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Experimental study on temperature distribution of membrane water wall in an ultra-supercritical pressure once-through boiler burning zhundong coal

Honghao He, Wenjun Li, Jun Zeng, Guohong Xie, Min Peng, Xuenong Duan

State Grid Hunan Electric Power Corporation Research Institute, Changsha, China

Abstract. Taking an ultra-supercritical pressure once-through boiler as an example, the temperature distribution of the lower membrane water wall is investigated experimentally, the conclusion reveals that increasing the proportion of Zhundong coal can effectively reduce the district heat load, which benefits the temperature uniformity in the lower membrane water wall. When the boiler being operated at middle load, the temperature deviation in lower membrane water wall increase simultaneously, one of the reasons is that the restriction orifice could not adjust the flow rate of working fluid as expected. By adjusting boiler performance, the temperature uniformity of lower membrane water wall can be improved to a certain degree.

1. Introduction

Coal, which is the main primary energy in China, is found a major reserve in the west of China, Zhundong, located in Xinjiang province, with the forecast reserves of 390 billion tons is the largest intact coalfield in the world, it is reckoned that the Zhundong coal can meet the needs for coal consumption in China for the next 100 years [1, 2]. The Zhundong coal is characterized by high volatile content, which leads to high ignition quality, and low exploitation cost. However, due to the process of coal formation is under a special natural environment, the content of sodium in Zhundong coal ash is exceptional high, generally in the range of 5% to 10% [3]. The high content of sodium usually results in severe slagging and fouling on heat transfer surfaces, in order to relieve the deposition, the boiler is specially designed with low district heat capacity, and Table.1 gives district heat capacity comparison between boilers burning different coal.

The membrane water wall safety is an essential aspect in plant boiler operation, especially for the ultra-supercritical pressure boiler, when the steam is being in the supercritical condition, the property is unstable, additionally, the variation of unit load or operation conditions may lead to saltation of steam property, and then induce problem of overheating of membrane water wall. As the Zhundong coal is exploited continuously, more number of boilers designed for burning high-sodium coal are put into operation. However, there is no research investigates temperature distribution of membrane water wall in boilers burning Zhundong coal. In this paper, experiment study is conducted to obtain characteristics of temperature distribution of membrane water wall in a commercial 660MW boiler with low district heat capacity.

Table.1 The comparison of district heat capcity of boilers burning different coal

Items	Unit	Common boiler A	Common boiler B	Boiler burning high-sodium coal
Volume heat capacity	kW/m^3	62.51	63.9	68~80
Section heat capacity	MW/m^2	3.83	3.915	4.0~5.0
Burner district heat capacity	MW/m^2	1.25	1.185	1.0~1.6

2. Experimental

2.1. Experimental object

The experimental object is a commercial 660MW boiler with Π type arrangement, single furnace, corner tangential firing, low NOx combustor, and the main design parameters is given in Table 2. The analyses of coal and ash is given in Table 3, the design coal and the testing coal A (coal A), with high content of sodium, are typical Zhundong coal, while the testing coal B (coal B), with relative low content of sodium, is a kind of common Chinese coal. Since there is no boiler that could completely be operated on Zhundong coal, the coal A was co-fired with coal B in this study.

Table.2 The main design parameters of the boiler

Items	Unit	Values
Main steam temperature	℃	605
Main steam pressure	MPa	28.25
Main stream flow	t/h	1948.38
Reheat steam temperature	℃	613
Reheat steam pressure	MPa	2.50
Reheat steam flow	t/h	1960.93
Section heat capacity	MW/m^2	3.83
Volume heat capacity	MW/m^3	62.51
Burner district heat capacity	MW/m^2	1.25

The furnace, consisted of membrane water wall, has a 19230×20336mm cross-section area, the high membrane water wall and the low membrane water wall is connected by mixture headers at height of 55600mm. Restriction orifices are designed and installed at entrance of the lower membrane water

Table. 3 Analyses of coal and ash

Items		Unit	Design coal	coal A	coal B
Ultimate analysis	C_{ar}	%	42.51	46.74	64.37
	H_{ar}	%	2.13	2.96	3.68
	O_{ar}	%	11.36	13.09	10.22
	N_{ar}	%	0.48	0.47	0.82
	$S_{t.ar}$	%	0.52	0.31	0.36
Proximate analysis	M_t	%	24.0	26.6	11.0
	M_{ad}	%	14.51	15.61	4.84
	A_{ad}	%	21.37	20.82	15.71
	V_{daf}	%	39.60	42.85	35.27
$Q_{net.\ ar}$		MJ/kg	14.81	13.51	22.57
Content of sodium in ash		%	3.70	3~4	1.28

Wall to regulate mass flux, the location of the restriction orifice is schematically shown in Fig 1. The low NOx combustor consists of six layers combustor, whose angle can be adjusted in range of -20°~20° in vertical direction, each layer combustor refer to a set of coal pulverizer.

2.2. Temperature measurement

In this study attention are mainly paid on characteristics of temperature distribution of low membrane water wall, and the outside temperature of tubes, near the inlet of the mixture header, is

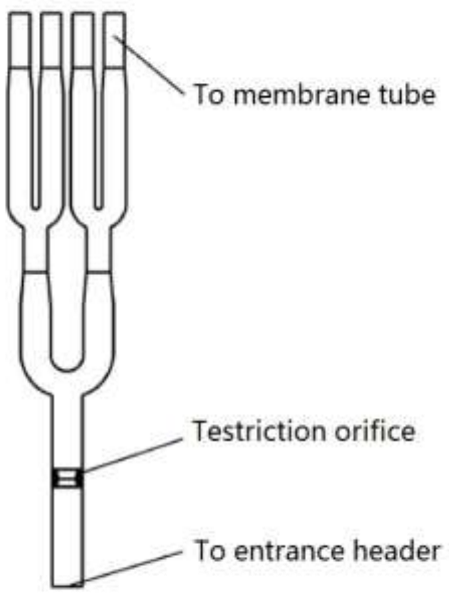

Fig.1 The schematic of restriction orifice location

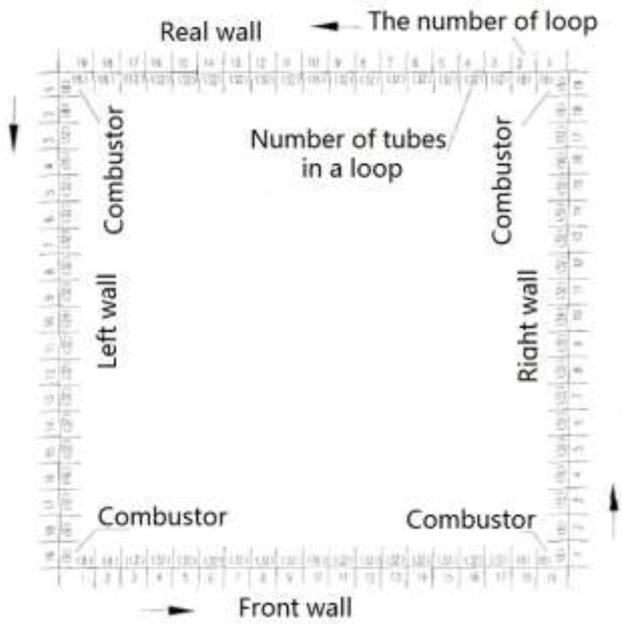

Fig.2 The schematic of loops in lower membrane water wall

Measured, temperature measurements are installed every 8 tubes. The low membrane water wall consists of numbers of loops, and the loop schematic is shown in Fig 2. The average temperature of tubes in a loop is calculated from temperature measurements in the same loop.

3. Results and discussion

3.1. Effect of coal A ratio

As illustrated in Fig 3, all the temperature distributions of the four walls display a bell-shaped appearance with a peak at the middle, which can be explained by heat load distribution in horizontal direction [4]. The coal powder need a certain time to be ignited after ejected into the furnace, then release heat at location near the number 13, 14 loop, which leads to a relative high heat load in this region. Consequently, large size of orifice is chosen in these loops to ensure sufficient mass flux of working fluid, which is illustrated in Fig 3. However, the temperature profile curves uncover a bad uniformity of temperature distribution in practice, especially for the front wall and the left wall.

In this study the coal A was co-fired with coal B, and the temperature distribution of low membrane water wall is affected by the coal A ratio, which can be indicated in Fig 3. When the boiler was operated with coal A ratio being 0%, the maximum temperature was 435℃ with deviation of 25℃ in the front wall, while the maximum temperature was 425℃ with deviation of 21℃ in the left wall. When the ratio of coal A increased to 50%, the maximum temperature descend to 414℃ with deviation of 14℃ in the front wall, while the maximum temperature descend to 419℃ with less change of deviation. In addition, the temperature level in the rear and right wall decline in a certain degree. When the boiler was operated at supercritical pressure, the thermophysical property of the working fluid is unstable, which may leads to hydraulic instability or deteriorates the profile of mass flux, these may even results in overheating or departure from nucleate boiling [5]. The district heat capacity near burner is higher than that of design when burning coal B exclusively, these would further aggravate the condition of membrane water wall.

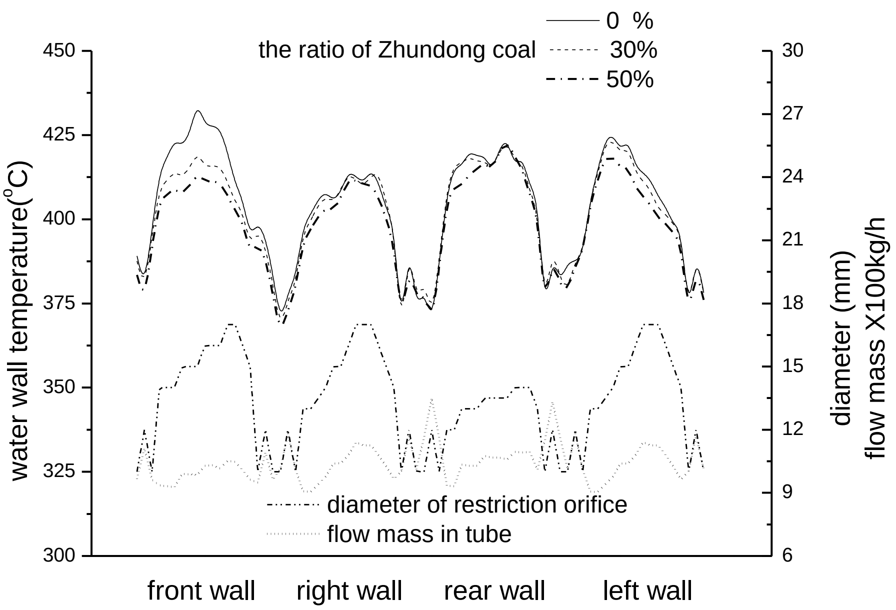

Fig.3 The temperature distribution of lower membrane water wall under tests with different ratio of Zhundong coal

3.2. Effect of unit load

When the boiler was operated at different load, the thermophysical property of the working fluid changes remarkably, as well as the flow field distribution in the furnace, those may leads to variation of temperature distribution of membrane water wall. Fig 4 shows the effect of unit load on the temperature of membrane water wall, with the boiler operating at 340 MW load, the working fluid is being at subcritical condition, leading to a homogeneous temperature distribution on the membrane water wall, especially for the right and left wall. As the unit load increase, the working fluid approaches supercritical condition, and the temperature distribution curve becomes similar to that of design.

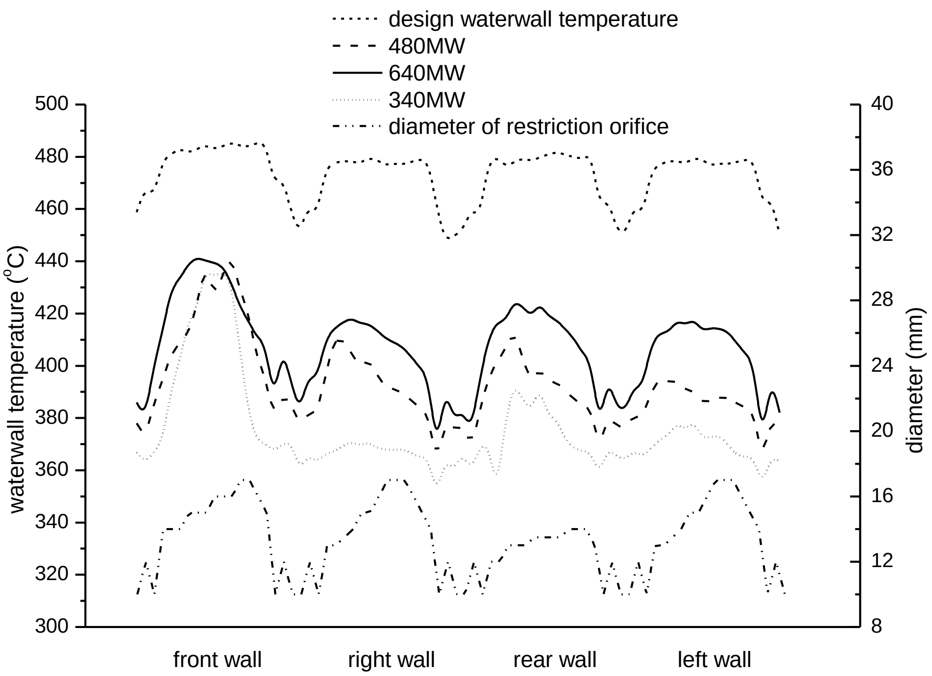

Fig.4 The temperature distribution of lower membrane water wall under different unit load

It worth mentioning that the maximum value of wall temperature increases with unit load, however, the uniformity improves notably. When the unit load increases from 480MW to 640MW, the maximum deviation of temperature reduce from 37℃ to 23℃ for front wall, 21℃ to 16℃ for right wall, 26℃ to 19℃ for rear wall.

The temperature decrease seems to benefit the safety of the membrane water wall at low unit load, nevertheless, regarding the temperature deviation, which is higher at low unit load, the threaten of membrane water wall restriction crack increase due to nonhomogeneous expansion. At present, more plant boilers of large capacity and high parameter have to undertake the mission of peak regulation as a result of oversupply in Chinese power market, this may lead to an increase of running time for the boilers operating at middle load, simultaneously, the unit load varies more frequently, so the augment of temperature deviation of membrane wall tubes should be paid more attentions.

Indicated from the temperature distribution of membrane water wall under 640MW unit load, the maximum temperature appears in number 7, 8 and 9 loop, while the restriction orifices of large size were installed in number 13, 14 and 15 loops, apparently, the restriction orifice do not achieve the mass flux regulation efficiently.

3.3. Effect of operation condition

Fig 5 reveals the temperature distribution of membrane water wall under different secondary air pressure. As can be seen in Fig 5, the overall temperature level decreases with increasing secondary air pressure, for the front wall, the maximum temperature present a decrease by 5℃, and the maximum deviation declines from 36℃ to 28℃, for the rest wall, the maximum value of both temperature and deviation present a certain decline. These can be explained as follow, the increase of secondary air pressure enhances the air momentum, then improves the fullness of flue gas in the furnace, which optimizes the temperature distribution.

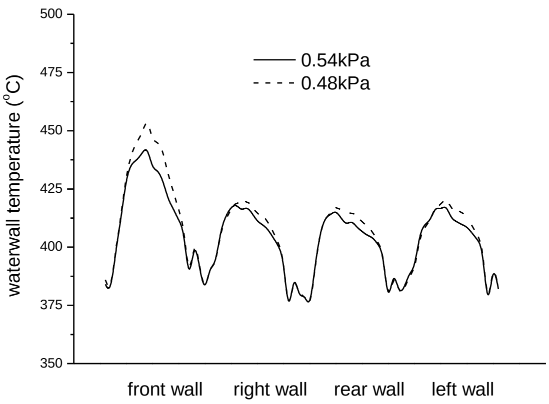

Fig.5 Influence of the secondary air on the temperature distribution of lower membrane water wall

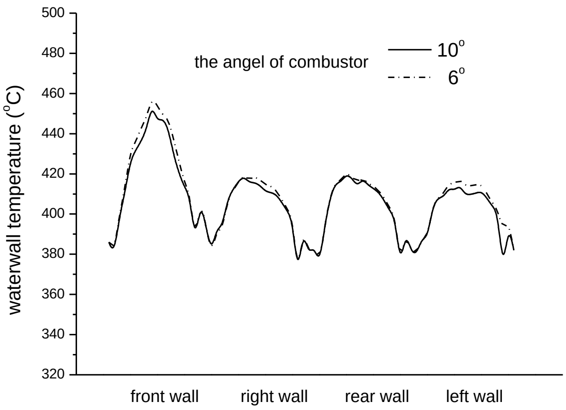

Fig.6 Influence of the combustor angle on the temperature distribution of lower membrane water wall

Fig 6 shows the effect of combustor angel on the temperature distribution of membrane water wall. In Fig 6, the overall temperature of the four wall rises with the combustor angel varies from 10^o to 6^o, this is because that the flame center of furnace ascends with increasing the combustor angel, which diminishes the district heat load of low membrane water wall. Similarly, the feed-coal quantity profile along vertical direction and the operation pattern of coal pulverizers may influence he temperature distribution of membrane water wall in the same way.

4. Conclusion

(1) When co-fired with common coal, the uniformity of temperature distribution of membrane wall tubes can be improved by increasing the ratio of Zhundong coal. The increase of district heat capacity usually lead to hydraulic instability or deteriorates the profile of mass flux, which may enlarge the membrane wall temperature deviation.

(2) When the boiler is operated at high unit load, the temperature distribution of membrane water wall is more similar to that of designed and the uniformity is better, by contrast, the temperature deviation increase at low unit load. The restriction orifices fail to regulate the flow mass as expect, especially for the restriction orifices in the front wall.

(3) The increase of secondary air pressure is beneficial to the temperature uniformity of membrane water wall. The increase of flame center of furnace, due to the adjustment of boiler operation conditions, can decline the district heat load of low membrane wall and temperature uniformity is improved.

References

[1] J. Xu, D. Yu, B. Fan, X. Zeng, W. Lv, J. Chen, Characterization of ash particles from co-combustion with Zhundong coal for understanding ash deposition behavior, Energy Fuels, 28 (2013) 678-684.

[2] L. Yan, X, Xia, S, Lv, et al. Great promotion of development of large scale integrative energy

base in Xinjiang [J]. Advanced Technology of Electrical Engineering and Energy,2011, 30(1): 1-7.

[3] S. Zhang, C. Chen, D. Shi, et al. Situation of combustion utilization of high sodium coal[J]. Proceedings of the CSEE, 2013, 33(5): 1-12.

[4] C. Jiang, M. Zhang, J. Xu, et al. Distribution characteristics of outlet temperature of working medium in lower waterwall of 600 MW ultra-supercritical boilers[J]. Journal of Power Engineering, 2009, 29(4): 335-341.

[5] G. Quan, W. Yan. Boiler Principle [M], Beijing: China Electric Power Press, 2004.