Research on heat absorption characteristics of high temperature heating surfaces of supercritical CFB boilers

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Abstract. Based on the field test and calculation, heat absorption characteristics and steam temperature deviation profile of high temperature heating surface of supercritical circulating fluidized bed (CFB) boilers with different heating surface arrangement were studied. The results indicate that heat absorption shares of the two supercritical CFB boilers are almost the same in different water stage, and heat absorption share of EHE is about 17.6% in the boiler arranged with EHE. There exits steam temperature deviation at the same tube panel of high temperature superheaters and high temperature reheaters inside the furnace, and deviation among high temperature reheater tube panel is larger. Rational control of enthalpy increment of high temperature tube panels inside the furnace has effect on reduction of steam temperature deviation.

1. Introduction

Circulating fluidized bed (CFB) technology has many advantages, such as wide fuel adaptability, low cost control on pollutants and so on, and it is recognized as one of the most clean coal power generation technologies [1]. At present a batch of 350MW and above supercritical CFB units have been put into production one after another. When steam parameter of CFB boilers span from subcritical to supercritical pressure, endothermic characteristics at steam-side have changed significantly. To maintain the reasonable temperature inside the furnace, arrangement and endothermic characteristics of heating surfaces in CFB boilers, especially for high temperature heating surfaces are particularly important [2-4]. Generally, high temperature heating surfaces are arranged inside the furnace or external heat exchanger (EHE) for supercritical CFB boilers [5-9].

In the literature [10-12], reseaches on endothermic characteristics of heating surfaces for supercritical CFB boilers were conducted. In the literature [13-17], study on factors influencing heat transfer in CFB boilers were also conducted in large scale CFB boilers. However, comparative study on heat absorption characteristics and steam temperature deviation of high temperature heating surfaces in 350 MW and above supercritical CFB boilers with EHE or not were so far not studied.

Consequently, in the present work steam-side thermal parameters at the inlets and outlets of heating surfaces such as steam flow rate, steam pressure, steam temperature were measured, as well as the outlet steam temperature profile of a high temperature reheater (HTR) and a high temperature superheater (HTS), then heat absorption share and steam temperature deviation profile of high
temperature heating surfaces could be obtained in 350MW and above supercritical CFB boilers. It provides reference for the design and operation of ultra-supercritical CFB boiler.

2. Experiment

2.1. Heating surfaces arrangement
Schematic diagram of the overall layout of supercritical CFB boilers arranging different heating surfaces is shown in Figure 1. Boiler A is a 600MW CFB boiler with EHE, and HTS is arranged inside the furnace, and HTR is arranged in EHE. Boiler B is a 350 MW CFB boiler without EHE, and HTS and HTR are both arranged inside the furnace.

![Diagram of Boiler A and Boiler B](image)

**Figure 1.** Schematic diagram of the overall layout of supercritical CFB boilers arranging different heating surfaces.

2.2. Experiment methodology
Based on original thermal measuring points installed on the boilers, two supercritical CFB boilers with different heating surfaces were tested to study the endothermic characteristics of high temperature heating surfaces. During the tests, all of gauge pressures and temperatures of steam at the inlets and outlets of heating surface were obtained from the Distributed Control System (DCS) database in the controlling center of the units. Superheated steam flow of each superheater can be measured and calculated by flow meters of feed water and de-superheating water of the boiler. Steam flow rate of each reheater was calculated by the main steam flow rate and total steam extraction flow of high pressure cylinder [18]. Heat absorptions of the heating surface are products of the corresponding steam mass flow rates and enthalpy increments from inlets to outlets. Heat absorption share of each heating surface is the ratio of the heat absorption of each heating surface to the total heat absorption of the boiler.

To study the details of HTS steam temperature deviation, forty shielded K type thermocouples (measuring range of -40 to 1150°C, precision accuracy of ±0.4%) were installed at the outlet walls of the HTS tube panels of Boiler B. Forty four shielded K type thermocouples were also installed at the outlet walls of the HTR tube panels of Boiler B to study the HTR steam temperature deviation. During the tests, since additional measuring ports were covered by heat-insulating materials, heat dissipation from the measuring ports was fairly unimportant. As a result, the measured wall temperatures can be considered as outlet steam temperatures of the corresponding tube panels.
During the test, steam-side parameters were conducted at full boiler load for two CFB boilers. HTS and HTR steam temperature deviation measurements were conducted at part boiler load. Table 1 gives proximate and ultimate analyses of burning coals.

Table 1. Coal characteristics of two boilers.

|                      | Boiler A |       | Boiler B |       |
|----------------------|----------|-------|----------|-------|
|                      | Proximate analysis | Ultimate analysis | Proximate analysis | Ultimate analysis |
|                      | M_{ad}  | C_{ar} | 47.87    | M_{ad}  | C_{ar} | 49.28    |
|                      | A_{ar}  | H_{ar} | 38.99    | A_{ar}  | H_{ar} | 36.52    |
|                      | V_{daf} | N_{ar} | 7.34     | V_{daf} | N_{ar} | 2.35     |
|                      | O_{ar}  | Q_{ar,net} | 0.57   | O_{ar}  | Q_{ar,net} | 0.73   |
|                      | Q_{ar,net} | S_{ar} | 17.58    | Q_{ar,net} | S_{ar} | 15.14    |

Notes: weight unit wt.%; Q_{ar,net} unit MJ/kg

3. Results and discussion

3.1. Heat absorption of high temperature heating surfaces

Figure 2 gives heat absorption share of different heating surfaces in different water stage at full boiler load. It can be seen that heat absorption shares of the two supercritical CFB boilers are almost the same. Heat absorption share of the superheaters in two boiler are about 30%, and heat absorption shares of the reheaters are about 19%.

Figure 3 shows heat absorption share of different boiler components at full boiler load. It can be seen that for two supercritical boilers heat absorption share in back pass are basically the same, which is about 36%. Heat absorption share of EHE is about 17.6% in the boiler arranged with EHE.

3.2. Steam temperature profile

Figure 4 gives outlet steam temperature profile of a HTS tube panel inside the furnace of Boiler B at part boiler loads. It is shown that as the boiler load increased, steam temperature profiles were similar, and the tubes on both sides of tube panel had lower steam temperatures.

Figure 5 shows outlet steam temperature profile of a HTR tube panel inside the furnace of Boiler B at part boiler loads. It can be seen that as the boiler load increased, steam temperature profiles were also similar, and the tubes on both sides of tube panel had lower steam temperatures. The tubes of
HTR tube panel which number is between 33 and 46 had higher steam temperatures due to high heat intensity for the tubes in the middle of the furnace.

There exits steam temperature deviation at the same tube panel of HTS and HTR inside the furnace. Although the characteristics of steam temperature distribution at the same tube panel of HTS and HTR inside the furnace are similar, but max steam temperature deviation at different boiler load decrease with the boiler load increases, shown in figure 6. It is shown that steam temperature deviation of HTR is greater than that of HTS, so more attention should be paid to the design of HTR to reduce the deviation. Max steam temperature deviation is 45°C in the measured HTS tube panel, while that is 67°C in the measured HTR tube panel at boiler load 175MW. It indicates that design optimization is needed to reduce steam temperature deviation of tube panel inside the furnace. An optimization method is shown in Figure 7, which had been applied in a 350MW CFB boiler. Steam temperature deviations at the same tube panel could be controlled between 15°C and 20°C at the best condition by controlling of enthalpy increment of high temperature heating surfaces in that boiler.

Figure 4. Outlet steam temperature profile of the a HTS tube panel inside the furnace of Boiler B at part boiler loads.

Figure 5. Outlet steam temperature profile of the a HTR tube panel inside the furnace of Boiler B at part boiler loads.

Figure 6. Max steam temperature deviation of HTS and HTR tube panel of Boiler B at different boiler load.

Figure 7. An optimization method to reduce the steam temperature deviation of HTS and HTR tube panel.
4. Conclusions
Heat absorption characteristics and steam temperature deviation profile of high temperature heating surface of supercritical CFB boilers were experimentally studied in the paper. The main findings of this paper include:

When inlet and outlet parameters of working fluid are close, heat absorption shares are almost the same in different stage of water. Heat absorption share in back pass of both two supercritical CFB boilers are basically the same, which is about 36% under full load. Heat absorption share of EHE is about 17.6% in the boiler arranged with EHE.

There exits steam temperature deviation at the same HTS and HTR tube panel inside the furnace of a 350MW CFB boiler. Max steam temperature deviation of HTS and HTR tube panel both decrease with boiler load increases. Max steam temperature deviation is 45°C in the measured HTS tube panel, while that is 67°C in the measured HTR tube panel at boiler load 175MW.

when steam parameter of CFB boiler achieve ultra-supercritical pressure, steam temperature deviation should be controlled at a lower level, so design of high temperature tube panels inside the furnace must be optimized to meet the requirements.

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