With the increasing of boiler load, the heat flux on each wall increases. The heat flux on rear wall is the highest, whereas the heat flux on front wall is the lowest. The numerical results in this study could provide a reference for optimization of combustion characteristics and design of gas-fired boiler.

Keywords: combustion characteristics, heat flux distribution, gas-fired boiler, different loads

1. INTRODUCTION

In the 21st century, high efficient and clean utilization of energy has become the focus in the world. Compared with coal-fired boiler, gas-fired boiler has received wide attention with the advantages of simple structure and low pollutant emission [1]. Therefore, the demand of gas-fired boiler in China has been increasing year by year.

Among the various research methods, the numerical simulation has unique advantages with economy and convenience [2]. In the past few decades, the numerical simulation has been widely adopted to carry on the comprehensive research to the boilers, including the problems of combustion process, heat transfer and NO_x emission. The numerical simulation could obtain the temperature, velocity, species field and the wall heat flux distributions, which could clearly reflect the combustion characteristics in the furnace [3]. Li et at. [4] studied the influence of different excess air coefficients on combustion characteristics of gas-fired boilers by numerical simulation. The temperature, velocity and species distribution under new gas-fired boiler with lower NO_x emission were investigated by different researches [5, 6]. The effect of flue gas recirculation on NO_x emission also get a lot of attention [7, 8]. Most researches focused on the combustion characteristics of boilers, whereas less attention was paid to the heat flux distribution under different boiler loads, which is beneficial for the accurate hydrodynamic calculation. What needs to be explained is that most research institutions in China adopted the heat flux distribution curves for hydrodynamic calculation, which was published in the calculation standard in 1983. However, with the development of boiler combustion organization and the improvement of operation parameters, the hydrodynamic calculation curves could not reflect the heat transfer characteristics very accurately on the present boilers. So nowadays, the heat flux distribution curves obtained by numerical simulation is widely used in hydrodynamic calculation, which could reflect the combustion characteristics in details.

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In this study, numerical study was carried on to investigate the combustion characteristics and heat flux distributions of the gas-fired boiler under 30%, 50%, 75% and 100% load. The results obtained by numerical simulation are compared with the thermal calculation to provide a guidance for design and operation of the gas-fired boiler.

2. MODELLING METHODOLOGY

2.1 Boiler structure

This simulation was performed on a gas-fired boiler. The height to the furnace exit is approximately 10840 mm, and the horizontal cross section of the furnace has a width of 8000 mm and depth of 4624 mm, as shown in Fig.1.

In the simulation of gas-fired boiler, the mesh quality of the boiler model has a great influence on the accuracy and effectiveness of the results. As observed in Fig. 2, unstructured grid is adopted to divide the burner nozzles due to the complexity of the structure. Mesh is refined in the burner zones due to the rapid combustion.

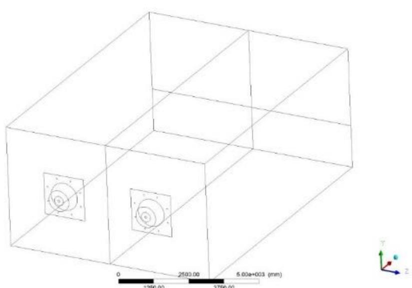

Fig.1 Gas-fired Boiler structure

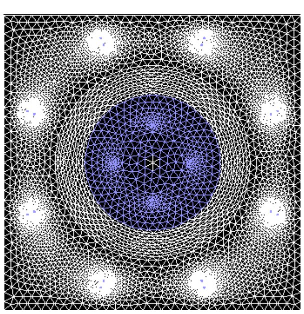

Fig.2 Burner mesh

2.2 Numerical models

In this study, SIMPLEC algorithm was carried out to solve the time averaged conservation equation for mass, momentum and energy [9]. The realizable $k-\varepsilon$ model was chosen to describe the turbulent flow process [10]. The mixture fraction/probability density function (PDF) was used to simulate the turbulent combustion process of gas phase [11]. The DO model was applied to model the radiation heat transfer. The weighted sum of gray gas model (WSGGM) was adopted to calculate the absorption coefficient [12].

2.3 Boundary conditions

Table 1 shows the natural gas species used in this study. Table 2 gives the boundary conditions of different loads.

Table 1 Natural gas species

CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_2H_4	N_2	H_2	CO_2
7.42	0.94	0.16	0.03	0.06	0.76	0.11	0.52

Table 2. Boundary conditions under different loads

load/%	PA/kg s^{-1}	SA/kg s^{-1}	PG/kg s^{-1}	SG/kg s^{-1}
100.0	8.662	34.648	0.489	1.956
75.0	6.471	25.882	0.365	1.461
50.0	4.296	17.186	0.242	0.970
30.0	2.573	10.291	0.145	0.581

3. RESULTS AND DISCUSSION

3.1 Result verification

The heat transfer and outlet temperature of numerical and thermodynamic results are shown in Fig.3.

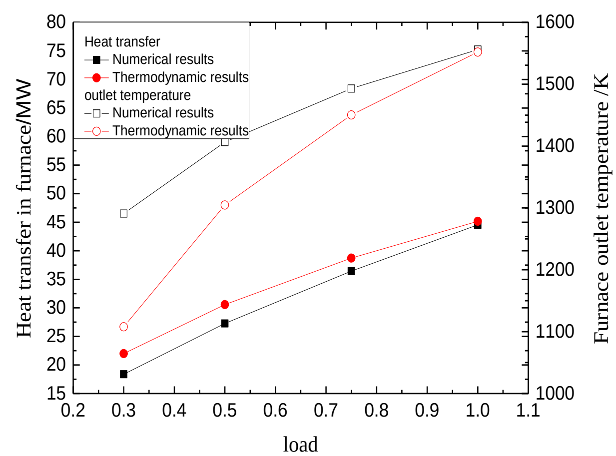

Fig.3 Comparison between numerical and thermodynamic results

According to Fig.3, under 100% load, the results of numerical study and thermodynamic calculation are basically the same. With the decrement of load, the difference between them gradually increases. In the simulation results, it was observed that with the decrease of furnace load, the flame fullness in the furnace decreased gradually, and the position of the main combustion zone moved towards the outlet of the furnace. On the contrary, the boiler thermal calculation standard adopts the zero dimensional model, which could not take the influence of the flame structure change into consideration.

Fig.4 shows the temperature of furnace outlet under different loads. It can be observed that the flue gas temperature of furnace outlet increases with the increment of load. When boiler load increases from 30% to 100%, the flue gas temperature of furnace outlet rises by 260 K.

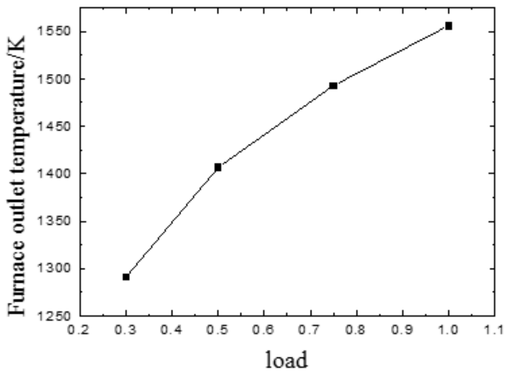

Fig.4 Temperature of furnace outlet

3.2 Temperature distributions under different loads

Fig.5 presents the temperature distribution contours under different loads. Temperature in the furnace increases gradually along the furnace height direction under different boiler loads. The highest temperature in the furnace appears near the furnace outlet, indicating that the heat release process in the whole furnace is continuous. When the flue gas leaves the furnace, there still are combustion reactions. With the decrement of the load, the temperature in the furnace decreases obviously.

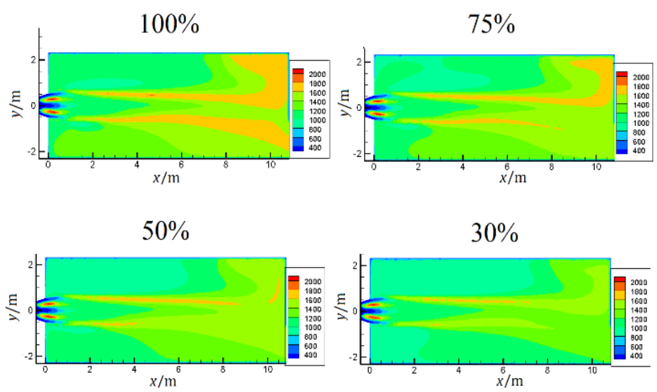

Fig.5 Temperature distribution contours

The velocity distribution in the furnace are shown in Fig. 6. With the decrement of the boiler load, the gas flow velocity in the furnace decreases obviously. The velocity distribution in the furnace is similar under different boiler loads. Some low-speed reflux regions are formed in the furnace, which indicates that the similar velocity field could be maintained in the furnace even under low boiler load. In addition, air and fuel enter the furnace at a high speed, the velocity decreases rapidly after entering the furnace, and the highest velocity region is always kept in the central area of the furnace.

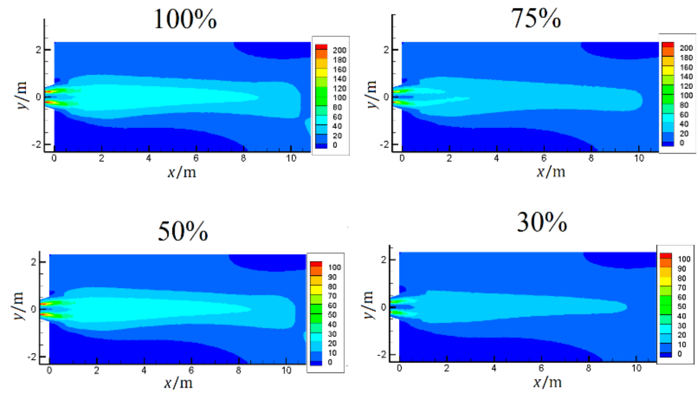

Fig.6 Velocity distribution contours

3.3 Heat flux distributions

Fig.7 presents the heat flux distributions on the water walls under different loads. It is found that the heat flux distributions on each water wall increase with the increment of boiler load. In addition, there is a significant difference between the heat flux on different water walls. The heat flux on rear wall is the highest, whereas the heat flux on front wall is the lowest.

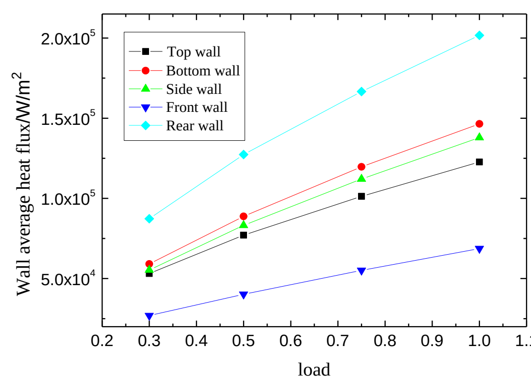

Fig.7 Heat flux distributions of water walls under different loads

Fig.8 gives the heat flux distribution on top wall and side wall. The heat flux on top wall is uneven, the highest heat flux appears in the second half of the furnace wall, the heat flux near center line of furnace is significantly higher than the other position of same cross section.

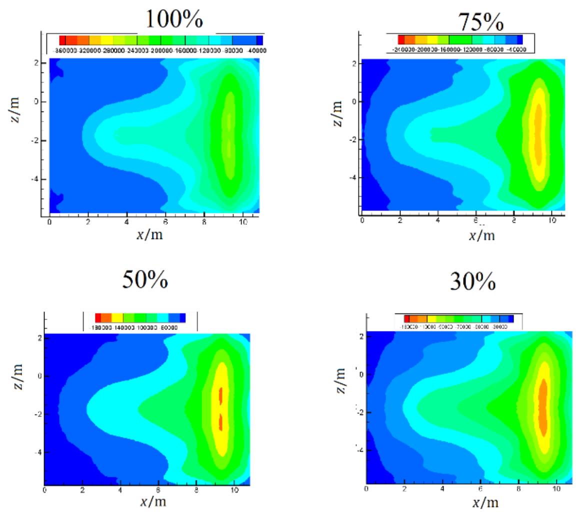

Fig.8 Heat flux distributions on top wall

4. CONCLUSIONS

In this study, the simulation was carried out under different boiler loads on the combustion and heat transfer characteristics in the furnace. The following conclusions are obtained:

(1) The results of heat flux distributions under thermal calculation and numerical simulation are different. Compared with the thermal calculation, the numerical simulation of three dimensional model could better reflect the combustion process in the furnace.

(2) With the increment of load, the flue gas temperature increases in the furnace. The velocity distribution is similar under different boiler loads. The higher boiler load, the higher gas velocity.

(3) With the increasing of boiler load, the heat flux on each wall increases. The heat flux distributions on different wall are different. Specifically, the heat flux on rear wall is the highest, whereas the heat flux on front wall is the lowest.

ACKNOWLEDGEMENT

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