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Combustion Characteristic Numerical Simulation and Analysis on New Type Pulverized Coal-Fired Hot Water Boiler

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Abstract. To take 1 single capacity 58MW pulverized coal fired hot water boiler manufactured by Shanxi Lantian Environmental Protection Equipment Co., Ltd as research object, by using FLUENT fluid calculation software to carry out numerical simulation calculation on the velocity field, temperature field, the concentration of oxygen inside the chamber combustion boiler which equipped hedge rotational flow burner. The calculation results showed that: when the boiler was at high load, perturbation action of stream field was more obvious with the increase of inner secondary air and outer secondary air ratio, when the boiler was at low load, the variation of the inner secondary air and outer secondary air ratio almost didn't affect the perturbation action of stream field; when at the same load, fly ash carbon content of furnace outlet was less with the increase of the inner secondary air and outer secondary air ratio, pulverized coal burning rate increased correspondingly.

Introduction

Pulverized coal fired hot water boilers was more and more used for heating in northern China region, because of its short operating time in China, lots of technology still had room for improvement, such as fly ash carbon content of small pulverized coal fired boiler was still high compared with large sized, the combustion efficiency is low, the burner structural arrangement was still diversity and so on. A lot of scholars carried out research on large pulverized coal fired boiler simulation, Ren Huizhong and others began to research furnace internal structure of boiler and aerodynamic field, by analyzing the three-dimensional dynamic field figure according to different furnace internal structure, to find out the best furnace internal aerodynamic field corresponding to the structure [1]. Jiao Feng carried out numerical calculation on aerodynamic field inside the boiler, the results showed that: flow field had characteristic shape which was not perfect circle but appeared as inclined elliptical shape, and the formation of the inclined elliptical air flow was mainly caused by deflection angle of each jet flow group, it provided theoretical foundation for jet flow component structure design [2]. Sudarshan Kumar et al carried out thermal state simulation calculation on a type of high efficient burner and the results showed that the burner had advantages as High heat release rate and low peak temperature compared with traditional burner [3]. Belosevic et al [4] adopted code program compiled by himself, to carry out numerical calculation on process in the furnace of pulverized coal fired boiler and analysis process in the furnace on different operating conditions such as different load, fuel and air distribution, size of pulverized coal fineness etc. Hwang et al [5] reformed a pulverized coal fired boiler, and carried out numerical calculation on ash recirculation and rekindle, results were used to analysis the best ash position and condition which didn't affect the boiler thermal efficiency of the normal operation.

For small industrial pulverized coal fired boiler, Domestic and abroad research scholars carried out very little simulation research, especially for boilers which were hedge burner structure disposal haven't yet carry out numerical research, so this article carried out numerical calculation on 58 MW pulverized coal fired hot water boiler furnace combustion by using Fluent software, and velocity field in the furnace, temperature field and oxygen concentration, pulverized coal burning rate, fly ash carbon content were analyzed at different load.

Physical Model and Mesh Generation

Physical Model

58 MW pulverized coal fired boiler adopted membrane water wall, load thermal control was implemented by adjusting pulverized coal quantity and primary secondary air capacity. Pulverized coal conveying system adopted ball grinder which storage bin equipped hot air supply system, and pulverized coal was feed into Venturi tube structure wind powder blender and sent into burner by primary air. Fig. 1 showed 58 MW pulverized coal boiler structure and size.

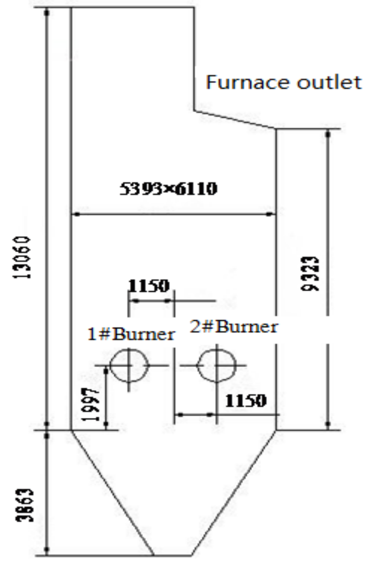

Fig.1 Schematic diagram of boiler size

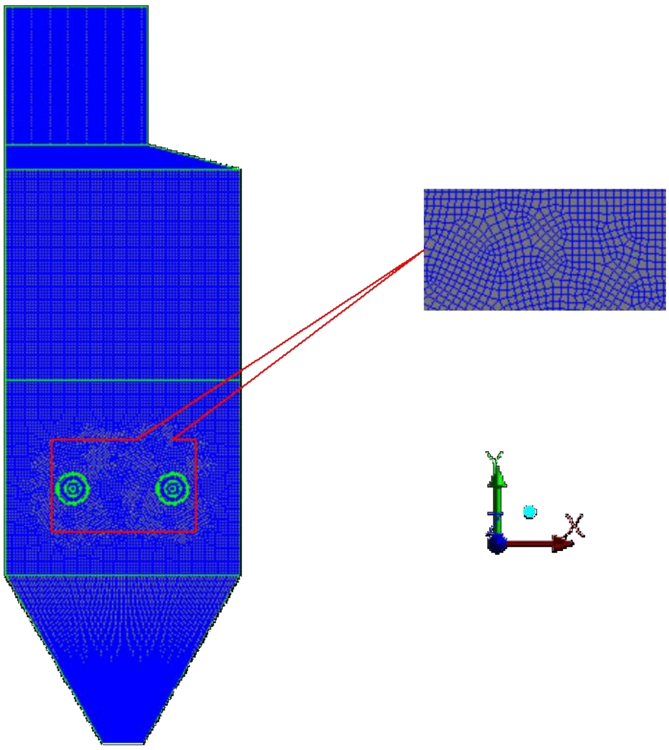

Fig.2 Grid division in calculation domain of furnace

Mesh Generation

The simulation calculation of the furnace computational domain adopted the proportion of 1:1, after simplifying the whole furnace calculation domain in the direction of X, Y, Z were 5.393 m×16.923 m×16.923 m. Fig.2 showed furnace computational domain mesh generation of the 58 mw pulverized coal fired boiler.

During the boiler furnace combustion operating time, pulverized coal mixed with air was feed into the furnace through the burner and combined fired in the furnace. In the establishment of physical model, the burner and furnace were overall considered, but the burner secondary air channel equipped on the 58 MW pulverized coal fired boiler was separately established physical model, and then to take as foundation of the subsequent furnace calculation by mesh generation. Fig.3 showed mesh generation of the inner secondary air and outer secondary air passage.

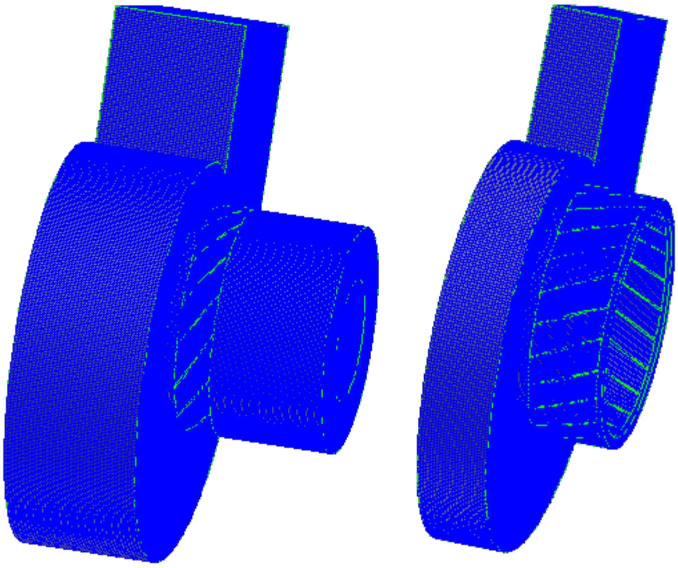

Fig.3 Mesh generation of secondary air passage of the burner

Mathematical Model and Calculation Method

Mathematical Model

To simulate the turbulent fluid flow by adopting Realize $k-\varepsilon$ model, choose P-1 model to calculate the radiation heat transfer in the furnace, select double step competition reaction model to simulate the volatile pyrolysis of the coal particle combustion reaction process, and the gas phase combustion selected mixing fraction-probability density function model, the coke combustion selected power-diffusion control the reaction rate model.

Boundary Condition and Calculation Method

Inlet Boundary Condition

The furnace inlet was set as velocity-inlet boundary condition, the center wind speed, velocity of primary air and pulverized coal particle flow according were set directly according to the designed operation parameters, velocity of inner secondary air and outer secondary air were set based on velocity vector profile file of the corresponding burners cold state analog output.

For the particle phase set method, the conditions at inlet:

1) Industrial analysis and elemental analysis of coal can be seen in table 1.

2) Pulverized coal particle diameter distributed based on the basis of Rosin – Rammler.

3) Pulverized coal import quality, density and other physical characteristics were set in real time based on different calculation conditions, it can be seen in table 2 the related volume settings under various load.

4) Pulverized coal particles took 0.8 times of the primary air velocity as the starting velocity, the temperature of pulverized coal was set as same as the primary air temperature.

Outlet Boundary Condition

The furnace out let planar flow boundary condition was assuming as outflow condition, which meant that gradient of all variables on the flow direction were zero. Given the outlet pressure as atmospheric pressure, outlet temperature was set according to different operation load, it can be seen in table 2 the related volume settings under various load.

Table 1 Industrial analysis and elemental analysis of coal

Industrial analysis(%)				Elemental analysis(%)				
Var	Aar	Mar	FCar	Car	Har	Oar	Nar	Sar
38.48	21.37	8.85	31.3	57.42	3.81	7.16	0.93	0.46
$Q_{net, ar}$ (kJ/kg)				22211				

Table.2 Correlation settings under each load

Load	100%	80%	60%
Pulverized coal quantityof each burner (t/h)	2.13	1.73	1.31
Pulverized coal particle temperature (K)	293	293	293
Furnace outlet temperature (K)	1100	950	800
Membrane water wall surface thermal flux (W/m^2)	2.0×10^5	1.62×10^5	1.23×10^5

Wall Surface Boundary Condition

After furnace wall surface was simplify disposed, setting was disposed according to zero slip, no turbulent flow up and quality penetration. Flow near the wall region selected standard wall function, cold wall surface set as thermal flux, specified under the different load, from 1.23×105 W/m^2 to 2.0 ×105W/m^2, it can be seen in table 2 the related volume settings under various load.

Result and Analysis

Simulation Condition Setting and Instruction

Table.3 Specific design parameters of each condition

Condition	Load (MW)	Primary air velocity (m/s)	Inner secondary air velocity (m/s)	Outer secondary air velocity (m/s)	Center wind velocity (m/s)	Inner secondary air and outer secondary air ratio
1	58	11.80	39.10	24.09	8.00	3:1
2	58	11.80	41.60	19.27	8.00	4:1
3	46.4	11.80	35.35	16.48	6.8	4:1
4	46.4	11.80	36.83	13.65	6.8	5:1
5	34.8	11.80	29.03	11.06	5.2	5:1
6	34.8	11.80	29.86	10.45	5.2	6:1

This section was simulation calculation of 58 MW pulverized coal fired boiler of 6 conditions under three different loads, and the specific design parameters are shown in table 3.

The Result and Analysis of Each Condition Velocity Field

Condition 1 and 2, 3 and 4, 5 and 6 were numerical simulation of boiler combustion which divided into three groups of different operation loads, moreover, in each group of the same operation load, the inner secondary air and outer secondary air ratio was different, that would affect the flow field in the furnace, the 3 groups flow field velocity difference among same load but different condition were analyzed, which also included same air volume effect on the flow field in the furnace under the different loads. Fig.4 showed that condition 1 and 2 velocity distribution vector diagram under operation condition.

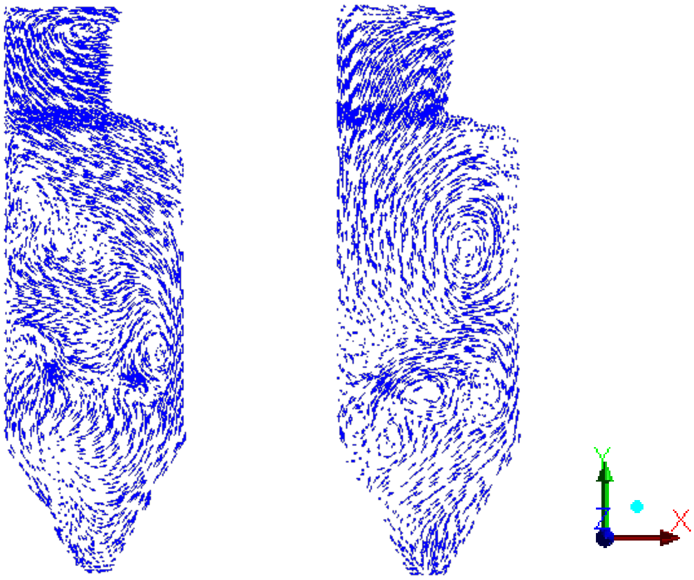

Fig.4 Velocity distribution vector diagram in condition 1 and 2

It could be seen through the 6 conditions comparison, inner secondary air and outer secondary air in the swirl burner were injected into the furnace, and it had the perturbation action to flow field in the furnace. Because of the different inner secondary air and outer secondary air ratio, the radiation scope of disturbance was also different, the 4:1 flux ratio was much better than 3:1 flux ratio when the load was 100%, condition 4 was much better than condition 3 while condition 3 had similar effect but also reduced when the load changed to 80%, for the same flux ratio, 5:1, condition 4 disturbance effect was better than condition 5 when the load was 60%, so it could be concluded that, when the load was 100% and 80%, disturbance effect of flow field was better with the increase of the flux ratio, but under the same flux ratio condition, with the reduction of the load, it also effected the flow field; when the load was 60%, the volume size of the flux ratio effected very little, basically tend to be the same, but for the same flux ratio in condition 4 and 5, the reduction of load resulted a great influence for the flow field disturbance.

The Result and Analysis of Each Condition Temperature Field

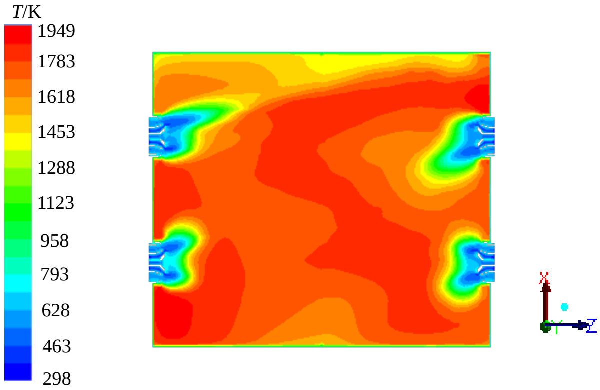

Fig.5 Temperature contour of cross section in condition 1

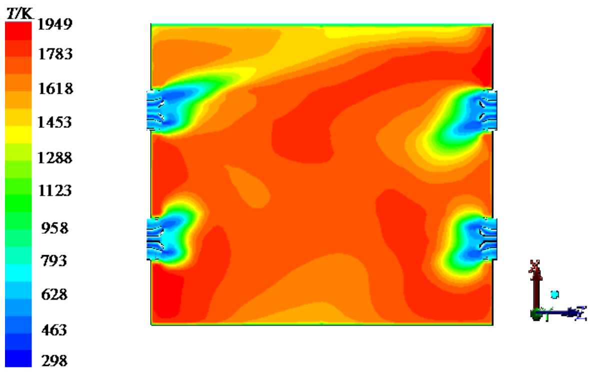

Fig.6 Temperature contour of cross section in condition 2

On the boiler left and right furnace side wall, 1#, 2#, 3#, 4# burners located at the same horizontal plane, when the load was 100%, fig.5 and fig.6 was respectively nozzle horizontal cross section temperature field distribution nephogram of the 3:1 flux ratio and 4:1 flux ratio corresponding condition 1 and condition 2.

Because of the turbulent burner adopted, burner nozzle had the effect of flue gas entrainment, so it generated obvious temperature changing gradient area near the nozzle, all burner nozzles in 6 conditions generated temperature distribution which shape was similar as the torch flame; with the reduction of boiler load, furnace nozzle horizontal cross section temperature also reduced. The different flux ratio caused different furnace nozzle horizontal cross section temperature distribution under the same load condition, especially when the load was 80%, flux ratio had the most obvious impact to the horizontal cross section temperature distribution which was also to the benefit to combustion; when the load was 60%, the increase of the flux ratio caused effect on the temperature field.

Average Temperature Distribution in the Furnace Height

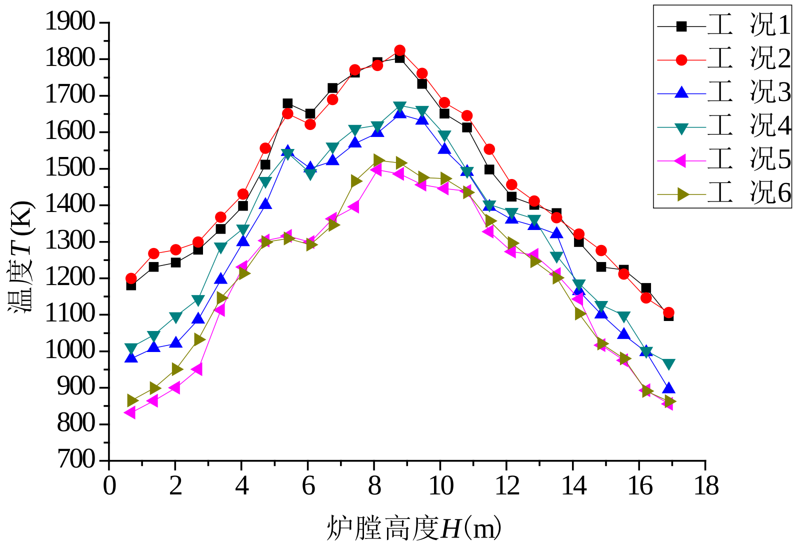

Fig.7 The average temperature distribution in the furnace height of various condition

It could be concluded in Fig.7 that the temperature trend in the furnace height was basic same, meanwhile, the high-temperature region of the furnace relatively shifted down when the load was 60%; when the load was 80% and 60%, the temperature in the high-temperature region of the furnace changed slowly which was basic same, and that could avoid negative effects to the membrane water wall caused by the temperature jump.

Oxygen Content Analysis

It could be concluded in Figure 7that oxygen content curve tendency was basic same under the different loads, meanwhile, the oxygen content distribution in the furnace height direction was also the same as the temperature in the furnace height direction, the oxygen content was low in the high-temperature region, and oxygen content in the furnace outlet was also low.

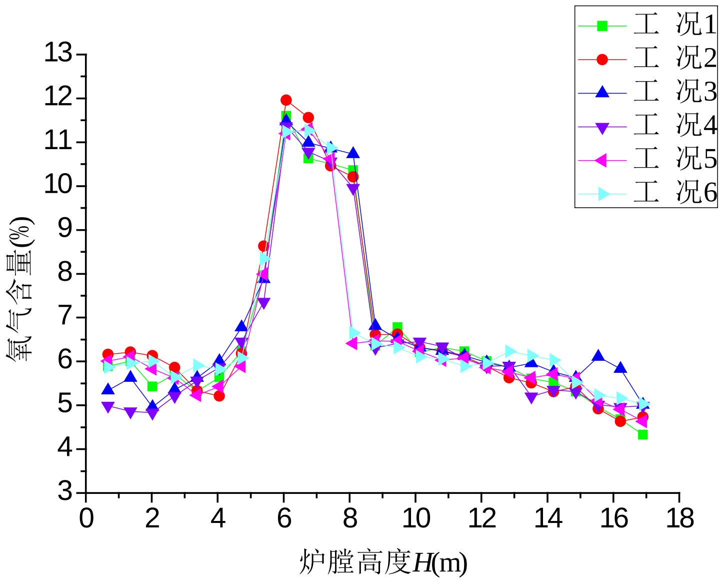

Fig.8 Oxygen content in the longitudinal section of the furnace in various condition

Conclusions

1) Inner secondary air and outer secondary air in the swirl burner were injected into the furnace, and it had obvious perturbation action to flow field in the furnace, the radiation scope of disturbance was different, when the load was 100% and 80%, disturbance effect of flow field was better with the increase of the inner secondary air and outer secondary air ratio, when the load was 60%, the volume size of the inner secondary air and outer secondary air ratio effected very little, basically tend to be the same; when the inner secondary air and outer secondary air ratio was same, disturbance effect of flow field would reduce with the reduction of the boiler load.

2) Because of the turbulent burner adopted, burner nozzle had the effect of flue gas entrainment, and caused low temperature near the nozzle, all burner nozzles in 6 conditions generated temperature distribution which shape was similar as the torch flame, with the reduction of boiler load, furnace nozzle horizontal cross section temperature also reduced. The different flux ratio caused different furnace nozzle horizontal cross section temperature distribution under the same load condition, especially when the load was 80%, flux ratio had the most obvious impact to the horizontal cross section temperature distribution which was also to the benefit to combustion.

3) Through the analysis to the average oxygen content distribution in the furnace height and oxygen content on the cross section, it could be concluded that oxygen content curve tendency was basic same only different in part; pulverized coal combustion was more intense in higher temperature region which oxygen concentration would be very low, when the load was 80%, and the oxygen concentration was above 9.6% near the burner nozzle, flux ratio 5:1 was better than flux ratio 4:1, meanwhile, the oxygen content distribution in the furnace and burner nozzle were both reasonable; with the increase of the flux ratio, the oxygen concentration was increased near the burner nozzle, the flue gas entrainment preheating capacity was stronger.

Acknowledgements

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