ISSN 2004-2965 Energy Proceedings, Vol. 18, 2021

International Conference on Applied Energy 2021
Nov. 29 - Dec. 2, 2021, Bangkok, Thailand
Paper ID: 070

The Influence of Flue Gas Recirculation on Heat Transfer Characteristics based on a Double-reheat Boiler

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ABSTRACT

Flue gas recirculation (FGR), which can regulate the heat transfer characteristics of double-reheat boilers, has received widely attention. The effect of FGR on heat flux distribution and heat absorption on heating area was investigated by numerical simulation based on a 660 MW tower-type double-reheat boiler. The results showed that when the FGR ratio increases, the heat flux in boiler ash hopper are decreased, and the area with high heat flux (260-330 kW m^{-2}) is reduced. The heat absorption in water-cooled wall zone is decreased, while that of reheater, superheater and economizer zone is increased once the RFG ratio increases.

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

NONMENCLATURE

Abbreviations

FGR	Flue Gas Recirculation
OFA	Overfire Air
SOFA	Seperated Overfire Air
DPM	Deformable Part Model
TCR	Thermal Calculation Results
SR	Simulation Results

1. INTRODUCTION

Coal consumption accounts for a large part of energy consumption in China. Reducing the energy consumption during coal-fired power generation and enhancing the thermal efficiency are necessary. The thermal efficiency can be improved effectively by increasing the steam parameters. Nowadays the steam parameters are raised from subcritical to supercritical and therefore the thermal efficiency is increased from 30% to 47%. However, due to the limitation of high temperature mental materials, it is difficult to significantly rise the steam temperature to 700 °C [1]. Double-reheat unit has received widely attention since the thermal efficiency can be increased by 1-2% compared with that of single-reheat unit [2]. The construction of ultra-supercritical double-reheat units has also been promoted in China nowadays.

However, there exist some problems. The reheated steam temperature could not reach the design value in the operation due to the complex arrangement of the heating surface [3]. It is acknowledged that flue gas recirculation (FGR) could change the heat distribution in the furnace [4-7]. The effect of FGR on temperature and NO_x distribution has been investigated by many researchers. However, little attention has been focused on heat transfer characteristics and heat flux distributions in the furnace.

In this study, the influence of different FGR ratios on heat flux distribution and heat absorption on heating area was investigated on a 660 MW double-reheat tower-type boiler. This study could provide a guidance for double-reheat boiler combustion optimization.

2. BOILER STRUCTURE AND MERHOD MODELLING

2.1 Boiler description

The furnace geometry and arrangement of flue gas recirculation nozzle in a 660 MW ultra-supercritical double-reheat tower-type boiler is shown in Fig. 1. FGR is sent into the furnace from the ash hopper area. The burner area of the boiler is 18150 mm × 18150 mm in length × width, and the furnace height is 97500 mm. Tangential combustion is formed by arranging the burners at four corners, and each corner consists of 5 primary air nozzles, 5 surrounding air nozzles, 7 secondary air nozzles, and 10 deflected secondary air nozzles, which are not shown in Fig. 1. Besides, two stages of OFA nozzles are arranged in the burnout zone.

The design coal type is Shanxi bituminous coal, and the coal properties are shown in Table 1. In this study, the effect of flue gas recirculation on heat flux distribution and heat absorption in heating zone is studied with no burner swing angle and a SOFA ratio of 34%. The horizontal swing angle of SOFA is -4°. The mass flow rate of burner and over-fire air inlet is calculated based on the load and the mass ratio among the air.

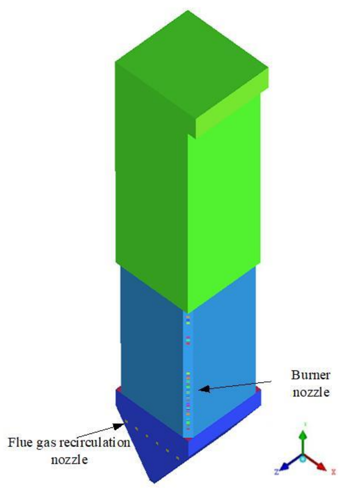

Fig. 1 Schematic of the boiler and arrangement of flue gas recirculation nozzle

Table 1. Properties of the coal

Ultimate analysis/wt%				
C_{daf}	H_{daf}	O_{daf}	N_{daf}	S_{daf}
78.86	5.62	12.60	2.20	0.72
Proximate analysis/wt%				
A_{ar}	M_{ar}	V_{ar}	FC_{ar}	Q_{net} (MJ/kg)
14.96	16.40	25.02	43.62	20.36

2.2 Numerical methods

The combustion process of pulverized coal involves many physical and chemical processes such as flow, heat transfer and chemical reaction [8]. For the turbulence model, the standard *k-Ɛ* model is selected, which can obtain better numerical solution [9]. The trajectory of pulverized coal particles is tracked by random trajectory. The gravity, drag and safman lift of pulverized coal particles are taking into account. The particle size of pulverized coal is obeyed 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 among particles is ignored, and DPM (deformable part 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 [10]. 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 post combustion treatment method. The recirculating flue gas temperature is given by UDF.

The grid independency test was conducted before formal calculation. The system cell number of 3 466 952 was selected in the numerical calculation balancing the calculation time and accuracy.

3. RESULTS AND DISCUSSION

3.1 Validation of the numerical models

Since the boiler in this study is still under trial operation, the correctness of the calculation results are verified by comparing the thermal calculation results (TCR) given by Shanghai Boiler Group Co., Ltd. with the simulation results (SR). And the results are shown in Table 2. The error rate of outlet temperature in economizer is 4.63%, the error rate of the heat absorption in water-cooled wall zone is 8.96%. The error rate is comparable with that in some studies [8, 11,12]. Thus the above-described numerical methods are valid for the current study.

Table 2. Comparison between SR and TCR value

Parameters	SR	TCR
Outlet temperature in economizer/K	701	670
Heat absorption in water-cooled wall zone/MW	672.5	617.2

3.2 Front Wall heat flux distributions

Compare to the single-reheat boiler, the arrangement of superheats of double-reheat 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.2 exhibits the heat flux distribution on front wall with different flue gas recirculation ratios. The negative heat flux means that the water-cooled wall absorbs heat from the high temperature gas in the furnace. From Fig.2 it can be seen that the maximum heat flux appears in the burner area, with the value of 330 kW m^{-2}. The violent combustion reaction leads to the rise in temperature, which enhances the heat exchange. When the FGR ratio increases, the heat flux in boiler ash hopper are decreased, and the area with high heat flux (260-330 kW m^{-2}) is reduced. Thus the safe operation is guaranteed.

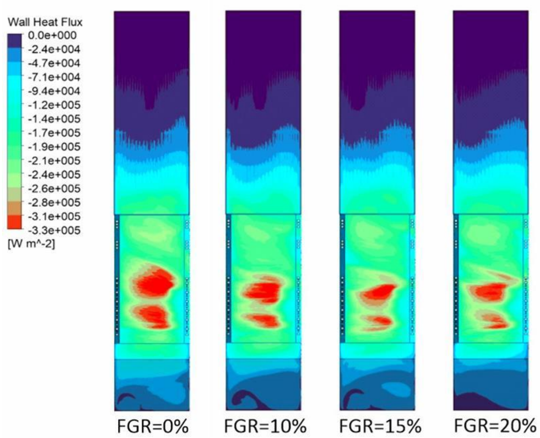

Fig.2 Heat flux distribution along water wall

3.3 Heat Absorption on heating area

The influence of FGR ratio on heat absorption in heating zone is shown in Fig. 3. It can be seen from the figure that the heat absorption of water-cooled wall zone is decreased, while that of reheater, superheater and economizer zone is increased once the FGR ratio increases.

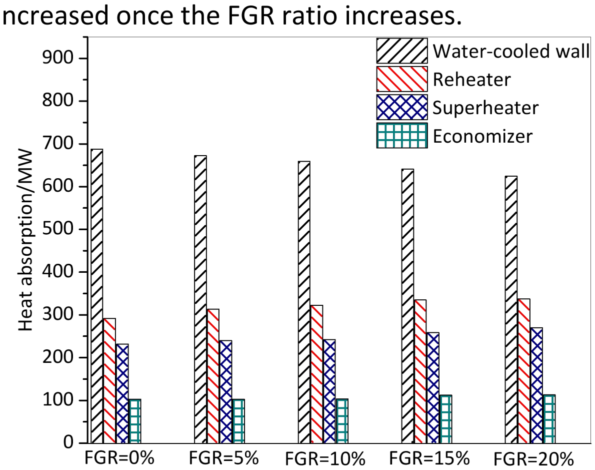

Fig.3 Heat absorption on various heating area

On the one hand, the heat transfer in water-cooled zone is decreased with the increase of FGR ratio. The heat generated during pulverized coal combustion process is carried by FGR to the upper part of the furnace, which increases the heat absorption in the convective heating area and panel in the upper section of the furnace. On the other hand, the flow velocity of the gas is increased, the char combustion is delayed in burnout zone, and the temperature in the upper part of the furnace is slightly increased with the injection of FGR. Thus the heat exchange in reheater, superheater and economizer zone is increased.

4. CONCLUSIONS

In present study, the numerical simulation model of a 660 MW ultra-supercritical double-reheat tower-type boiler was established to analyze the heat transfer characteristics. The validation of the numerical models showed the deviation between the model and the thermal calculation results is acceptable from an engineering perspective. The simulation results revealed that the injection of FGR has an influence on the front wall heat flux distribution and the heat absorption in heating zone.

When the FGR ratio increases, the heat flux in boiler ash hopper is decreased, and the area with high heat flux (260-330 kW m^{-2}) is reduced.

The heat absorption in water-cooled wall zone is decreased, while that of reheater, superheater and economizer zone is increased once the FGR ratio increases.

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