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NUMERICAL SIMULATION OF COMBUSTION IN 300 MW TANGENTIALLY FIRED PULVERIZED HIGH-ALKALI COAL BOILER ON UNDERLOAD OPERATION

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ABSTRACT

This paper numerically simulates the combustion in a 300MW tangentially fired pulverized high-alkali coal boiler under low-load conditions. The combustion process, temperature distribution and the thermal load in the furnace at different height are analyzed under three different load conditions, which are 30%, 45% and 60% of full load. The temperature distribution and the variation of NO_x concentration under different load conditions are investigated, as well. The results show that the combustion processes of pulverized high-alkali coal in the furnace are similar under different load conditions, but the positions of the fuel's full combustion are related to the loads. With the load increasing, the high temperature area gradually expands from the burner area to the central area of the furnace and extends to the upper part of the furnace. The distribution of NO_x concentration is significantly related to the loads. The distributions of NO_x concentration at 45% and 60% of full load are roughly similar, and mainly concentrate in the areas near the burner and up the burner area, which are the high temperature regions. But the distribution of NO_x at 30% of full load mainly concentrates in the upper part of the furnace, while the NO_x concentration in the burner area is relatively low.

Keywords: *Boiler combustion; high-alkali coal; low load; numerical simulation*

1. INTRODUCTION

Among the numerous pulverized coal boilers, the four-corner-tangentially fired boiler (FCT) is the most widely used and technically perfect boiler type in China, which accounts for a large proportion in the total use of pulverized coal boilers (Shao Weitao, 2017). FCT is characterized by good fire stability, uniform distribution of furnace flame, and is very compatible with China's diversified coal burning types (Huang Jun, 2018 and Yan Shunlin, 2018). With the increasingly strict control of NO_x pollutant emissions in the power industry (Chen Shinan, 2016 and Hu Min, 2015), controlling NO_x emissions on the basis of ensuring full combustion of boilers and rationally optimizing combustion inside boilers has become a hot issue in the boiler industry (Liu Xiangjun, 2000). However, considering that the combustion process of the boiler is very complex, the traditional experimental method is very expensive and difficult to solve theoretically, the use of fluid dynamics related software to simulate the combustion characteristics inside the boiler has become one of the commonly used methods in the industry (Liu Liping, 2009). In this paper, a 300MW four-corner rounded high-alkali pulverized coal boiler is numerically simulated by relevant simulation software, and the temperature distribution, NO_x concentration distribution and temperature in the furnace with the height of the furnace are obtained under different low-load conditions， which provides a theoretical basis for the application and optimization of the same type of boiler.

2. BOILER OVERVIEW AND GRID STRUCTURE

2.1 Boiler introduction

This research bases on a subcritical parameter boiler with type DG1146/17.55-II13 in a power plant in Xinjiang, China. The boiler is a four-corner circular firing method, a natural circulation drum furnace, a single furnace Π-type arrangement, designed to burn bituminous coal, and the actual combustion of Quasi-East coal. A schematic diagram of the boiler's grid is shown in Fig. 1.

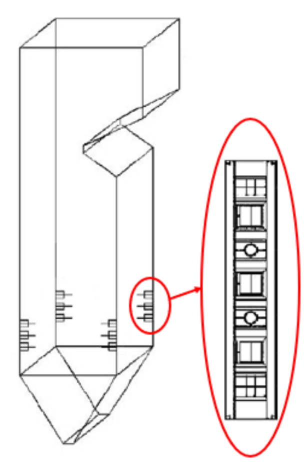

Fig. 1 Scheme of the boiler

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2.2 Physical models and grid generation

The geometry of the solution area is constructed according to the structural dimensions of the boiler furnace, and the entire furnace is used as the calculation area. The furnace is zoned and meshed in the burner area to accurately simulate the flow characteristics of the area, the total number of meshes used after mesh independence testing is 3814426. A schematic diagram of the boiler's grid is shown in Fig. 2.

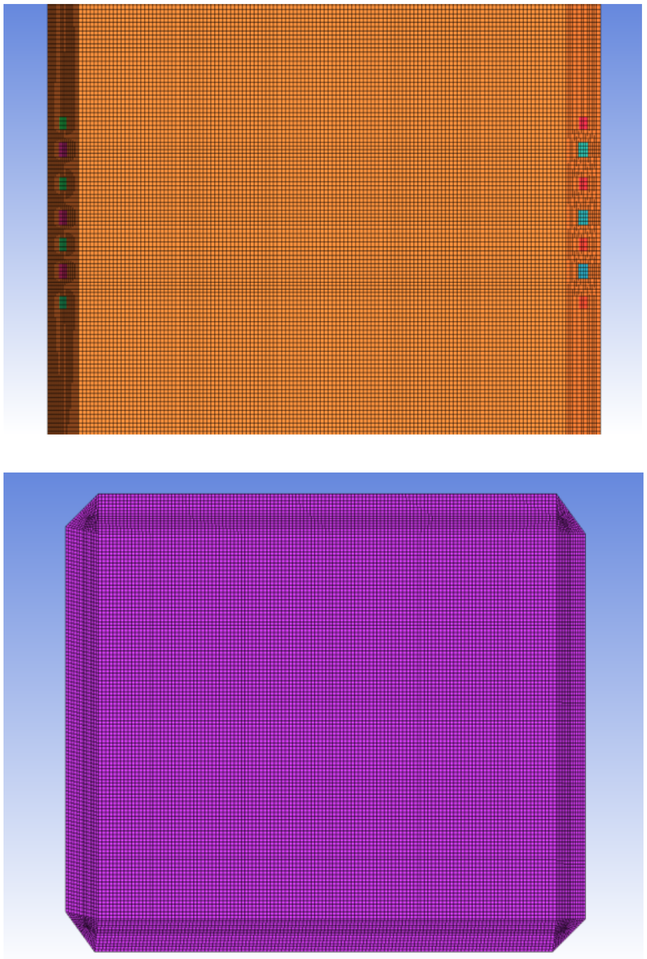

Fig. 2 Numerical grid scheme

2.3 Mathematical model and calculation conditions

The furnace is simulated by fluid dynamics calculation software, the three-dimensional steady-state calculation is selected, the gas phase turbulence is simulated by the mixing fraction-probability density function (Mixture-Reaction/PDF) combustion model is non-premixed, the standard k-ε turbulence model is selected to simulate the gas phase turbulence, the particle random track model simulates the movement of different coal pulverized coal particles, the coke combustion adopts the diffusion-dynamic control combustion model, and the gas-solid two-phase flow model adopts the Euler-Lagrange method. The radiant heat transfer model uses the P1 radiation model based on the heat flow method to simulate the radiant heat transfer process in the furnace (Cheng Huaizhi, 2015). The generation and reduction of NO_x are mainly based on the Thermal NO_x and Fuel NO_x models (Fang Lijun, 2018 and Fan Jianren, 2000). The furnace wall adopts a constant wall temperature boundary condition. When calculating iterations, the SIMPLE algorithm is used to solve the pressure and velocity coupling of discrete equations, the line-by-line iteration method and the low relaxation factor are used to solve the equations, and the discrete methods are all second-order style.

The boiler rated load condition is 330MW, and the simulated load is 30%, 45% and 60% of the rated load condition. The excess air coefficient under the three simulated loads is 1.2, with a total of 12 primary air inlets and 16 secondary air inlets. The primary wind temperature and secondary wind temperature were 65 °C and 260 °C respectively, and the primary wind speed and secondary wind speed were 27.5 m/s and 50 m/s, respectively. At 30%, 45% and 60% of the load The proportion of the next wind was 0.45, 0.41 and 0.36, the primary air volume was 30.25 Nm3/s, 45.11 Nm3/s and 48.95 Nm3/s, the proportion of secondary wind was 0.55, 0.59 and 0.64, the secondary air volume was 36.97 Nm3/s, 65.68 Nm3/s, 85.42 Nm3/s, and the consumption of pulverized coal was 11.58 kg/s, 19.09 kg/s, 23.15 kg/s.

The coal used in the calculation is high-alkali coal, and the specific parameters are shown in Table 1.

Table 1 Coal quality analysis.

Component name	*Unit*	*Amount*
Total moisture M_t	%	29
Air dried basis moisture M_{ad}	%	16.56
Ash as received basis A_{ar}	%	4.8
Dry ash-free volatiles V_{daf}	%	31.98
Total sulfur as received basis ($S_{t,ar}$)	%	0.59
Received basis gross calorific value ($Q_{gr,ar}$)	MJ/kg	19.92
Net calorific value as received basis ($Q_{net,ar}$)	MJ/kg	18.78
Received base carbon (C_{ar})	%	53.3
Receiving base hydrogen (H_{ar})	%	2.29
Received base nitrogen (N_{ar})	%	0.47
Received base oxygen (O_{ar})	%	9.55

3. SIMULATION RESULTS AND DISCUSSION

3.1 Temperature field distribution

The longitudinal section temperature distribution of the furnace under the three working conditions is shown in Fig.3, it can be seen from the figure that due to the low temperature of the primary wind powder, the high-alkali coal has a heat-absorbing heating process after entering the furnace. After the pulverized coal temperature reaches the ignition point, the pulverized coal begins to burn and releases heat. Comparing the longitudinal profile distribution of furnace temperature under three different working conditions, it can be seen that the ignition combustion process of pulverized coal in the furnace under three working conditions is basically similar. However, as the boiler load increases, it is obvious that the high temperature combustion area in the furnace is gradually expanding. When the load is under 30%, the combustion area of pulverized coal is basically concentrated near the burner nozzle of the boiler. When the load increases from 30% to 45%, the combustion area in the furnace is particularly enlarged. When the load increases from 45% to 60%, the combustion area of pulverized coal gradually fills the center of the furnace and expands along with the upper part of the furnace in the secondary wind direction.

The change of the average temperature of the furnace section with the height of the furnace is shown in Fig.4, and the temperature change under 100% load is introduced for comparison. It can be seen that the temperature in the furnace under four working conditions is gradually increased with the increase of the furnace height. After the maximum heat is reached at the upper position of the burner area due to the combustion of pulverized coal, the temperature starts to decline slowly with the gradual reduction of pulverized coal combustion and the continuous blowing of secondary air.

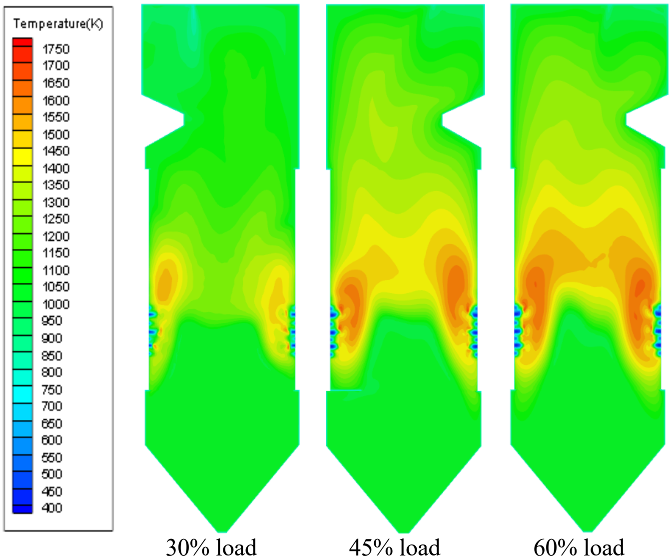

Fig. 3 Temperature distribution of boiler longitudinal profile under three different load conditions.

Comparing the four temperature change curves, it can be seen that the increase of boiler load is not linearly related to the change of average temperature in the furnace. The average temperature in the furnace at 45% of full load increases about 140K compared with that at 30% of full load, but the average temperature in the furnace at 60% of full load is only about 50K higher than that at 45% of full load, and the temperature is significantly increased at full load, which is about 230K higher than that at 60% of full load. And the height of reaching the highest temperature at 45% and 60% of full load is close, while the height at 30% of full load is lower. It can be seen that the combustion of 30% of full load in the furnace process does not fill the furnace, but the combustion after 45% of full load can basically fill the inside of the furnace, and there is no obvious change in the continued increase of load.

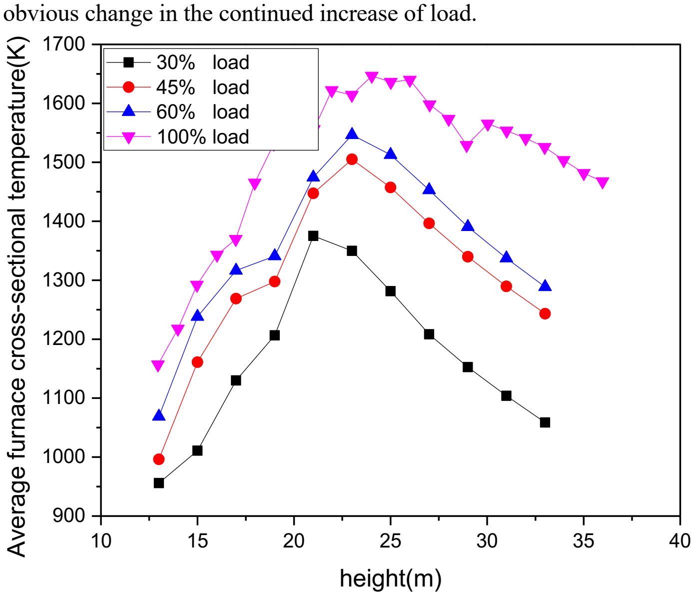

Fig. 4 Variation of average temperature of furnace section with furnace height.

Fig. 5 shows the cross-sectional temperature distribution of the burner area in the furnace under three working conditions. Comparing the cross-sectional drawings of the furnace under the three working conditions, it can be seen that the ignition combustion process of high-alkali coal in the furnace under the three working conditions is basically similar. In the section near the primary air inlet, due to the low temperature of the primary air powder. The temperature near the air inlet will be affected after the air powder enters the furnace. With the increase of load, it can be clearly seen from the figure that the distance from the endothermic temperature rise to the start of combustion of pulverized coal after blowing into the furnace gradually decreases.

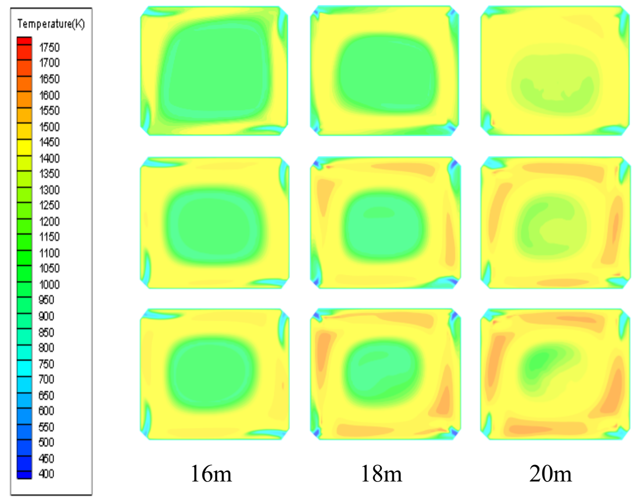

Fig. 5 Temperature Distribution of Boiler Burner Area Cross Section under 30%, 45% and 60% Load from Top to Bottom

Fig.6 shows the variation of the average temperature of the horizontal section at the burner area with the height of the furnace. It can be seen that the temperature trend in the furnace under the three working conditions is basically similar, and the heat is released by endothermic combustion after the pulverized coal enters the furnace, and the temperature gradually rises. However, near the height of 18 meters (slightly below the primary air inlet in the second row), the temperature drops significantly under all three conditions. Because the cooler primary wind blows into a large amount of coal, which brings a temperature drop in the furnace. The biggest drop occurs at 60% of full load, because more wind is blown in. The temperature at 30% of full load then continues to rise rapidly after 18 meters. The temperature at 45% and 60% of full load rises after 18 meters, and goes a slight drop at around 19.5 meters due to the other lower temperature primary wind blowing in. Then, because more coal is blown in when the load increases and it quickly releases heat by quick combustion due to the high temperature in the furnace. It indicates that when the pulverized coal is blown by layers, the subsequent blown pulverized coal can be quickly burned and release heat.

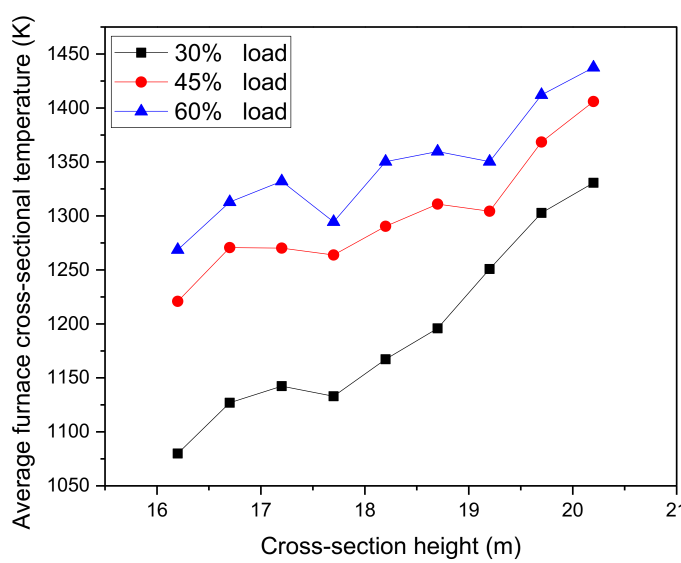

Fig. 6 Variation of average temperature of furnace section with furnace height (burner area)

3.2 NO_x concentration field distribution

Fig. 7 is the NO_x distribution of the longitudinal section of the furnace under three load conditions. It can be seen that NO_x concentrations are close at 30% and 45% of full load, and NO_x concentrations at 60% of full load are significantly lower than that of lower loads. Fig.7 shows that the production of NOx under 30% load is mainly concentrated in the upper part of the furnace, because the temperature is relatively low under 30% load and is not reached 1500K at which thermal NO_x can be generated, so the NO_x produced under 30% load is mainly fuel NO_x. The formation of NO_x in the anoxic combustion state in the burner area is inhibited, and the nitrogen in the fuel decomposes the intermediate products that are further oxidized at high temperatures to form NO_x after being exposed to oxygen in the upper part of the furnace. Due to the combustion releasing more heat under 45% load, the temperature in the furnace is higher in addition to the generation of fuel-type NO_x, and a large amount of thermal NO_x is generated, so the NO_x concentration in the furnace is higher than that under 30% load. NO_x under 45% load is mainly concentrated near the burner area and in the upper range of the burner area, combined with Fig.3, it can be seen that the NO_x high concentration area is mainly concentrated in the high temperature area. This is because nitrogen in the air is oxidized to NO_x in high temperature areas, i.e. in addition to fuel NO_x, NO_x is mainly generated in form of thermal NO_x as well under 45% load. The NO_x distribution under 60% load is similar to that under 45% load, but the NO_x concentration decreases significantly due to the reduction of oxygen concentration.

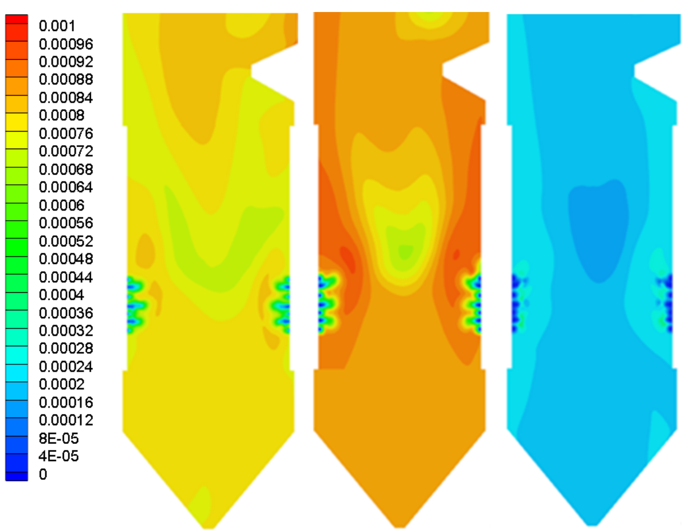

Fig. 7 NO_x Distribution of Boiler Longitudinal Section under 30%, 45% and 60% Load from Left to Right.

4. CONCLUSIONS

This paper establishes a model based on a 330MW four-corner rounded high-alkali pulverized coal boiler in a power plant, and studies the combustion law and NO_x generation law of the boiler under three low-load conditions through numerical simulation research, so as to provide scientific guidance for the application in industry. The main conclusions are as follows:

- The combustion process of high-alkali coal under the three working conditions is basically similar, but the increase of boiler load is not linearly related to the increase of the average temperature in the furnace. The high temperature area of pulverized coal combustion gradually expands from near the burner area to the center of the furnace and the upper part of the furnace with the increase of load, and the pulverized coal combustion is basically full of the furnace at 45% load, and the full combustion position does not change significantly with the increase of load.
- In the burner area, the blowing of primary air will reduce the overall temperature in the furnace near the air inlet area. Properly increasing the temperature of the primary air is advantageous to the stability of the temperature in the furnace. With the increase of the height of the burner, the pulverized coal blown in the upper burner would burn and release heat more quickly.
- NO_x concentration distribution under the three load conditions is clearly different. At 30% of full load, the fuel type NO_x is mainly concentrated in the upper part of the furnace center; The NO_x distribution at 45% of full load is mainly concentrated in the high temperature area near the burner and near the furnace wall; The distribution of NO_x at 60% of full load is basically similar to that at 45% of full load, but the overall concentration of NO_x is significantly reduced.

REFERENCES

Chen Shinan., 2016, “Optimization of burner arrangement of 600MW round cutting boiler and its hydrogen sulfide generation characteristics.” Beijing Jiaotong University.
https://cdmd.cnki.com.cn/Article/CDMD-10004-1016074563.htm

Cheng Huaizhi, Wen Lei, Song Zhengchang.,2015, “Low nitrogen combustion transformation and parameter optimization design of 350MW pulverized coal boiler.” *Journal of Chinese Society of Power Engineering*, 35(09), 704-708.
https://www.cnki.com.cn/Article/CJFDTotal-DONG201509003.htm

Fan Jianren, Zha Xudong, Sun Ping, Cen Kefa., 2000, “Numerical simulation of NO_x generation in tangential combustion boiler furnace.” *Power Engineering*, (03), 689-692+663.
https://dong.cbpt.cnki.net/wke2/WebPublication/paperDigest.aspx?paperID=E40E22B0-F704-4A65-BC4F-14DD01348238

Fang Lijun, Liu Xueying, Gao Taoshen., 2018, “Numerical simulation of combustion process of 330MW four-corner circular coal-fired boiler.” *Applied Energy Technology*, (12), 29-33.
https://www.cnki.com.cn/Article/CJFDTOTAL-KXJS201510041.htm

Hu Min., 2015, “The Action Plan for Upgrading and Upgrading Coal Power Energy Conservation and Emission Reduction (2014-2020) released and implemented.” *Oil Refining Technology and Engineering*, 45 (01), 42

https://www.cnki.com.cn/Article/CJFDTOTAL-LYSZ201501013.htm

Huang Jun., 2018, “Study on variable load characteristics of four-corner circular combustion ultra-low NO_x boiler.” *Boiler Technology*, 49(01), 47-52.
https://www.cnki.com.cn/Article/CJFDTotal-GLJS201801011.htm

Liu Liping., “Numerical simulation of combustion and air distribution in four-corner circular pulverized coal furnace.” Dalian University of Technology, 2009.
https://cdmd.cnki.com.cn/Article/CDMD-10141-2009040506.htm

Liu Xiangjun, Xu Xuchang, Fan Hongli., 2000, “Combustion behavior of pulverized coal in the furnace chamber of four-corner tangential pulverized coal boiler.” *Journal of Engineering Thermophysics*, (01), 105-109.
https://wap.cnki.net/qikan-GCRB200001025.html

Shao Weitao, Pan Weiguo, Wang Wenhuan, Li Wei., 2017, “Numerical calculation of combustion characteristics of four-corner circular coal-fired boiler based on different air distribution modes.” *Environmental Engineering* ,35(06),73-77.
https://www.cnki.com.cn/Article/CJFDTOTAL-HJGC201706016.htm

Yan Shunlin, Han Wei, Wang Haoxuan, Zhang Yongsheng, Liu Yang., 2018, “Numerical simulation of pulverized coal combustion process in four-angle circular boiler furnace.” *District Heating*, (01), 104-109+118.
https://www.cnki.com.cn/Article/CJFDTOTAL-RNWS201911013.htm