Calculation of working temperature of water wall of ultra-supercritical boiler

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Abstract. Ultra-supercritical coal-fired power generation technology is an advanced and efficient power generation technology. Due to the high parameters of the ultra-supercritical boiler, the heat transfer of the working substance in the water wall is complicated. Therefore, this paper takes an ultra-supercritical boiler as the research object and uses MATLAB to calculate the temperature of working substance inside the water cooling wall. The results show that when operating under low load there is a phase change zone in the working substance of the water cooling wall, the heat transfer is complex in this zone, and the temperature of the water cooling wall may rise to dangerous range. Therefore, it is necessary to pay attention to the fluctuation of temperature of working substance.

1. Introduction

China's economic aggregate is increasing year by year, the economy is developing rapidly, and the demand for electricity is correspondingly increasing year by year. China is trying to improve its energy structure, but thermal power is still the main source of electricity. By the end of 2018, the total installed capacity of thermal power in China accounts for 60.2% of the total installed capacity of full caliber power generation. With the demand for electricity increased, the environmental pollution problem it brings with has become a serious problem. Therefore, it is very important to develop clean and efficient coal-fired technology. Ultra supercritical coal-fired technology is an efficient coal-fired technology, and the safe operation of water wall of ultra-supercritical boiler is the key point of ultra-supercritical coal-fired technology. Therefore, many scholars choose these as their study topic. Qi Guangze [1] studied the hydrodynamic stability of water wall theoretically and experimentally, and analyzed the influence of pressure, flow rate and other factors on the hydrodynamic instability of water wall.

Zhang Zhizheng et al. [2] studied the on-line detecting method of the wall temperature of the water wall, and put forward an indirect measurement method. By detecting the temperature of characteristic point from the back fire side of the water wall, the temperature of the water wall can be calculated. K. zarrabi [3] puts forward a dimensionless variable, and points out that temperature is one of the important factors that affect the life of pipe wall, and the condition of pipe wall can be predicted by dimensionless quantity.

In this paper, the heat transfer model of the furnace is established, the average wall heat load is calculated [4], and then the pressure drop of the working fluid flowing in the water wall tube is calculated. The temperature distribution along the height of the furnace is calculated by the
combination of above two parameters.

2. Introduction of water wall parameters

The water wall calculated in this paper is membrane water wall. The water wall is composed of two parts, including the spiral coil arranged obliquely at the lower part and the vertical coil at the upper part. The upper and lower parts shall be separated at an elevation of 70m. Among them, the lower part of the spiral pipe ring is arranged at an angle of 26.21° with 716 smooth pipes. The pipe diameter is φ38.1 * 7.2mm and the pitch is 53mm. Operation parameters are shown in Table 1.

| Table 1 Working condition parameter |
|-------------------------------------|
| Project                            | Company | BMCR  | 75%BMCR | 50%BMCR |
| Fuel quantity                      | t/h     | 355   | 254     | 198     |
| Water supply                       | Kg/（m²*s） | 2275  | 1527    | 1139    |
| Inlet working substance pressure   | MPa     | 35    | 27      | 22      |
| Inlet working substance temperature| ℃       | 375   | 352     | 345     |

3. Mathematical model building

According to the thermodynamic calculation of the furnace, the average heat load of the furnace is calculated, and then the heat load distribution curve along the height of the furnace and the depth of the furnace is calculated according to the uneven coefficient of the heat load of the furnace. Then the working substance flow inside the water cooling wall is assumed to be one-dimensional flow, and the pressure drop of the water cooling tube with the height direction is calculated. Then the enthalpy increase of working substance is calculated according to the wall heat load and working substance parameters, and then the temperature distribution of working substance inside the water cooling wall along the height direction is calculated.

3.1 Mathematical model of furnace thermodynamic calculation

The basic basis of furnace calculation is energy conservation equation and radiation heat transfer equation. The mathematical model of radiation heat transfer in furnace is as follows:

\[ Q = \varphi B_{ou} (I_a - I_f^*) \]  \hspace{1cm} (1)

\( \varphi \) is the heat retention coefficient and is the modification of furnace heat dissipation;

\( B_{ou} \) is calculate fuel consumption;

\( I_a \)、\( I_f^* \) is the flue gas enthalpy at theoretical combustion temperature and flue gas enthalpy at furnace outlet temperature.

According to the basic formula of heat transfer, the mathematical model for calculating radiation heat transfer is as follows:

\[ Q_f = a_f \sigma_0 \varphi FT_{by}^4 \]  \hspace{1cm} (2)

\( a_f \) is the blackness of furnace;

\( \sigma_0 \) is the average effective thermal coefficient;

\( F \) is the total area of furnace wall;

\( T_{by} \) is the flame temperature.

3.2 Mathematical model of pressure drop calculation in tube

The flow pressure drop in the tube is mainly composed of four parts: gravity pressure drop, local resistance, acceleration loss and friction resistance. The pressure drop in the water wall tube is mainly concentrated in the gravity pressure drop and friction resistance [6]. Therefore, the calculation formula of pressure drop after acceleration loss and local resistance are ignored is as follows:
\[ \Delta p = \lambda \frac{\Delta x}{D \sin \alpha} \cdot \frac{\rho w^2}{2} + \rho g \Delta x \]  

(3)

\(D\) is the pipe inner diameter;  
\(\lambda\) is friction resistance coefficient;  
\(\alpha\) is the dip angle of water wall;  
\(\rho, w\) are density and velocity of working substance respectively.

3.3 Mathematical model for calculating the temperature of working substance in tube

When calculating the temperature of working substance in tube, the average water wall tube is divided into several small pieces, the inlet parameters of first section for the water wall is the supply parameters, through the heat load and the pressure drop of this the enthalpy increase of working substance can be calculated, thus the outlet parameters of this is available by calculation which are used as the inlet parameters of next. By analogy, the temperature distribution of the whole water wall working medium is calculated. The heat balance equation of each section is as follows:

\[ q_i d\Delta t = m [ h(p_{i+1}, t_{i+1}) - h(p_i, t_i)] \]  

(4)

\(q_i\) is the heat load received by the calculation section;  
\(d\Delta t\) is the length of each calculation section;  
\(m\) is the mass flow of water wall in this section;  
\(h(p_{i+1}, t_{i+1}), h(p_i, t_i)\) represents the enthalpy of working substance in the water wall tube in the i and i+1 sections respectively.

According to the above formula, the enthalpy increase of the i section can be calculated by the heat load of water wall. At the same time, the enthalpy of the working substance in the i+1 section is derived by taking the parameters of i section as known conditions. According to the pressure drop calculation, the temperature of substance in the i+1 section is calculated by calculating the working pressure of substance in the i+1 section.

4 Calculation results

First, the average wall heat load of the furnace is calculated according to the heat load calculation in the previous paper. Then, according to the furnace non-uniformity coefficient [7], the heat load distribution in the central area of the water wall along the height direction of the furnace is obtained. The distribution curve of wall heat load under three working conditions is obtained, as shown in Figure 1. It can be seen that along the height direction of the furnace, the wall heat load of the water wall increases first and then decreases. The relative height of the furnace corresponding to the combustion area of the furnace is the peak value of the wall heat load.

![Figure 1. Distribution of wall heat load along the height of furnace in the central area of water wall](image)

According to the calculated heat load on the wall, the enthalpy increase of the working fluid in the tube along the height direction of the water wall can be obtained. Combined with the mathematical model of the pressure drop in the tube, the temperature distribution of the working fluid in the tube along the height direction of the furnace can be obtained. As shown in Figure 2. It can be seen from the image that under the BMCR condition, because the inlet state is just above the critical point of
water, there is no phase change in the tube and the temperature of the working substance rises uniformly. Under the condition of 75% BMCR and 50% BMCR, there is a subcritical state of the working fluid in the tube. With the increase of the working fluid temperature, there is a phase change zone, and the heat transfer situation is complex, which may be dangerous.

![BMCR](image1)

![75%BMCR](image2)

![50%BMCR](image3)

Figure 2. Distribution of working substance temperature in water wall tube along furnace height

5. Conclusions
In this paper, the matlab program is used to calculate the heat load distribution in the furnace according to the furnace nonuniformity coefficient, and the distribution of working substance temperature in the water wall tube is obtained by combining with the mathematical model of pressure drop in the tube. The results show that under BMCR condition the temperature of the working fluid rises uniformly and there is no phase transition zone. Under low load condition, there is a phase transition region in the working substance, and the temperature of the working substance does not change obviously with the increase of enthalpy of the working substance. The heat transfer in the phase transformation region is complex, so the corresponding water wall region may be in danger of wall temperature rising. It is necessary to pay attention to the change of wall temperature in the phase transformation area to prevent the occurrence of tube explosion.

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