Chapter 83
Furnace Outlet Temperature Prediction Model of a 350 MW Ultra-Supercritical Boiler

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Abstract Ultra-supercritical boiler has been widely applied due to its advantages of high combustion efficiency and low pollutant emission. Furnace outlet temperature can indicate the boiler operating status, because of which, related investigations draw various researchers' attention. Based on a 350 MW design data, this paper established a model for predicting furnace outlet temperature. Comparison of design data and predicted result validates the accuracy of present model. Furnace outlet temperature of different operating parameter (e.g. excess air coefficient) is predicted, which can provide reference for actual operation

Keywords Ultra-supercritical boiler · Temperature prediction

83.1 Introduction

Ultra-supercritical boiler has been widely applied due to its advantages of high combustion efficiency and low pollutant emission. Furnace outlet temperature can indicate the boiler operating status, because of which, related investigations draw various researchers' attention. Based on a 350 MW design data, this paper established a model for predicting furnace outlet temperature. Comparison of design data and predicted result validates the accuracy of present model. Furnace outlet temperature of different operating parameter (e.g. excess air coefficient) is predicted, which can provide reference for actual operation.

The requirements of high combustion efficiency, low pollutant emission and operating flexibility drive the investigations on fossil-fire plant with high parameter. In recent decades, an increasing number of once-through boilers with ultra-supercritical parameter are designed and put into services, and many researchers focus on the heat transfer, fluid flow and construction of boiler. However, due to the complexity of combustion process and heat transfer in furnace, investigation may not be possible to involve all the whole process of actual operating condition.

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In present paper, a model of classical zero-dimensional model is established to cast light on the heat transfer capacity, heat flux distribution (radiative and convective), temperature of theoretic combustion and furnace outlet at different operation condition with varies in unit load and excess air coefficient. Relative result may provide reference and perspective for graduates, operator and researchers.

83.2 Model and Governing Equations

See Table 83.1.

In order to utilize the zero-dimension model, several assumptions should be made:

1. Fossil combustion and heat transfer in furnace proceeds separately.
2. Combustion process finishes immediately and combustion products diffuse into whole furnace with uniform physical character.
3. The influence of platen superheater on heat transfer within furnace is neglected.

Based on the assumptions above, the flue temperature at furnace outlet Tout (K) can be calculated as:

$$T_{out} = \frac{T_a}{M\left(\frac{\sigma_0 \Psi \mathrm{F}_1 a_1 T_a^3}{\varphi B_j V_{cpj}}\right)^{0.6} + 1} \tag{83.1}$$

where

M Parameter related with height on which the highest flame temperature lies;

σ_0 Absolute blackbody radiation coefficient, 5.67×10^{-11} kJ/(m^2 s K^4);

Ψ Thermal Effectiveness Coefficient;

F_1 Heating surfaces area in furnace;

a_1 Furnace blackness;

T_a theoretical combustion temperature;

φ Heat preservation coefficient;

Table 83.1 Boiler main parameter

Item	Unit	BMCR	75% THA	50% THA	30% THA
Main steam flow	t/h	1172	748	486	352
Main steam pressure	MPa g	25.4	23.5	15.7	11.5
Main steam temperature	°C	571	571	571	571
Reheat steam flow	t/h	962	631	420	307
Reheat steam pressure	MPa g	5.22	4.84	2.25	1.60
Reheat steam temperature	°C	569	569	569	544
Feedwater temperature	°C	295	267	243	226

B_j Calculated fuel consumption;
V_{cpj} Mean specific heat.

The calculation of parameter involved in Eq. 2-1 can be referred in literature (Thermodynamic calculation of boiler unit 1973). After getting the theoretical combustion temperature and furnace outlet temperature, the radiative and convective heat transfer flux ($\mathrm{Q_f}$ and $\mathrm{Q_d}$) can be calculated as:

$$\mathrm{Q_f} = a_1 \Psi \sigma_0 T_x^4 F_1$$

$$\mathrm{Q_d} = \alpha_d (T_x - T_b) F_1$$

$$\frac{T_x}{T_a} = \left(\frac{T_{out}}{T_a}\right)^n$$

$$T_b = T_s + \frac{s}{\lambda} \Psi a_1 \sigma_0 T_x^4$$

where

T_x Mean temperature of flame;
T_b Fouling surface temperature;
α_d Heat transfer coefficient, calculation method varies, present study take advantage in Miu (1996).

Based on the model above, the theoretical combustion temperature Ta, furnace outlet temperature Tout, radiative heat transfer capacity, convenctive heat transfer capacity can be obtained. In present study, a validation is made by comparing the calculated furnace outlet temperature with design data, then working condition of different excess air coefficients is investigated.

83.3 Calculation Condition, Validation and Result Analysis

Four typical working conditions of BMCR, 75% THA, 50% THA and 30% BMCR are in scope of present investigation (Table 83.2).

Table 83.2 Main calculating parameter setup

	BMCR	75%	50%	30%
Coal feed (t/h)	187.0	129.5	89.2	67.5
Excess air coefficient	1.15	1.20	1.32	1.45
Hot wind temperature (°C)	330	310	293	282

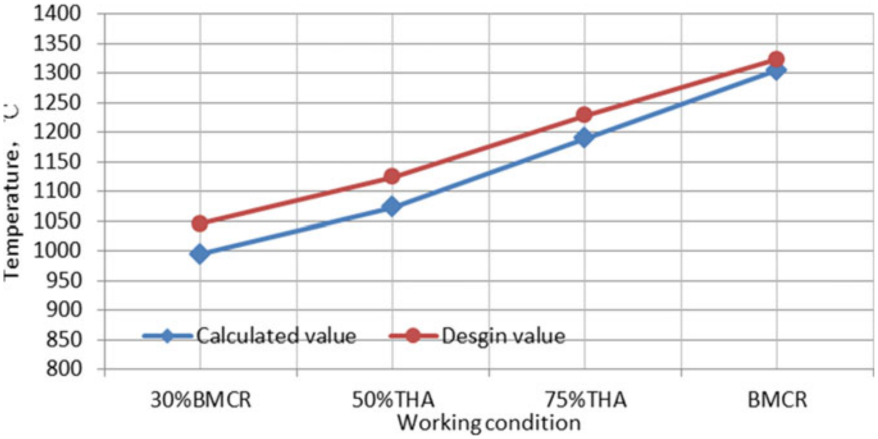


Fig. 83.1 Validation: comparison of calculated and design temperature

Hence, the calculated furnace outlet temperature and design data can be compared as shown Fig. 83.1.

As can be seen from the figure above, the deviations between the calculated and design temperature at four typical working conditions are limited within 50 °C, and this value is generally accepted in furnace thermal calculation, which validates the accuracy of present model, including relative parameter setup.

The theoretical combustion temperature can indicate the stability of combustion to a certain extent, and is determined by coal and excessive air coefficient. Figure 83.2 shows the influence of boiler load and operating excess air coefficient on theoretical combustion temperature. It can be seen obviously that as the load increases and excess air coefficient decreases, the theoretical combustion temperature rises accordingly. One reason low load requires high air coefficient is that though the combustion

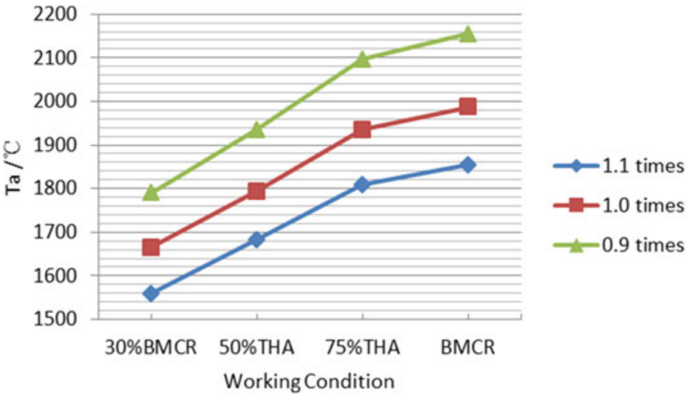


Fig. 83.2 Theoretical combustion temperature under different load and excess air coefficient

period lies in dynamic period, excess air is needed to promote the burn out of the coal particle.

In terms of radiative and convective heat transfer capacity, the four typical working conditions exhibit an inclination: with boiler load increases, the amount of heat transfer in radiative form increases while the form in conduction decreases, as shown in Fig. 83.3. And calculated result also accords with the assumption of neglect of convection in furnace in some furnace thermal calculation model.

In actual operating status, change in air coefficient occurs frequently, resulting in variation of combustion. Hence, it is important to get the changing rules of critical parameter in heat transfer—furnace outlet temperature. Figure 83.4 shows the deviation from design condition. When the excess air coefficient in furnace decreases, the outlet temperature increases. However, by comparing the theoretical combustion temperature and furnace outlet temperature, it can be noticed that changing amplitude in theoretical combustion temperature is much more than furnace outlet temperature. It is mainly because the rise in combustion temperature leads to more furnace heat absorption, especially in form of radiation. According result can be seen

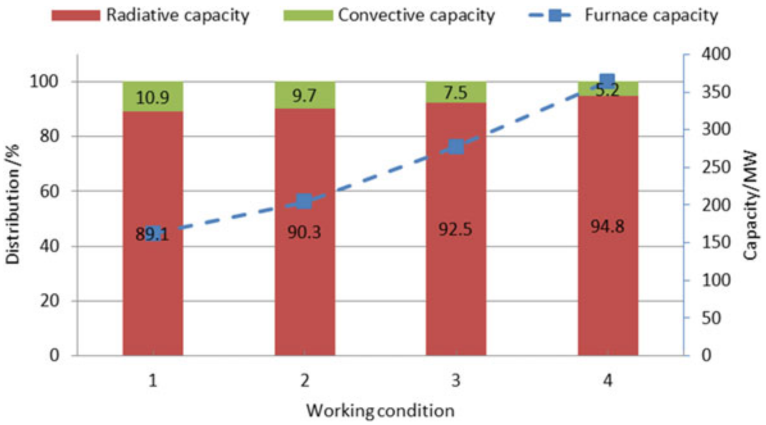
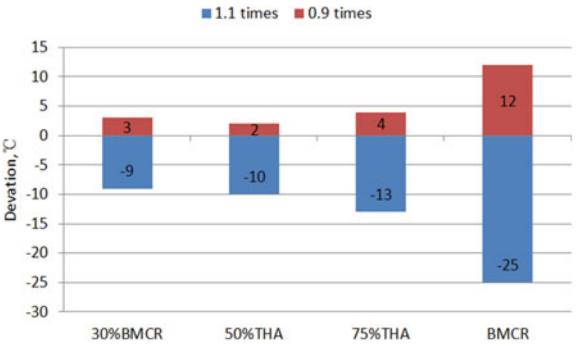


Fig. 83.3 Furnace overall capacity and distribution of radiation and convection

Fig. 83.4 Excess air coefficient's influence on furnace outlet temperature



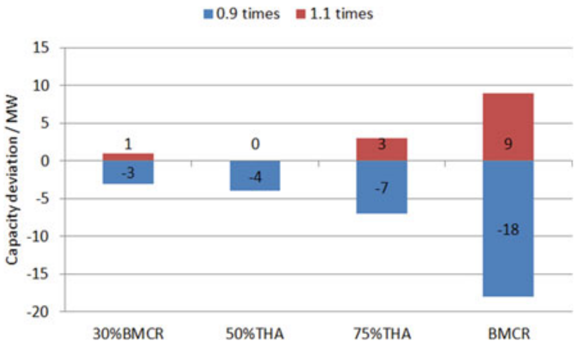


Fig. 83.5 Excess air coefficient's influence on furnace overall capacity

in Fig. 83.5, and the change in BCMR condition is the most in the four compared working condition.

83.4 Conclusion

1. By comparing the calculated and design furnace outlet temperature, the validation of zero-dimension model in present paper is made.
2. As excess air coefficient decreases, theoretical combustion temperature increases, indicating good combustion condition without regarding to the burning out of coal particle.
3. The furnace outlet temperature increases with the decrease in excess air coefficient, but the change amplitude is much less compared with theoretical combustion temperature due to the change in furnace heat absorption capacity.
4. The convective takes less than 10% in all studied working conditions, indicating the assumption in other thermal calculation model is adoptable.

References

Miu Z (1996) Model and application of particle convection heat transfer in pulverized coal furnace. J Shanghai Jiaotong Univ 7:100–105

Thermodynamic calculation of boiler unit. Beijing Boiler Works (1973)