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Study on Heat Transfer Characteristics in 350MW Supercritical CFB Boiler

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ABSTRACT

Supercritical circulating fluidized bed boiler has the advantages of good environmental performance and high efficiency of units, which is suitable for large-scale promotion and has a bright commercial application prospect. It is the inevitable choice of clean coal power generation technology in our country at present. When the steam parameter of CFB boiler is raised from 300 MW sub-critical to 350 MW supercritical parameter, the characteristics of steam water in the heating surface tube screen and the gas-solid flow and combustion heat transfer characteristics in the furnace have great changes, and the overall structure and system layout of the boiler also have significant differences, which brings about changes in the heat transfer characteristics in the furnace. In this paper, the heat transfer coefficient of the working medium in the tube and the heat flux distribution in the furnace are obtained by measuring the temperature on the back fire side of the water wall. The results show that the furnace height increases from 6000W/ (m^2·℃) to 31000 W/ (m^2·℃). The heat flux in the furnace decreases with the increase of furnace height.

KEYWORDS

350MW Supercritical CFB Boiler; Temperature Measurement; Heat Transfer Coefficient; Heat Flux.

1. INTRODUCTION

Scholars from various countries have conducted in-depth and detailed studies on the heat transfer characteristics of circulating fluidized bed boilers with sub-critical and below parameters. However, compared with 300 MW sub-critical circulating fluidized bed boilers, the furnace height of 350 MW supercritical circulating fluidized bed boilers has increased from 38m to 55m. When the furnace height further rises, There are few reports on whether the material flow and heat transfer in supercritical CFB boiler are very different from those in subcritical CFB boiler, and the results of real furnace test are even rarer. The experimental study on heat transfer in the operation of supercritical circulating fluidized bed boiler is also a concern of many scholars [1-4].

In this paper, the heat transfer in 350MW supercritical circulating fluidized bed boiler is studied mainly by using the temperature distribution on the fire side of the cold wall, and the local heat flux absorbed by the water wall of the furnace from the furnace is analyzed. It provides theoretical support for the design and operation of supercritical CFB boiler.

2. EXPERIMENT AND CALCULATION METHOD

2.1. Wall Temperature Measurement Method

The temperature of the working medium in the water wall tube is obtained by installing thermocouples on the back fire side of the water wall tube, and measuring points are installed at 5 different heights of the furnace, as shown in Figure 1.

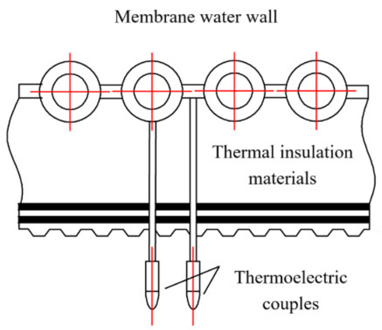

Fig 1. Schematic diagram of wall temperature measurement points

2.2. Calculation Method of Local Heat Flux in Furnace

2.2.1. Calculation of Heat Transfer Coefficient of Working Medium in Tube

Aiming at the convective heat transfer of working medium in the water wall of supercritical circulating fluidized bed boiler, due to the complexity of the heat transfer process, a large number of scholars at home and abroad have conducted a lot of research on the heat transfer coefficient of working medium under supercritical pressure by means of experiments. For the water wall tube size and boiler operation parameters involved in this paper, according to the error size of the heat transfer coefficient correlation formula and the selection range of parameters [1,2], the following heat transfer correlation formula can be used to calculate the convective heat transfer coefficient of the working fluid in the tube:

$$Nu = 0.0183 Re_b^{0.82} Pr_b^{0.5} \left(\rho_w / \rho_b\right)^{0.3} \left(\overline{c_p} / c_{p,b}\right)^n \quad (1)$$

2.2.2. Calculation of Local Heat Flux

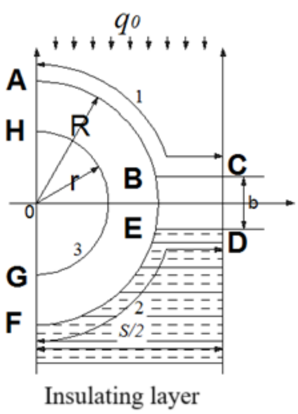

Fig 2. Calculation model of membrane water wall tube.

It is difficult to directly measure the heat flux in a 350MW supercritical circulating fluidized bed boiler without destroying the flow field near the furnace wall, and the method of measuring the temperature of the backfire side of the film water wall to measure the heat flux in the furnace has been applied [5,6]. The furnace temperature of the 350 MW supercritical circulating fluidized bed boiler is theoretically very uniform, and the heat transfer in the furnace is mainly based on the vertical heat flow absorbed by the membrane water wall tube from the boiler furnace, and the heat transfer between the two adjacent membrane water wall tubes can be ignored. Therefore, the heat transfer in the membrane water wall tube can be regarded as a two-dimensional steady state heat transfer problem, that is, the solution of the Laplacian equation of the membrane water wall tube under given boundary conditions under steady state. The calculation model and equation are shown in Figure 2 and formula (2).

$$\begin{cases} \dfrac{\partial^2 t}{\partial x^2}+\dfrac{\partial^2 t}{\partial y^2}=0 \\ \left.\dfrac{\partial t}{\partial n}\right|_{AC}=-\dfrac{q(x)}{\lambda} \\ \left.\dfrac{\partial t}{\partial n}\right|_{GH}=-\dfrac{h_v\left(t_{w,in}-t_b\right)}{\lambda} \\ \left.\dfrac{\partial t}{\partial n}\right|_{FD,GF,AH}=0 \end{cases} \tag{2}$$

The heat flux in the furnace is obtained by measuring the temperature difference between F point and D point, using the correlation between temperature difference, heat transfer coefficient and convective heat transfer coefficient in the tube. As shown in formula (3).

$$\Delta T_{FD}=a\cdot q_0\cdot h_v^b \tag{3}$$

3. RESULTS AND ANALYSIS

3.1. Distribution of Heat Transfer Coefficient in Water Wall Tube

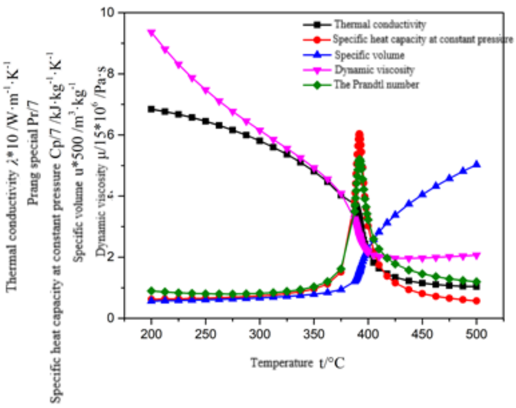

Fig 3. The changing trend for the physical property parameters of water in water wall tube with the temperature raising at 100% MCR boiler load.

Figure 3 shows the distribution of the average measured temperature, measurement error and convective heat transfer coefficient between the working medium and the inner wall of the tube along the furnace height under 100% MCR condition. The measurement temperature of the working medium is the measurement temperature of the water wall tube. As can be seen from FIG. 3, when the boiler is operating under 100% MCR condition and the distance from the air distribution plate is less than 30m, the temperature of the working medium in the water wall tube rises slowly, and the change speed of the physical parameters of the working medium is also slow. Therefore, the change speed of the convective heat transfer coefficient between the working medium and the inner wall of the water wall tube is also slow. However, when the height of the furnace rises to more than 30m, the convective heat transfer coefficient between the working medium in the water cooling wall and the inner wall of the tube changes dramatically, rising rapidly from 12000 $W \cdot m^{-2} \cdot °C^{-1}$ to 30000 $W \cdot m^{-2} \cdot °C^{-1}$. The main reason for this change is that the temperature of the working medium inside the water-cooled wall keeps rising with the increase of the furnace height. When the distance from the height of the air distribution plate is more than 30m, the temperature of the working medium inside the tube gradually enters the area of large specific heat capacity, and the physical parameters of the working medium change dramatically (as shown in Figure 4) [8], heat transfer in the working medium inside the tube is enhanced. The convective heat transfer coefficient between the working fluid and the inner wall of the tube is increased. In addition, it is worth noting that when the outlet steam temperature exceeds the pseudo-critical temperature (the corresponding pseudo-critical temperature under 100% MCR condition is 395.4°C, and the average outlet steam temperature of the water wall is 390.6°C), the heat transfer enhancement of the working fluid in the tube is also weakened due to the drastic decrease in the physical property parameters of the working fluid in the tube. The heat transfer coefficient between the working medium in the tube and the inner wall of the tube will decrease, and even the heat transfer will deteriorate in serious cases.

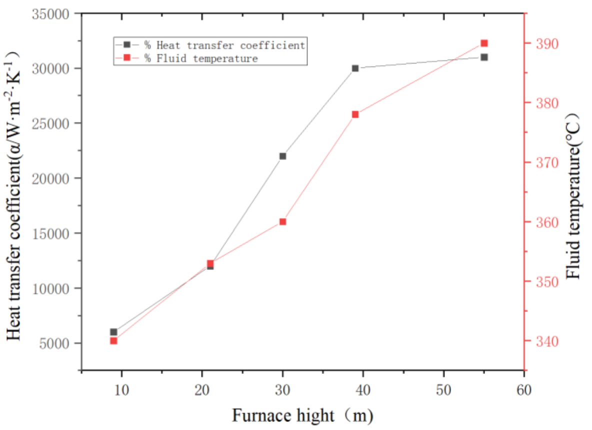

Fig 4. The heat transfer coefficient in the tube and the temperature of the working medium in the tube change with the furnace temperature.

3.2. Heat Flux Distribution in the Furnace

When calculating the heat flux inside the furnace, the measured temperature values of specific points F and D on the back fire side of the water wall in Figure 2 are used to calculate the heat flux inside the furnace toward the fire side by using the temperature difference between the two points and the convective heat transfer coefficient between the working medium in the tube and the inner wall of the water wall tube. Before calculating the heat flux in the furnace, the coefficient k(x) in the direction of the length of the water wall tube absorbing the heat flux on the fire side of the furnace should be calculated. As can be seen from the above, since k(x) is only related to the size of the membrane water-wall tube [7], the calculation results of heat flux k(x) along the length direction of the membrane water-wall tube used in the 350MW supercritical CFB boiler studied in this paper are shown in Figure 5.

For the film type water wall tube used in the 350 MW supercritical CFB boiler studied in this paper, the relationship between the heat flux (q_0) in the furnace corresponding to its size, the temperature difference at a specific point (ΔT_{FD}) and the convective heat transfer coefficient (h_v) can be shown in Figure 5. By combining the relations between q_0, ΔT_{FD} and h_v in Figure 5, formula (4) can be obtained:

$$q_0 = 620.4 \cdot \Delta T_{FD} \cdot h_v^{0.223} \quad (4)$$

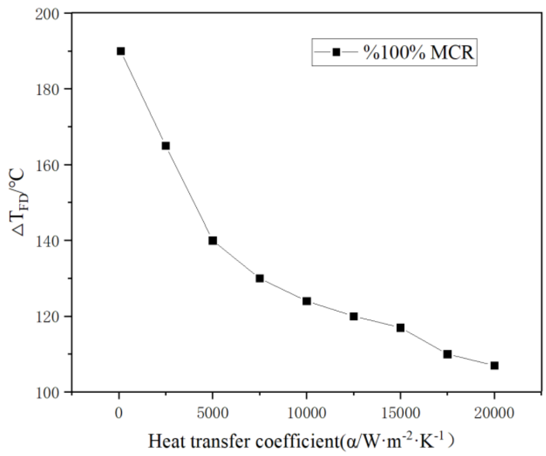

Fig 5. The relationship between the temperature difference of points F and D, heat-transfer coefficient and heat-flux.

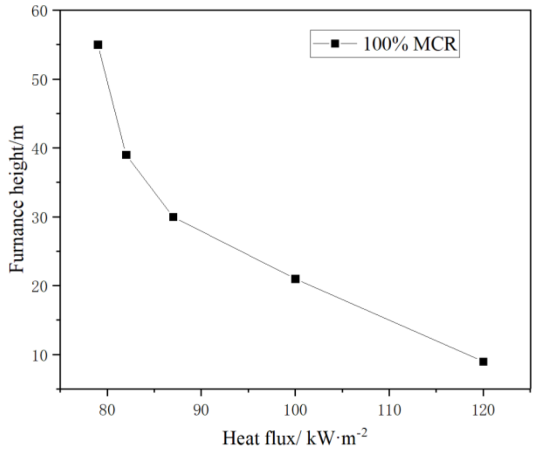

Fig 6. The average heat flux distribution along the furnace height of each measuring levels at different boiler loads.

Figure 6 shows the distribution of the average heat flux in the furnace along the furnace height at each measurement point. It can be seen that the heat flux in the furnace decreases with the decrease of the boiler height. In the dilute phase zone, the overall change trend of the heat flux in the furnace is small.

4. CONCLUSION

In this paper, the heat transfer characteristics of 350 MW supercritical circulating fluidized bed boiler in thin phase zone are studied in real furnace. Based on the measured temperature distribution results of specific points on the back fire side of the water wall, the heat flux distribution near the wall, the heat transfer coefficient of the working medium inside the water wall and the heat transfer coefficient between the furnace and the heating surface of the water wall in the area from 9m to 55m from the height of the air distribution plate were calculated, and the main conclusions were drawn as follows:

1) The heat transfer coefficient of the working medium in the tube is within the range of 6000 W·m^{-2}·°C^{-1} to 31000 W·m^{-2}·°C^{-1}, and the heat transfer coefficient is large enough and can effectively cool the water wall tube when the distance is less than 40m from the air distribution plate. When the distance from the air distribution plate is more than 30m, due to the drying of the working medium in the tube or exceeding the pseudo-critical temperature, the heat transfer coefficient in the tube will decrease, and there is a risk of overtemperature of the water cooling wall. However, the calculation

results show that the decrease of heat transfer coefficient does not affect the operation safety of the water wall pipe.

2) The heat transfer coefficient between the furnace and the water wall gradually decreases along the direction of the furnace height.

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