Investigation on Intermediate Point Temperature Adjustment in Once-Through Boiler Based on Enthalpy Distribution

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Abstract. The developed power plants take advantage of variable pressure operation in wide range of working condition, during which liquid physical property is influenced by pressure change to a great extent. It can result in complex heat transfer condition, even over-temperature in heated tubes. Based on enthalpy distribution, present paper studies the different degrees (1 ℃-15 ℃) of superheat in steam-water separator in four working conditions (30%, 50%, 75%, 100%). Meanwhile, the impact of pressure deviation (-10bar- 10bar) on the enthalpy distribution is in scope in present paper.

1. Introduction

Power plants are increasingly getting engaged in grid peaking operations, which indicates great fluctuations in unit load and steam system pressure [1]. Moreover, the unit safe operation is also challenged by deviation from design coal quality [2]. Although, the combustion stability in furnace can be handled through combustion adjustment or enhancement in coal burner, the increased flue volume due to inferior coal makes significant differences on the heat distribution of heating, evaporating and overheating period [3]. In most cases, main steam temperature is prone to rise and desuperheating water is inclined to excess of rated design, reducing economy and efficiency of the unit.

Present paper casts light on the adjustment in temperature and pressure of intermediate point in order to improve the economy of unit and avoid over-temperature. Different degrees of superheat on enthalpy distribution are investigated, and pressure deviation from -10bar to 10bar is also studied in present paper.

2. Governing equations

Equ. 2-1 and Equ. 2-2 describe the energy conservation in overheater and waterwall, respectively.

\[ B_{\text{coal}} Q_{\text{sup}} = D_{\text{sup}} q_{\text{sup}} \]

\[ B_{\text{coal}} Q_{\text{wall}} = G_{\text{wall}} r_1 \]

Equ. 2-3 can be obtained by dividing Eq. 2-1 by Eq. 2-2.

\[ \frac{Q_{\text{sup}}}{Q_{\text{wall}}} = \frac{D_{\text{sup}} q_{\text{sup}}}{G_{\text{wall}} r_1} \]
where

- $D_{\text{sup}}$ - Steam flow in superheater, kg/s;
- $G_{\text{wall}}$ - Feedwater flow in waterwall, kg/s;
- $B_{\text{coal}}$ - Coal supply kg/s;
- $Q_{\text{sup}}$ - Heat per kilogram coal delivered to superheater, kJ/kg;
- $Q_{\text{wall}}$ - Heat per kilogram coal delivered to wall and economizer kJ/kg;
- $r_1$ - evaporation heat, for once-through boiler, $r_1 = h_1 - h_{gs}$, kJ/kg;
- $h_1$ - steam specific enthalpy at separator outlet, kJ/kg;
- $h_{gs}$ - feedwater specific enthalpy, kJ/kg

Due to the existence of desuperheating water, the enthalpy rise in superheater is decreed as below:

$$q_{\text{sup}} = \Delta h_{\text{sup}} + \phi (h_1 - h_{desup}) \tag{2-4}$$

$$\phi = \frac{d_{desup}}{d_{sup}} \tag{2-5}$$

$$G_{\text{wall}} = D_{\text{sup}} (1 - \phi) \tag{2-6}$$

Combine Equ. 2-4, 2-5, 2-6 and Euq. 2-3, bellowing equations can be obtained.

$$\frac{Q_{\text{sup}}}{Q_{\text{wall}}} = \frac{\Delta h_{\text{sup}} + \phi (h_1 - h_{desup})}{(1-\phi)r_1} \tag{2-7}$$

where

- $\Delta h_{\text{sup}}$ - specific enthalpy rise in superheater, $\Delta h_{\text{sup}} = h_{\text{sup}} - h_1$, kJ/kg;
- $\phi$ - ratio of desuperheating water;
- $h_{desup}$ - specific flow of desuperheating water, kJ/kg;
- $D_{desup}$ - desuperheating water flow, kg/s;

In Eq. 2-7, we can figure out that enthalpy distribution in superheater system is mainly related with $h_1$ in given working condition where $Q_{\text{sup}}$ and $Q_{\text{wall}}$ are constant. Thus, by adjusting $h_1$ through changing temperature and pressure in certain extent, more ideally working condition of superheating system can be reached.

### 3. Results and thermal analysis

**Table 1.** Main parameters of different working conditions

| Load   | Main steam pressure/MPa | Separator Pressure/MPa | Feedwater Pressure/MPa | Feedwater Temperature/°C | Saturate Temperature Separator/°C | Main Steam Temperature/°C |
|--------|-------------------------|------------------------|-------------------------|---------------------------|----------------------------------|---------------------------|
| 105MW  | 11.38                   | 11.71                  | 12.22                   | 225.1                     | 322.7                            | 571.0                     |
| 175MW  | 13.83                   | 14.32                  | 14.84                   | 244.3                     | 338.3                            | 571.0                     |
| 260MW  | 20.58                   | 21.23                  | 22.35                   | 267.5                     | 370.6                            | 571.0                     |
| 350MW  | 25.08                   | 25.22                  | 26.26                   | 287.2                     | 385.5                            | 571.0                     |

In this section, four typical working conditions (30%, 50%, 75% and 100% rate load) of 350MW coal-fired power plant are selected, and different intermediate point temperature and pressure deviation are studied. Actual working parameters are shown in Tab. 1, and according enthalpy rise in heating and superheating system is demonstrated in Fig.1.
As shown in Fig 1, the proportion of intermediate enthalpy is gradually increasing as load increases. And detailed investigation is in following content.

3.1. Impact of temperature on enthalpy distribution

In actual operation, intermediate point temperature is kept slightly above saturate temperature in corresponding pressure. Therefore, degree of superheat 1℃, 5℃, 10℃ and 15℃ are investigated in present study.

Fig 2. Intermediate temperature on enthalpy distribution (superheating system enthalpy rise)
From Fig 2, it can be seen that as the overheat temperature increases from 1°C to 15°C, proportion of overheating heat in waterwall shows a concomitant increasing inclination in all working condition. Meanwhile, enthalpy distribution of different load (pressure) at same superheat degree shows obvious regulation. When the load (pressure) is rising, the enthalpy proportion is making greater difference in adjusting main steam temperature.

Under the same working condition, it can be figured out that enthalpy proportion increases more significantly at low superheat degree, which indicates unit degree fluctuation at this time will lead to more prominent changes in main steam temperature. Fig 3 demonstrates the same rule of Fig 2.

3.2. Impact of pressure deviation on enthalpy distribution

Plant operators constantly adjust steam system pressure to reach a more economic working condition, which may lead to variation in main steam temperature to a certain degree. Thus the impact of pressure deviation from -10bar to 10bar is investigated for the four working condition with 10 superheat degree of separator in this section.

Fig 3. Intermediate temperature on enthalpy distribution (overall enthalpy rise)

Fig 4. Pressure deviation in 105MW (11.38MPa)  

Fig 5. Pressure deviation in 175MW (13.83MPa)
As seen in Fig 4, 5, 6 and 7, the impact of same pressure deviation varies with the change of working condition and steam system pressure. In Fig. 4, 5, and 6, the enthalpy proportion of intermediate point is gradually increasing with the rise of steam pressure. Moreover, in Fig 6, the rising trend of enthalpy proportion begins to accelerate at the pressure of 21.08MPa and 21.58MPa, which means unit intermediate point temperature change makes greater difference in enthalpy distribution and main steam temperature. Meanwhile, as pressure rises, the ratio of intermediate point enthalpy is increasing by transvers comparison among Fig. 4, 5 and 6.

However, the pressure of 350MW reaches 25.08MPa, above the critical pressure (22.12MPa) as shown in Fig 7. As pressure increases, the enthalpy proportion shows reversal inclination. The overall intermediate point enthalpy proportion is decreasing with rise of pressure. Due to the sharp change of water physical character, the enthalpy proportion first increases then begins to decreases. In addition, the enthalpy proportion at 350MW is less than that of 260MW, though the pressure at this working condition is greater. It is mainly because the water physical character changes violently when reaching and around critical point.

4. Conclusion
Through experimental data and thermal analysis, following conclusions can be made.

1) As intermediate point temperature rises, the enthalpy proportion increases in all working conditions investigated. And this trend is more obivious in a low superheat degree.

2) Before reaching critical pressure (22.12MPa), enthalpy proportion of intermediate point is gradually increasing with the rise of steam pressure, indicating unit temperature adjustment in intermediate point leads to better result in high pressure.

3) Due to violent changes in water physical character at critical point, working condition with pressure above 22.12MPa shows reversal trend. The overall intermediate point enthalpy proportion is decreasing with rise of pressure.

These conclusions mentioned above can be used as reference for actual operations. And detailed investigation in enthalpy distribution around critical point will continue in further study.

References
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