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Research on Heat Transfer Inside the Furnace of Large Scale CFB Boilers

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RESEARCH ON HEAT TRANSFER INSIDE THE FURNACE OF LARGE SCALE CFB BOILERS

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ABSTRACT

Field tests in one unit of 135MWe and two units of 300MWe commercial Circulating Fluidized bed (CFB) boilers (A&B) with different structures were carried out. The influence of operating conditions on the thermal boundary layer, local heat transfer coefficient and peripheral distribution of heat transfer coefficient were studied. It was found that, in the 135MWe and 300MWe-A CFB furnace, the thickness of the thermal boundary layer was almost constant, about 100mm, and independent of the height above the distributor and the boiler load. The local heat transfer coefficient increased with increasing load as well as the coal feeding rate and air volume in both the 135MWe and 300MWe-A CFB boilers.

The boiler structure and heating surface layout had a great influence on the distribution of the heat transfer coefficient in the large-scale CFB boilers. In both the 135MWe furnace and the 300MWe-B CFB boilers, the heat transfer coefficient was lower in the center than near the corner due to higher suspension density in the corner. In the 300MWe-B CFB with heating surfaces in the furnace, because of the uneven layout of the heating surface and the mal-distribution of gas-solid flow caused by the asymmetric arrangement of cyclones, heat transfer coefficients tended to be higher in the middle part than at the walls.

INTRODUCTION

The distribution of the heat flux and the heat transfer coefficient inside a circulating fluidized bed (CFB) boiler, which is related to the arrangement of heating surfaces, is of great significance to the design and operation of the boiler. Many studies on heat transfer in CFB boilers have been conducted (Glicksman (1); Wirth (2); Andersson and Leckner (3); Basu and Nag (4)) and the results showed that the heating transfer coefficient from bed to heating surface was affected by the solids suspension density, particle size and bed temperature. Pagliuso, et al. (5) found that the profile of the heat transfer coefficient along the riser correlated well with that of the solid suspension density. They also found that the heat transfer coefficient increased with the increasing particle size, which became more obvious for smaller particles and higher suspension density. Breitholtz and Leckner (6) presented a correlation between heat transfer coefficient and suspension density based on measurements in six CFB boilers ranging from 12 to 300 MW_{th}. In addition, with increasing bed temperature, T_b, thermal conductivity and radiation heat transfer of the gas increased accordingly, which lead to an increase of the heat transfer coefficient. This was confirmed by the test of Jestin, et al. (7) in a 125MWe CFB boiler and the experiment of Jeon, et al. (8).

Many studies on gas-solid flow and heat transfer in CFB boilers were carried out in laboratory scale CFB combustors, which differ from industrial ones because of smaller height to diameter ratios. Zhang, et al. (9) and Noymer, et al. (10) found the height to diameter ratio of a riser has a significant impact on the gas-solid flow inside the furnace. Besides, considering the difference in temperature, particle size distribution and suspension density between laboratory scale CFB combustors and industrial ones, previous test results may not totally represent those found in industrial CFB boilers. At the same time, the heat transfer coefficient is also affected by boiler load, which was proven by Zhang et al. (11).

Therefore, it is necessary to measure the distribution of the heat transfer coefficient inside an industrial CFB boiler for proper design and arrangement of heating surfaces. In recent years, large-scale CFB boilers have been developed, however, only a few test results on heat transfer in large-scale CFB boilers have been published. To compare and analyze heat transfer characteristics in different large-scale CFB boilers, field tests in one unit of 135MWe CFB boiler and two units of 300MWe CFB boilers with different structures were conducted. The influence of boiler load on the local heat transfer coefficient and thermal boundary layer distribution were studied in this work.

EXPERIMENTAL

The tests were carried out in a 135MWe CFB boiler and two 300MWe CFB boilers, which are all reheat, natural circulation boilers. The 135MWe CFB boiler has single furnace with height of 38m from distributor to the roof and with a cross section of 6.6m×13.1m. Two refractory-lined cyclones were used as the gas solid separators. Lean coal was burnt during the experimental test. Two 300MWe CFB boilers, referred to as A and B respectively, have different furnace structures. Boiler A has a pants leg furnace structure with height of 36m and a cross section of 14.8m×12.6m. Four cyclones are arranged on both sides of the furnace. A higher bed temperature (890℃) was adopted for coal with a low volatile content to improve combustion efficiency. The boiler was operated with a high solids circulation rate. Boiler B has a single furnace with height of 40m from the distributor to the roof, and a cross section of 8.4m×28.2m. There were two water cooled wing walls hung in the furnace. Three steam-cooled cyclones are used as gas solid separators.

Local heat transfer coefficient (a), heat flux (b), the peripheral distribution of the heat transfer coefficient (c), the temperature profile near the wall (d) and the vertical distribution of the solid suspension density along the furnace height at different loads (e) were measured respectively.

The local heat transfer coefficient, K, was measured by a water-cooled conductive heat flux meter designed by Tsinghua University, shown in Fig.1. According to the heat conduction law, the local heat transfer coefficient can be calculated from the axial temperature gradient inside the probe-defined as heat flux method (HFM).

The heat flux, q, was calculated based on the temperature difference measured with thermocouples installed in the fin-tube (shown in Fig.2) with a two-dimensional finite element calculation method (FEM), which has been investigated by many researchers (Andersson and Leckner (12); Zhang, et al. (13); Wang, et al. (14); Zhang et al. (15)). The heat flux profile was obtained by arranging a number of measuring points peripherally at different heights along the furnace. The relationship between the heat transfer coefficient and the heat flux can be expressed as:

$$q=K\triangle T$$

The temperature difference, $\triangle T$, was determined by the difference between the furnace temperature and the stream temperature at each point. The former can be gained from the temperature distribution at certain boiler height. The stream temperature inside the tube is the saturated water temperature under drum pressure. So, the heat transfer coefficient can be derived from equation above by knowing the heat flux q and the temperature difference $\triangle T$.

The temperature profile near the wall was measured with a multi-thermocouple probe, shown in Fig. 3. Pressure sensors were placed at different level to monitor the vertical profile of the suspension density along the furnace height.

Measurements (a)~(e) were all conducted in the 135MWe CFB boiler while measurements (a), (d), (e) were performed in the 300MWe-A CFB boiler and measurements (b), (c), (e) performed in the 300MWe-B CFB boiler.

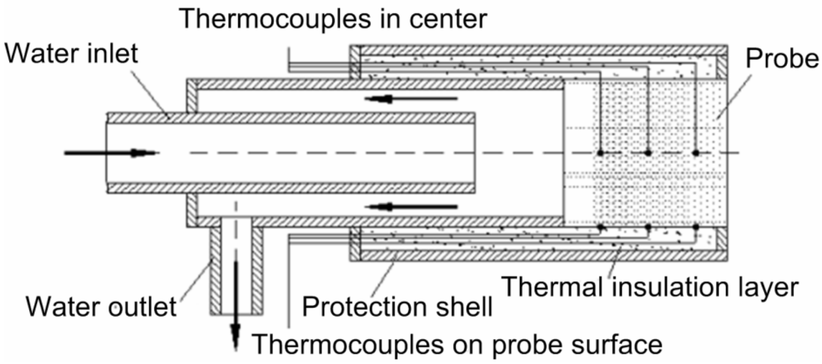


Figure 1. Heat flux meter

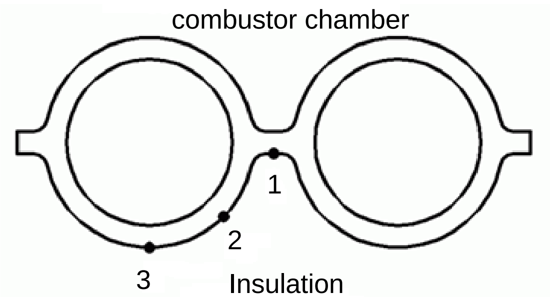


Figure 2. Thermal couple distribution on tube surface

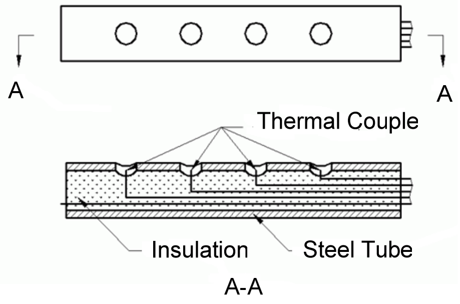


Figure 3. Temperature measurement probe

RESULT AND DISCUSSION

Thermal boundary layer

Fig.4 shows the temperature profiles near the wall in the 135MWe CFB boiler at full load. Measurement points were located at three different heights. Fig.5 shows temperature profiles near the wall in the 300MWe-A CFB boiler at full load. Measurement points 1-4 were symmetrically located 3m below the cyclones, with 1 and 2 on the rear wall and 3 and 4 on the front wall. Point 5 was located 3m above the distributor, where the bed temperatures were lower than those measured at 1-4. The temperature profiles remained similar at different boiler loads. It was found that furnace temperatures increased significantly in the region near the wall, about

100mm, and then become almost constant, at a temperature considered to be the furnace core temperature. The thickness of the thermal boundary layer was defined as the distance to the tube wall where the temperature was 90% of the core temperature. Figs.4 and 5 show that the thicknesses of the thermal boundary layers measured in both boilers were about 100mm and were independent of the boiler load and furnace height. This was consistent with the study of Wang et al. (16).

Local heat transfer coefficient

Fig.6 shows the measured local heat transfer coefficient in the 135 MWe CFB boiler. Heat transfer coefficients increase with increasing load and decrease with increasing height, which agrees well with previous work (Zhang, et al. (11)). When the boiler load increases, the coal feeding rate, gas velocity and air volume increase correspondingly, resulting in a higher particle velocity that results in more particles participating in contacting the water wall per unit area. As a result, the heat transfer coefficient increases. The solid suspension density gradually decreases in the furnace from the distributor to the roof. Therefore, the heat transfer coefficients decrease with the height for a constant boiler load.

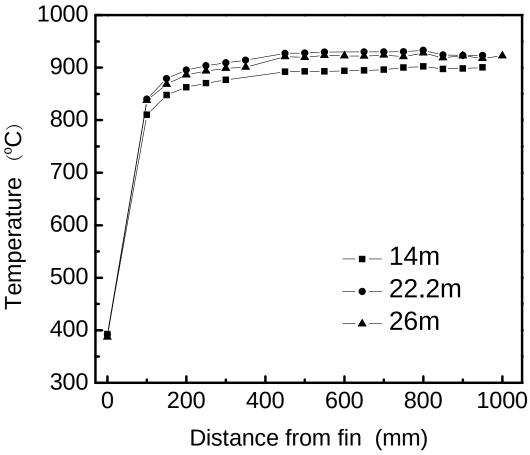


Figure 4. Temperature profile (135MWe)

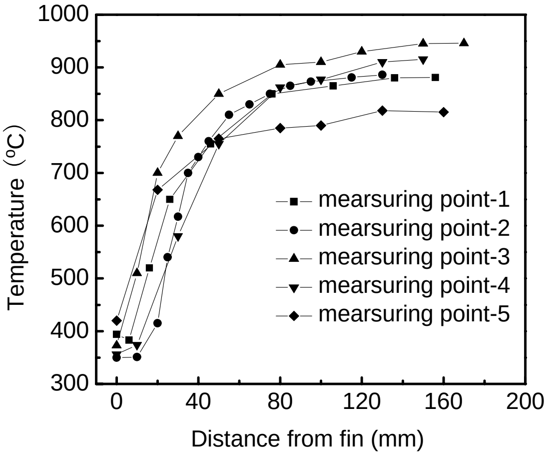


Figure 5. Temperature profile (300MWe-A)

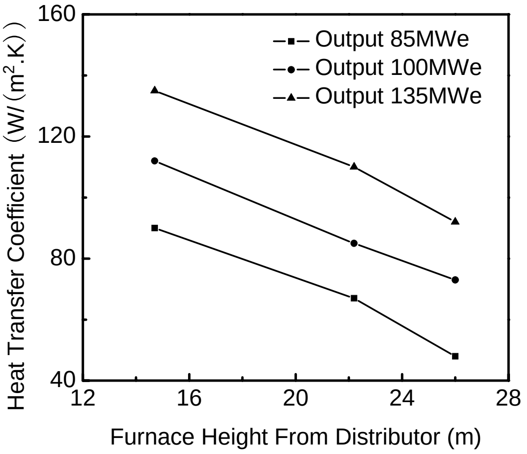


Figure 6. Local heat transfer coefficient (135MWe)

Table 1. Local heat transfer coefficient at measurement point-4 (300MWe-A)

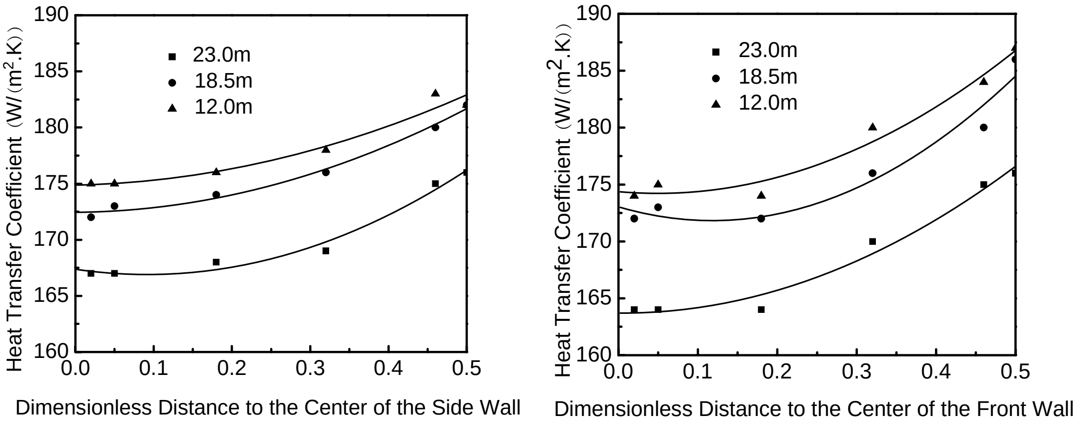
Measurement point	Boiler load MWe	Furnace temperature °C	Local heat transfer coefficient W/(m²K)
4	260	908	161
	300	915	183

The measurement of the local heat transfer coefficients at point 1-4 in 300MWe-A boiler verified the conclusions above. Typical results are listed in Table 1. The heat transfer coefficient at point 4 increased from 161 W/(m^2K) to 183 W/(m^2K) when the boiler load was increased to 300MWe from 260MWe. Though the effect of height on the heat transfer coefficient is not proved directly, it is reasonable to assume that the coefficient would decrease with increasing height because the suspension density decreases with height.

Peripheral distribution of the heat transfer coefficient

The peripheral distribution of the heat flux at different levels, from which the heat transfer coefficient distribution can be derived, was indirectly measured in the 135 MWe and 300 MWe-B boiler by the finite element method discussed above.

In the test of the 135MWe CFB boiler, measuring points were arranged in the left front wall and the front left side wall at heights of 12m, 18.5m, and 23m above the distributor. The bed temperature was about 882~894℃, the water temperature was about 353~354℃, the superficial gas velocity was about 5.78~5.86m/s, the tube dimension was 60×5mm and the tube pitch was 90 mm. Fig. 7 shows the heat transfer coefficient distribution over half of the front wall and the left side wall at different height levels. Consistent with the result by HFM, the heat transfer coefficients by FEM also decreased with the increasing height. In the cross section, the heat flux and the heat transfer coefficient were lower in the center than in the corner on both the front wall and the side wall.



(a)

(b)

Figure 7. Peripheral distribution of heat transfer coefficient on side wall and front wall (135MWe)

In the 300MWe-B boiler, the measuring points were arranged in the left half of the rear wall and the back half of the left side wall at heights of 13m (L1), 19m (L2), 25m (L3), 30m (L4), and 35m (L5). In particular, the entire rear wall and left side wall at L1 were fitted with measuring points. The water temperature was about 358.6~359.3℃, the superficial gas velocity was about 3.6~3.9m/s, the water tube dimension was 57×6.5mm and the tube pitch is 87mm. As the heat transfer at different heights was similar, results in L1 were set as an example for the analysis. The heat flux and the heat transfer coefficient distribution along the rear wall are shown in Figs.8 and 9 respectively. It is seen that, the heat fluxes between the wing walls appear to be higher than between the side wall and the wing wall. Also, heat fluxes on the left side are higher than on the right side. For the correlation of the coefficient and heat flux by calculation, the heat transfer coefficient prolife trend was similar trend to the pattern of the heat flux profile.

In actual operation, it is found that the solids mix well in the dense zone at the bottom of the furnace. In the upper furnace, the two wing walls divide the furnace into three parts, marked as left, middle and right. Three cyclones were also arranged asymmetrically. Therefore, the gas-solid flows in these three regions were relatively independent, which prevents solids in upper furnace from experiencing good lateral mixing. Furthermore, the layout of the heating surfaces was not uniform. A_1 is the heating surface area in the left or right section, A_2 is the heating surface area in the middle section. Calculating from the heating surface structure, A_2/A_1 is about 0.91, which means less heating surface is placed in the middle part compared with that in left or right part. As a result, the temperature between the wing walls tends to be higher than that between the side wall and the wing wall. This can explain the temperature non-uniformity. The uneven layout of the heating surface is the essential reason for the uneven heat flux distribution.

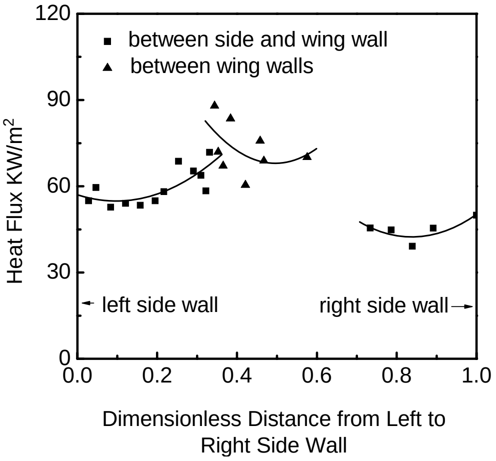


Figure 8. Peripheral distribution of heat flux in the whole rear wall (300MWe-B)

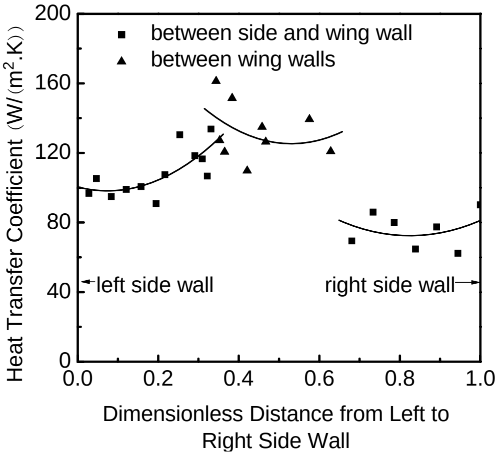


Figure 9. Peripheral distribution of heat transfer coefficient in the whole rear wall(300MWe-B)

It is clear that the heat flux and heat transfer coefficient have a close relationship with suspension density and bed temperature. The peripheral distribution of the bed temperature, shown in Fig.10, gives good agreement with that of heat flux with the fact that bed temperature in center section was greater. Also, the temperature on the left side seems to be lower than that of right side, contrary to the heat flux distribution. This is supported by the result that the section has a greater suspension density than right, as derived from the pressure profile during the experiment. It is the combined effects of the suspension density and the bed temperature, that result in the heat flux and heat transfer coefficient characteristics presented above.

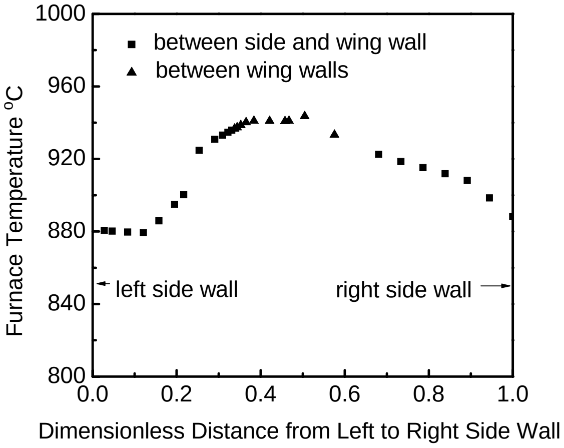


Figure 10. Temperature distribution in the furnace (300MWe-B)

In Fig.9 the heat transfer coefficient was found to increase near the corner formed by the rear wall and either side wall or the wing wall, which is consistent with what was found in the 135MWe boiler. It can be inferred that in large-scale CFB boilers, a corner effect does exist, causing the heat flux and the heat transfer coefficient near the corner to increase compared to the central area. Considering the relationship between the heat transfer coefficient and the suspension density, the suspension density in this area is likely to be higher, which is also indicated by the fact that tube erosion near the corner is greater than the central area in CFB boilers.

CONCLUSIONS

Field measurements mainly on heat transfer performance has been carried out in a 135 MWe CFB boiler and two 300 MWe CFB boilers with different configurations. It was found that:

1. The thickness of the thermal boundary layer is about 100mm and remains constant with height above with distributor and with boiler load.
2. The local heat transfer coefficient decreases with increasing furnace height and with decreasing boiler load.
3. The heat flux and the heat transfer coefficient have an uneven distribution in large-scale CFB boilers. Near the corner formed by rear wall with the side wall and wing wall, the heat flux and heat transfer coefficient is higher than that in the central area. In a 300 MWe CFB boiler with two wing walls arranged unevenly inside the furnace, heat flux and heat transfer coefficient tend to be higher in middle section than in the left or the right section at a particular level.

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NOTATION

A_1	heating surface area of the left or right part in 300 MWe-B, m^2
A_2	heating surface area of the intermediate part in 300 MWe-B, m^2
K	heat transfer coefficient, $W/(m^2K)$
q	heat flux, W/m^2

$\triangle T$	temperature difference, K
Abbreviations	
CFB	Circulating Fluidized bed
FEM	Finite element method
HFM	Heat flux method

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