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Evaluation of the Uniformity of Heat Flux Distribution on Water Wall of a 600 MW Boiler under Varying Load Conditions

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ABSTRACT

With the development of renewable energy generating, the conventional power plants put forward higher requirements for flexible load regulation. While the heat flux distributions on water walls could change at varying load conditions. In the present study, the numerical simulation model of 600 MW tangentially coal-fired boiler was established to calculate the heat flux on water walls. The results revealed that the center of the heat flux area has a small offset with the geometric center of the furnace. The boiler load, primary air rate, air staging, burner and SOFA air swing were adopted as influencing factors to heat flux distribution, the heat flux deviation coefficient is selected as the index of evaluation. Orthogonal analysis indicated that the order of the influence of various factors was: boiler load > burner swing > air staging > SOFA air swing > primary air rate. The research was expected to provide the suggestions for the boiler operation and retrofit.

Keywords: heat flux distribution, membrane walls, uniformity evaluation, wide load

NONMENCLATURE

Abbreviations	
CFD	Computational Fluid Dynamics
AUX	auxiliary air
UFA	under-fire air
CCOFA	close-coupled over fire air
SOFA	separated over fire air

Symbols	
S	heat flux deviation coefficient
q_i	various simulated heat flux
$\bar{q}$	mean simulated heat flux
n	node number of water walls

1. INTRODUCTION

In order to improve the efficiency of power plant and meet the strict emission requirements, the utility boilers are moving towards high pressure and elevated-temperature. While large-scale renewable energy such as wind generation and photovoltaic system connected to power grid has important influence on the stable operation of conventional power generation [1]. However, local overheating of the water wall could occur at the boiler load adjusting process due to heat flux deviation and flow maldistribution [2].

The 0-D performance calculation model is widely applied to the design and diagnosis of boiler components under operating conditions [3]. The heat flux distributions along with the furnace height originate from a standard curve, which could not take into account the thermal effect caused by the air staging, burner swing, boiler load, primary to secondary air rate. Meanwhile, the combustion center position is acquired by semi-empirical formula at 0-D model, which greatly influences the calculation of outlet flue gas temperature. Compared with the natural circulation boiler, the once-through circulation boiler possesses weak self-compensation. Thus, the heat deviation along width and height of the hearth between the design and operation could result in a pipe-broken accident for the supercritical once-through boiler.

Much attention has been devoted to the measurement and distribution of heat flux in furnace water walls. Sankar et al. [4] found that the chordal thermocouple technique was an optimal selection on the large scale heat flux measurement. Zhang et al. [5] established the numerical simulation model to reveal the heat flux distribution on the water walls in an arch-fired boiler. Several researchers [6-8] coupled the thermal-hydraulic modeling with furnace CFD modelling to obtain more precise heat flux simulation results. Nevertheless, little work is available on the influence of operating variables such as operating load, air staging, burner swing, primary to secondary air rate on the uniformity of heat flux distribution.

Consequently, the aim of this paper was to evaluate the effect of operating load, air staging, burner swing and primary to secondary air rate on the uniformity of heat flux distribution by orthogonal tests. The numerical simulations on the heat flux distribution of water walls at various operating conditions were conducted on a 600 MW tangentially coal-fired boiler. It can be expected that the results could provide suggestions for the boiler operation and retrofit.

2. NUMERICAL APPROACH

2.1 Boiler description

The furnace geometry and burner arrangement of the 600 MW tangentially coal-fired boiler are shown in Fig. 1. The height of the boiler is 63.75 m. The furnace is rectangle in cross-section, which with a width of 18.816 m and a depth of 17.696 m. The rated capacity of the boiler is 1913 t/h and the main steam parameters were 25.4 MPa and 571 °C. There are six layers of burners and one layer of auxiliary air (AUX) between two burners. The under-fire air (UFA) nozzle, close-coupled over fire air (CCOFA) nozzles and separated over fire air (SOFA) nozzles are arranged as the boiler design manual.

Tables 1 and 2 show the coal properties and several operating parameters according to actual operation.

2.2 Numerical methods

In the present simulation, the gas turbulence was calculated by the standard $k-\varepsilon$ model which was widely used in coal combustion and of good performance [9]. Radiation transport in the furnace was solved using the discrete ordinates (DO) model, and gaseous radiative heat transfer was described by the domain-based weighted sum of gray gases model (WSGGM) [10]. The

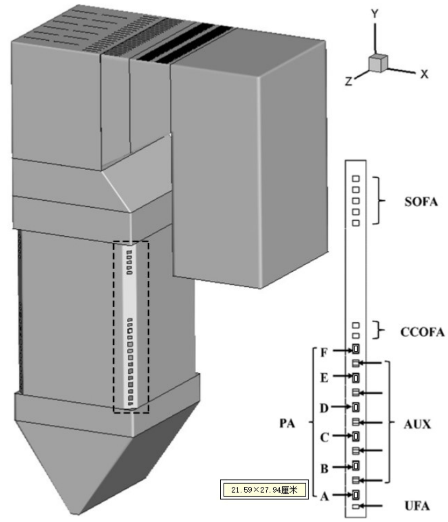

Fig 1 Schematic of the boiler and burner arrangement

discrete random walk model was adopted to calculate the coal particles flows, in which Saffman lift force, drag force and gravity were taken into account [11]. The eddy-dissipation finite rate model was employed to the gas phase combustion, and the kinetic/diffusion-limited model was adopted to describe the char combustion.

The grid independence test was conducted before formal calculation, and the system cell number of 2067250 was selected in the numerical calculation since its temperature field was basically coincide with a larger cell system.

Table 1 Coal properties

Ultimata analysis (wt%)				
C_{ar}	H_{ar}	O_{ar}	N_{ar}	S_{ar}
59.41	3.48	9.47	0.80	0.58
Proximate analysis (wt%)				
A_{ar}	M_{ar}	V_{ar}	FC_{ar}	LHV_{ar} (MJ/kg)
11.26	15.00	36.50	37.24	22.66

Table 2 Operation parameters under variable loads

Load	Coal feed rate (t/h)	Layers of burner	Excess air coefficient
BMCR	216.3	A-E	1.2
75% THA	148.2	B-E	1.33
50% THA	101.8	A-C	1.37
35% BMCR	86.2	B-C	1.47

3. RESULTS AND DISCUSSION

3.1 Validation of the numerical models

The numerical model was validated by the conduction on the 600 MWe tangentially boiler. The simulated values of furnace exit temperature and transferred heat to membrane wall were 1254 K and 660 MW, and the deviations were 5.86% and 8.27% compared with the measured value, respectively. Thus, the model adopted in the present study was suitable for similar combustion technology.

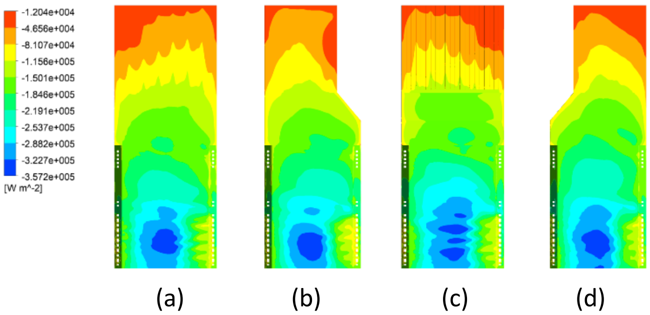

Fig 2 Heat flux distribution on the four water walls: (a)front wall (b)right wall (c)rear wall (d)left wall

The heat flux distribution contours of four water walls are shown in Fig 2. The combustion reaction was produced as the coal particle injected into the furnace, and the flame center formed, which led to the high heat flux area at the burner area. However, the center of the heat flux area has a small offset with the geometric center of the furnace. It could be that the secondary air plays the role of cooling the near wall as shown in Fig. 2.

3.2 Orthogonal analysis of operation parameters

The orthogonal design table which contain 5 factors and 4 levels are listed in Table 3. The boiler load, primary air rate, air staging, burner and SOFA air swing are adopted as factors, the heat flux deviation coefficient (*S*) is selected as the index of evaluation. The formula of S is as follows:

$$S=\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(q_i-\bar{q}\right)^2}$$

where q_i is the various simulated heat flux, $\bar{q}$ represents for the mean simulated heat flux, *n* stands for the node number of water walls.

The heat flux deviation coefficient *S* of the front wall of water walls has been considered. The visual analysis of the orthogonal test is shown in Fig. 3. The greater the range of the factors, the more significant the influence. The range analysis in Fig. 3 illustrated the order of the influence of various factors on the heat flux deviation coefficient is as follows: boiler load > burner swing > air staging > SOFA air swing > primary air rate. In addition,

Table 3 $L_{16}(4^5)$ level table of orthogonal design

Level	Factor				
	Load	primary air rate	air staging	burner swing	SOFA air swing
1	BMCR	0.18	0.75	-10	-10
2	75% THA	0.2	0.8	0	0
3	50% THA	0.22	0.85	15	15
4	35% BMCR	0.24	0.9	20	25

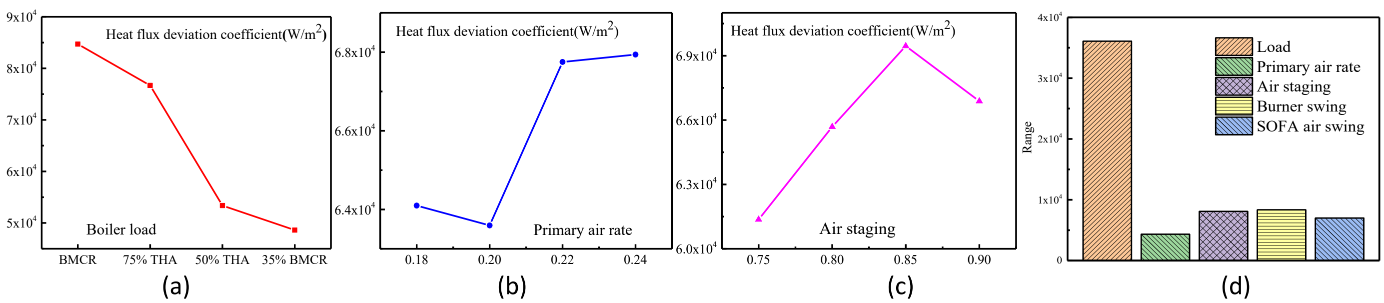

Fig 3 Visual analysis of the orthogonal test

the heat flux deviation coefficient declines with the boiler load decreased.

4. CONCLUSION

In the present study, the numerical simulation model of 600 MW tangentially coal-fired boiler was established to calculate the heat flux on water walls. The validation of the numerical models showed the deviation between the model and the real plants is acceptable from an engineering perspective. The simulation results revealed that the center of the heat flux area has a small offset with the geometric center of the furnace.

The boiler load, primary air rate, air staging, burner and SOFA air swing were adopted as influencing factors to heat flux distribution, the heat flux deviation coefficient is selected as the index of evaluation. Orthogonal analysis indicated that the order of the influence of various factors was: boiler load > burner swing > air staging > SOFA air swing > primary air rate. The research was expected to provide the suggestions for the boiler operation and retrofit.

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