Study on thermal load test of water wall of 350MW supercritical circulating fluidized bed boiler

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Abstract. The thermal load distribution of water wall is the key parameter for the structural design of water walls in supercritical and ultra-supercritical circulating fluidized bed boiler (CFB). In this paper, the temperature distribution of the water wall of a 350MW supercritical CFB boiler under typical working conditions was measured by installing 118 temperature measuring points at the back-fire water wall tube and adjacent fins. The deviation in the heat load of water wall as a function of furnace height, width and depth was obtained as well. The experimental results show that temperature of the working medium in water-wall tube increases with increasing furnace height. The thermal deviation of the steam temperature in water wall tube in the direction of furnace width and depth is large at the initial boiler start-up period, the transition period from dry to wet state, and the low load condition. Despite these, the heat load distribution of water wall at the same furnace height remains the same. The results provide a reference for the structural design and operation optimization of supercritical and ultra-supercritical CFB boiler.

1. Introduction
Circulating fluidized bed boiler (CFB) is developing towards higher parameters and larger capacities in order to improve its economy and reliability. The furnace size of the CFB boiler is inevitably increased as a result. In this case, the combustion characteristics and heat flux distribution within the furnace will be no longer the same to the subcritical CFB boilers, affecting both the design and operation of subcritical CFB boiler [1-5]. Figure 1 shows the constant pressure specific heat of water as a function of pressure. For supercritical unit-through boilers at over critical mass pressure 22.2 MPa and temperature around 375℃ point, the constant pressure specific heat of water $c_p$ can reach a maximum. At this region, namely the large specific heat region, the maximum specific heat is much larger than that in other regions [6]. The large hot zone generally occurs in the water wall heating surface, at which the specific heat, specific volume, thermal conductivity and dynamic viscosity of the working fluid vary sharply. While the volume changes, the local tube resistance would be increased, decreasing the mass flow within the tube and the heat release coefficient $\alpha$ as well [7-11]. It is therefore essential to comprehend the thermal load of water wall in supercritical and ultra-supercritical CFB boilers.

In order to obtain the heat load distribution of the water wall of the supercritical circulating fluidized bed boiler, the test was creatively established on a 350MW supercritical circulating fluidized bed boiler. The temperature distribution of the water wall under typical working conditions was measured by installing a number of temperature measuring points at the back-fire water wall tube and...
adjacent fins. It is expected that the results would provide a reference for the structural design and operation optimization of supercritical and ultra-supercritical CFB boiler.

2. Test methods

2.1. Introduction to test boiler
The test object selected for this paper is a 350MW supercritical parameter circulating fluidized bed boiler (CFB), primary intermediate reheat, total steel suspension, balanced draft, M type arrangement, the front wall of the boiler have 8 coal feeding point, the back wall have 7 slag outlets point, and equipped 4 under-bed starting burners.

This test boiler using the secondary rising hydrodynamic system, the relatively high mass velocity is adopted to ensure the reliability of low load hydrodynamic force, and the outlet temperature of water wall changes little with enthalpy, and the temperature of water cooling screen rises low. The water circulation adopts the secondary rising structure; the water wall outlet tube integrates two falling tubes to introduce the water cooling screen, and the water cooling screen leads into two steam water separators.

2.2. Site layout
Figures 2 and 3 illustrate the location of the test point in the water wall and the layout of water wall measuring points along furnace height. A total of 118 measuring points at both front, rear and side water walls in six layers at furnace height were arranged according to the actual structure size and layout of the boiler. One K-type thermocouple was installed at the top of the backfire side of water wall, and a fin temperature measuring point is set at the middle point of the fin.

Figure 1. The constant pressure specific heat of water.

Figure 2. The location of the test point in the boiler water wall.

Figure 3. Layout of water wall measuring points along furnace height.
2.3. Installation of measuring points and data acquisition

Figures 4 to 6 present the thermocouple installation site and the field data acquisition system. As the test boiler adopts a tight closed form, all the measuring elements are therefore in very stable environmental conditions, despite the test was carried out in cold winter. The test results were therefore independent of environmental temperature, wind speed and other factors.

The data collector is set to automatic and saves one data each 1 minute continually for 24 hours per day without interruption. The total duration of the test is 26 days. An average value of the collected data as well as DCS data under each working condition was analyzed.

![Figure 4. Thermocouple site installation.](image1)

![Figure 5. Compensating wire collection box.](image2)

![Figure 6. Field measurement data collector.](image3)

2.4. Operating conditions

Table 1 lists the working conditions as tested. A total of five conditions, i.e., 100% BMCR, 75%BMCR, 50%BMCR, 30%BMCR and wet to dry condition were considered.

![Table 1. working conditions.](image4)
3. Results and discussion

3.1. Every layers temperature distribution discussion

Figures 7 to 11 give the obtained temperature of water wall at five boiler loads as abovementioned. It can be seen that except the wet to dry condition, the water wall temperature is lower in the L1 layer of the boiler; the water wall temperature in the L2 to L6 layers is increasing gradually, and the temperature is evenly distributed. In addition, the tube temperature of the front wall and the right wall of the boiler is higher in the area near the side angle of the furnace, and the tube temperature of the front wall near the center of the furnace appears the lowest point. The tube temperature of the right wall is not only higher in the area near the side corner, but also higher in the center of the furnace. The back water wall tube temperature fluctuation stably than the front and right water wall, this is mainly because the external recycling materials back to the furnace from the back of the boiler, and the temperature of the back wall is relatively high at 1/4 curve position and 1/2 curve position and 4/5 curve position, the relative low temperature appear at 1/3 curve position and 2/3 curve position.

For the temperature deviation at 100% working load, the temperature difference between the water wall is relatively large between L1 and L2 layers, reaching a maximum 26°C in L1. However, the temperature deviation of water wall at layers L3-L6 is relatively small. Moreover, as the boiler load decreases, the temperature difference of water wall decreases gradually as shown in Figures 7-11.

Figure 7. 100% BMCR water wall temperature distribution.

Figure 8. 75% BMCR water wall temperature distribution.

Figure 9. 50% BMCR water wall temperature distribution.

Figure 10. 30% BMCR temperature distribution of water wall.
3.2. Every layers average temperature distribution discussion

Tables 2 and 3 show the average temperature at measuring points of each layers under different loads, and the temperature differences between measuring points of each layers. Figure 12 is a schematic diagram of the average temperature distribution of water walls under different loads. In Table 2 and 3, 1-2 represents the temperature difference between L2 and L1 layers. As can be seen from the above table, with the increase of load, the temperature deviation between different layers is increasing, and the main growth area is L1 and L2 layers, 30%BMCR increases by 2.5°C, 50%BMCR increases by 9.6°C, 75%BMCR and 100%BMCR increase by 16.3°C and 19.1°C respectively. The average temperature between the layers in the upper part of the water wall change little. Except that the temperature deviation between L3 layer and L2 layer reached 6.4°C in 100%BMCR condition, the temperature deviation was within 4°C in other conditions at different layers.

Table 2. Average temperature of measuring points at different loads.

| measuring layers average temperature (°C) | 100%BMCR | 75%BMCR | 50%BMCR | 30%BMCR | wet to dry state |
|-------------------------------------------|-----------|----------|----------|----------|-----------------|
| 1                                          | 363.2     | 358.9    | 359.7    | 336      | 337             |
| 2                                          | 382.3     | 375.2    | 369.3    | 338.5    | 338.3           |
| 3                                          | 388.7     | 378.6    | 372.9    | 339.5    | 338.6           |
| 4                                          | 390.2     | 380.5    | 373.7    | 340.6    | 339.8           |
| 5                                          | 392.8     | 383.5    | 375.5    | 341.3    | 341             |
| 6                                          | 395.7     | 386.5    | 377.8    | 343.1    | 342             |
| DCS                                        | 403.5     | 395.7    | 396.8    | 352.1    | 355             |

Table 3. Average temperature difference between upper and lower layers at different loads.

| measuring layers average temperature | 100%BMCR | 75%BMCR | 50%BMCR | 30%BMCR | wet to dry state |
|--------------------------------------|-----------|----------|----------|----------|-----------------|
| 1                                    | 19.1      | 16.3     | 9.6      | 2.5      | 1.3             |
| 2                                    | 6.4       | 3.4      | 3.6      | 1        | 0.3             |
| 3                                    | 1.5       | 1.9      | 0.8      | 1.1      | 1.2             |
| 4                                    | 2.6       | 3        | 1.8      | 0.7      | 1.2             |
| 5                                    | 2.9       | 3        | 2.3      | 1.8      | 1               |
| 6                                    | 7.8       | 9.2      | 19       | 9        | 13              |
| DCS                                  | 19.1      | 16.3     | 9.6      | 2.5      | 1.3             |
It can be seen from Table 2 and Table 3 that the water wall temperature in L1 and L2 layers arranged at 27.3m and 34.6m away from zero meters increased the most. The temperature deviation between 50%BMCR-75%BMCR and 75%BMCR-100%BMCR at the measuring point of L1 layer was 0.8°C and 4.3°C respectively, while the temperature deviation in corresponding conditions in L2 layer reached 5.9°C and 7.1°C respectively. At the same time, the two layers are also the biggest area of temperature deviation between each tube, and that increase the thermal difference between each tube and the multivalued property of hydrodynamic force, the situation is easy to make the tube flow changes with the time and the load, and lead the tube temperature volatility near the area, and finally case the tube fatigue, burst, and so on.

4. Conclusions

According to the experimental test results and the DCS picture data, the wall temperature can reach 410°C when the boiler is normally operating in the 100%BMCR condition, and the tube materials of the boiler is 15GrMoG, the fins material is 15GrMo, its limited temperature is 550°C much higher than that of water wall tube temperature, so when the boiler is normally operating, the water wall tube is safe; However, from the above analysis, it can be seen that the heat deviation of the water wall tubes between L1 layer and L2 layer is lager, and the heat transfer coefficient of the water wall is easy to be small in this area. Therefore, more attention should be paid to the change of tube temperature in this area during the operation of the boiler.

The boiler wall metal temperature can directly reflect the heating surface tube actual working conditions, and also easy to be directly measured, collected important parameters, and often compared with the limited material temperature of the tube to determine whether the heating surface overtemperature, and used to analyze the local heat transfer deterioration, heat load distribution, and so on. In this test, the temperature measuring points of 6 layers on water wall tube and fin on the back fire side were arranged at different heights of the furnace, and the distribution of the water wall temperature under different conditions are found, through comparison and analysis, the following conclusions are obtained:

(1) The water wall temperature of the boiler gradually increases along the height of the furnace, and the water wall temperature in the region of 27.3m and 34.6m away from zero meters increase the largest, and the increase amplitude increases with the increase of loads;

(2) In the area of 27.3m and 34.6m away from the water wall of the boiler, the working condition of the water wall tube is the worst, with large thermal deviation between tubes and have the lower heat transfer coefficient of working medium inside the tube, which is easy to cause the temperature of the tube overtemperature and cause tube explosion; Since the water wall temperature is sensitive to the boiler operation and can reflect the actual heat load distribution in the furnace, so the water wall temperature of the tube should be monitored in real time, especially in the high specific heat area of the water wall.

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