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The Influence of Flue Gas Recirculation on the Combustion Characteristics and Heat Flux Distributions under 660 MW Double-reheat Boiler

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ABSTRACT

Flue gas recirculation (FGR), which is adopted to control the reheat steam temperature of double-reheat boilers, significantly affects the temperature, heat flux and NO_x distributions. The effects of FGR on combustion characteristics and heat flux distributions were investigated by numerical simulation on 660 MW tower-type double-reheat boiler. The results show that, the FGR could reduce the temperature in the furnace under boiler maximum continuous rating (BMCR), 70% turbine heat acceptance (THA) and 50% THA loads. With the injection of recirculation flue gas (RFG), the heat flux in the combustion zone decreases, more heat is transmitted to the upper part of the furnace. The peak value of wall heat flux appears near the center line of furnace wall. The NO_x emission increases with the decline of boiler load and the FGR technology could effectively reduce the NO_x emission.

Keywords: Flue gas recirculation, combustion characteristics, heat flux distribution, numerical simulation, double-reheat boiler

1. INTRODUCTION

Developing coal-fired power generation technology with clean and efficient utilization of coal is the main direction of power industry in the future [1]. The ultra-supercritical (USC) double-reheat boiler with high efficiency, large capacity and low emission has drawn a lot of attention [2]. Compared with the single-reheat unit, the thermal efficiency of the double-reheat unit could be increased by 1-2% [3]. This technology has been applied in coal-fired power plants since 1950s at the abroad while relatively later in China. During the "Twelfth Five-Year Plan" of China, the State Energy Administration officially approved the construction of ultra-supercritical double-reheat coal-fired power generation projects, which means that China has started to rapidly develop the double-reheat technology in coal-fired power plants.

One of the difficulties of the double-reheat boiler is that the reheat steam temperature could not reach the design value in the actual operation due to the complex arrangement of the heating surface [4]. It is acknowledged that flue gas recirculation (FGR) could change the heat distribution in the furnace. In addition, FGR significantly affects the temperature field and NO generation in furnace. Sidrokin et al. [5] examined the effect of FGR on the NO_x emission in a steam boiler. Ling et al. [6] studied the effect of FGR locations on NO_x emissions in an industrial furnace. The influence of FGR on temperature and NO_x distribution in small-scale boilers has been investigated by many researchers [5-8]. However, little attention has been focused on the combustion characteristics and heat flux distributions of double-reheat boiler due to the later development of USC double-reheat boiler.

In recent years, numerical simulation has been adopted to investigate the combustion and pollutant formation process in pulverized coal fired boiler with more economical and convenient than experimental study [9]. In this study, the influence of FGR on combustion characteristics and wall heat flux characteristics is investigated on the 660 MW double-reheat tower-type boiler. This study could provide a guidance for double-reheat boiler combustion characteristics optimization.

2. BOILER STRUCTURE AND MERHOD MODELLING

2.1 Boiler structure

The simulation is based on a 660 MW USC double-reheat tower-type boiler, which adopts single furnace and tangential firing. The cross-section of the furnace is a square with 18150 mm × 18150 mm in width × depth, and the height of furnace is 97500 mm. Fig.1(a) displays the boiler structure. Recirculation flue gas (RFG) was sent into the furnace from the ash hopper area. The structure mesh was used to divide the boiler. The mesh system is demonstrated in Fig.1(b). Owing to the intensity combustion reaction in burner area, the mesh was refined in this zone to improve the accuracy of calculation. The properties of the Shanxi bituminous coal used in simulations are presented in Table 1.

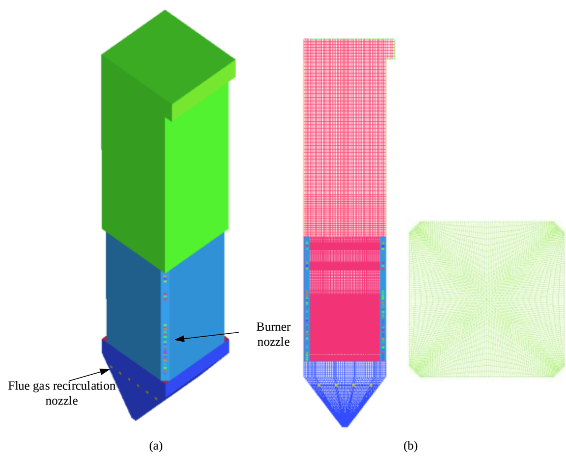

Fig. 1 Boiler structure and mesh

Table 1. Properties of the coal

Proximate analysis (ar, %)		Ultimate analysis (daf, %)	
w(*V*)	25.02	*w*(C)	78.86
w(*FC*)	43.62	*w*(H)	5.62
w(*A*)	14.96	*w*(O)	12.60
w(*M*)	16.40	*w*(N)	2.20
		w(S)	0.72
Q_{net} (MJ kg^{-1})		20.36	

2.2 Numerical simulation method

The combustion process of pulverized coal involves many physical and chemical processes such as flow, heat transfer and chemical reaction [10]. For the turbulence model, the standard $k-\varepsilon$ model is selected, which can obtain better numerical solution [11]. The trajectory of pulverized coal particles is tracked by random trajectory. The gravity, drag and safman lift of pulverized coal particles are taken into account. The particle size of pulverized coal obeys Rosin-Rammler distribution, the average particle size of pulverized coal is 69.4 mm. Due to the small proportion of pulverized coal in the two phases, the interaction between particles is ignored. DPM model is used to calculate the interaction between gas phase and solid phase. P1 radiation model is adopted to calculate the heat transfer in the furnace. The two-step competitive reaction model is applied for pulverized coal pyrolysis [12]. Considering that the formation of NO_x has little effect on the combustion and heat transfer process in the furnace, NO_x is calculated by the post-processing method.

2.3 Case condition

In this study, the effect of flue gas recirculation on the combustion process and wall heat flux distribution was studied under maximum continuous boiler rating (BMCR), 70% turbine heat acceptance (THA) and 50% THA loads. Table 2 gives the boundary conditions. The burner nozzles are defined with mass flow inlet in this study.

Table 2. Boundary conditions

load	FGR ratio	Primary air (kg s^{-1})	Second air (kg s^{-1})	FGR (kg s^{-1})
BMCR	0%	138.60	469.20	0.00
	20%	138.60	469.20	133.60
70% THA	0%	90.85	307.60	0.00
	20	90.85	307.60	93.60
50% THA	0%	69.92	236.76	0.00
	20%	69.92	236.76	67.00

3. RESULTS AND DISCUSSION

3.1 Grid independence test and validation of the CFD simulation

Three sets of grid system, 1 413 228, 1 632 584 and 2 037 866 were applied for numerical simulation. Fig. 2 presents the temperature distribution along the furnace height of the three grid systems. Considering the computation time and precision, the grid system of 1 632 584 cells was adopted in this study.

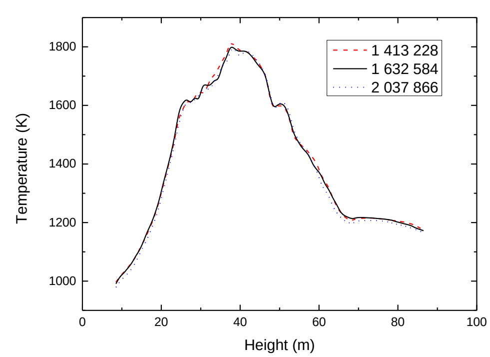

Fig. 2 Mesh independence test

The boiler studied is still under construction, it is impossible to verify the model with experimental data. Therefore, the CFD results is compared with the design parameters provided by Shanghai Boiler Group Co., Ltd. Fig. 3 shows the numerical simulation results and thermal calculated value. The results show that there is little difference between the simulation results and the thermal calculated value. The numerical simulation results are reliable.

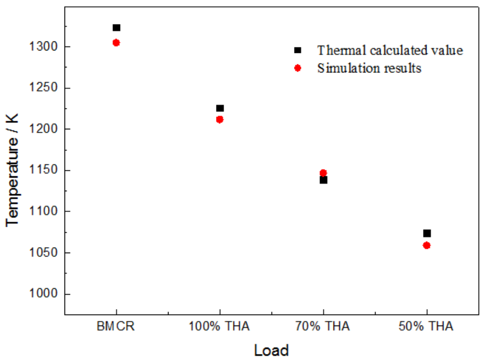

Fig. 3 Comparison among the numerical simulation results and thermal calculated values

3.2 Temperature distributions

The temperature distributions along the furnace height under three boiler loads with FGR or not are shown in Fig.4. It can be seen that the temperature near the burner nozzle is higher at different cases. With the increment of furnace height, the over fire air is sent into furnace, the unburned carbon continues to burn and release heat. In the upper part of furnace, the temperature gradually decreases with the heat absorption of water-cooled wall and superheaters. Under low and middle load, the burner nozzle is closed gradually. The four-layer burner nozzles are in operation under 70% THA load, while three-layer burner nozzles are used under 50% THA. The temperature decreases with the decrement of boiler load owing to the reduction of coal feed rate, which is agrees with the results of Liu et al. [7].

When RFG is introduced from ash hopper area, the high temperature area (1600 K < T < 2000 K) is reduced, which can be seen at full case. At the same time, the recirculation flue gas reduces the oxygen concentration in the primary combustion zone, which delays the combustion reaction process in the furnace and leads to the temperature decrement in the primary combustion zone.

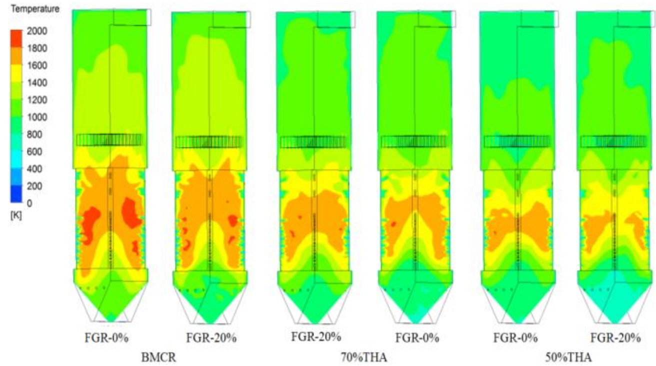

Fig.4 Temperature distributions under different loads

3.3 Wall heat flux distributions

Compare to the single-reheat boiler, the arrangement of double-reheat superheats are more complex. FGR is widely used to adjust the reheat steam temperature due to the steam temperature could not reach the design value in actual operation of double-reheat boiler. The wall heat flux distributions are related to the safety of water-cooled wall. Fig.5 exhibits the heat flux distribution on left wall under different loads. The heat flux is negative, which means that the water-cooled wall absorbs heat from the high temperature gas in the furnace. The higher heat flux appears in the burner area, which is consistent with the temperature distribution. Also, it can be observed that the heat flux peak arises in the middle area of width direction. The heat flux decreases with the decrement of boiler load, which are similar with the temperature distribution. It can be referred that with the injection of FGR, the heat exchange in combustion zone decreases and the heat is transferred to the upper part of the furnace The FGR technology could change the heat distribution in the furnace.

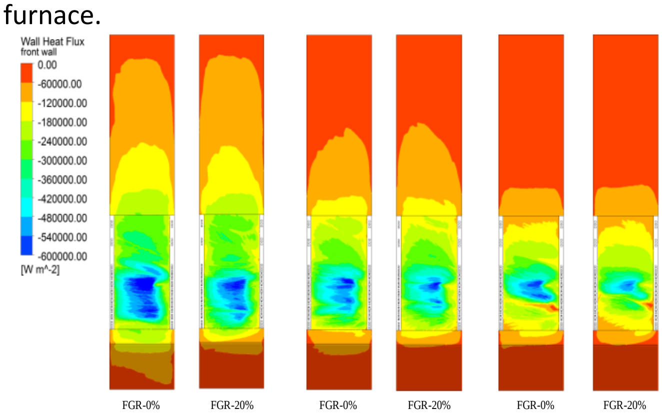

Fig.5 Heat flux distributions on left wall under different load

3.4 NO_x emission

Fig.6 shows the NO_x emission at the furnace outlet under different boiler loads. It can be clearly seen that the FGR could effectively reduce the NO_x emission. It could be explained by following reasons. First, with the injection of a large amount of low temperature air, the furnace temperature decreases. The formation of thermal NO_x in the furnace is inhibited. Second, FGR reduces the oxygen concentration in the furnace, the thermal and fuel NOx emission decrease. Thus, FGR technology could effectively reduce NO_x emission.

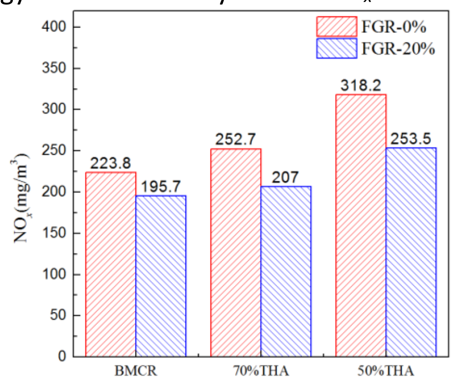

Fig.6 NO_x emission at the furnace outlet

4. CONCLUSIONS

FGR technology has received widely attention, which could control the reheat steam temperature and reduce the NO_x emission. The effect of FGR on combustion characteristics and heat flux distribution was investigated by numerical simulation under different boiler loads.

1) The temperature in the furnace decreases with the decrement of boiler load, the high temperature area appears in the primary combustion zone. With a large amount of low temperature air into the furnace, the flue gas temperature in the furnace decreases.

2) The heat flux on left wall decreases with the boiler load decreases. The heat flux is weakened by the RFG, which improves the safety of water-cooled wall. The peak value of heat flux appears near the center line of left wall. With the injection of RFG, the heat transfer in combustion zone decreases and more heat is transferred to the upper part of the furnace.

3) The FGR technology could effectively reduce the NO_x emission.

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REFERENCE

[1] Chang SY, Zhuo JK, Meng S, et al. Clean Coal Technologies in China: Current Status and Future Perspectives[J]. Engineering, 2016.

[2] Wang CY, Qiao YQ, Liu M, et al. Enhancing peak shaving capability by optimizing reheat-steam temperature control of a double-reheat boiler[J]. Applied Energy, 2020, 260:114341.

[3] Dong JC, Zhou T, Wu XJ, et al. Coupled heat transfer simulation of the spiral water wall in a double reheat ultra-supercritical boiler. Journal of Thermal Sciences: English edition,2018.

[4] Ma K, Li CF, Yan WP, et al. Effect of flue gas recirculation on reheated steam temperature of a 1000 MW ultra-supercritical double reheat Boiler. IOP Conference Series Earth and Environmental Science, 2018, 146.

[5] Sidorkin V T, Tugov A N, Moshnikov A N, et al. Effect of flue gas recirculation on the technical and environmental performance of a boiler. Power Technology & Engineering, 2016, 49(5):354-358.

[6] Ling Z, Zhou H, Ren T. Effect of the flue gas recirculation supply location on the heavy oil combustion and NOx emission characteristics within a pilot furnace fired by a swirl burner. Energy 2015,91:110–6.

[7] Liu H, Zhang L, Li QQ, et al. Effect of FGR position on the characteristics of combustion, emission and flue gas temperature deviation in a 1000 MW tower-type double-reheat boiler with deep-air-staging. Fuel, 2019, 246:285-294.

[8] Qian FP, Chyang CS, Chiou JB, et al. Effect of flue gas recirculation (FGR) on NO_x emission in a pilot-scale vortexing fluidized-bed combustor. Energy & Fuels, 2011, 25(Nov.-Dec.):5639–5646.

[9] Zhou H, Mo G, Si D, et al. Numerical simulation of the NOx emissions in a 1000 MW tangentially fired pulverized-coal boiler: influence of the multi-group arrangement of the separated over Fire Air[J]. Energy & Fuels, 2011, 25(5):2004-2012.

[10] Liu H, Liu YH, Yi GZ, et al. Effects of air staging conditions on the combustion and NO_x emission characteristics in a 600 MW wall fired utility boiler using lean coal. Energy & Fuels, 2013, 27(sep.-oct.):5831-5840.

[11] Li ZQ, Zeng LY, Zhao GB, et al. Numerical simulations of combustion characteristics and NO_x emissions for two configurations of swirl coal burners in a 300 MWe wall-fired boiler. Numerical Heat Transfer, 2011, 60(5):441-460.

[12] Li ZQ, Liu GK, Chen ZC, et al. Effect of angle of arch-supplied overfire air on flow, combustion characteristics and NO_x emissions of a down-fired utility boiler. Energy, 2013, 59(sep.15):377-386.