Compare the Calculations of Steam Extraction Efficiency of Power Plant Turbine by Simple Heat Balance Method and Equivalent Enthalpy Drop Method

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Abstract. At present, the calculation method of steam extraction efficiency of power plant turbine have five methods: heat balance method, equivalent enthalpy drop method, cyclic functional method, composite structure method and matrix method. In this paper, a 600MW grade subcritical thermal power plan is take as an examplefor comparing the calculation by the simple heat balance method and the equivalent enthalpy drop method. The result shows that the computational results of simple heat balance method agree with equivalent enthalpy drop method. So simple heat balance method can be used to replace equivalent enthalpy drop method in order to reduce calculation amount in practical application.

Keywords: Power Plant Turbine, Steam Extraction Efficiency

1 Introduction

The efficiency of steam extraction is the percentage between lost work and steam extraction heat when steam extraction is used for steam supply or heat supply. It can be calculated by heat balance method, equivalent enthalpy drop method, cyclic functional method, composite structure method and matrix method. The physical object of these methods is identical and the basic thought of these methods is based on the first law of thermodynamics. However, there are still many differences in the point of view and the ease or complexity of calculation.

Heat balance method is a basic analysis methods of thermodynamic systems for coal fired power plants. It is a simple steam-water mass balance and energy balance method. It focuses on singly heater, the steam-water mass balance and energy balance formulas of every heater are derived in order to calculate the steam extraction coefficients. The heat economic indicators are calculated by the power formulas the absorbed heat formulas. The simple heat balance method is simple calculation method based on heat balance method.

The essence of equivalent enthalpy drop method is thermal power conversion principle, the same as the heat balance method. Based on the quality of equipment, the thermodynamic system structure and the parameters, some thermal parameters are obtained.

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The equivalent enthalpy drop is used to analyze the heat economical efficiency of thermodynamic system with a premise which are invariable new steam flow, invariable initial and final parameters of cycle and invariable steam condition curve.

Cyclic functional method is a new simplify thermal calculation method. According to the second law of thermodynamics, it is built base on the concept of heating unit. It can qualitative analyse the economics of steam cycle by cycle irreversibility and quantitative analyse the economics of steam cycle by cycle functional. The thermodynamic system is computed by series method, and steam extraction of heat recuperator and cycle efficiency are computed by cycle functional. Thermodynamic system can be divided into heat recuperator cycle and assist cycle. Then the added amount of this two value is calculation.

Matrix method is a general term, and not a specific method. It combine heat balance equations of every regenerative heater and can completes the thermodynamic calculation by solving linear parametric equations[1].

## 2 The calculation of steam extraction efficiency

In this paper, a 600MW grade subcritical thermal power plan is take as an example for comparing the calculation by the simple heat balance method and the equivalent enthalpy drop method. The simple heat balance method is simple calculation method based on heat balance method and can be used to separate calculate the efficiency of steam extraction. For convenience, the heaters from highest mass to lowest mass are numbered 1-8 according to preference of coal-fired power plants. The original parameters are shown in turbine.

| Steam extraction enthalpy | Unit | Value | Steam extraction mass | Unit | Value |
|---------------------------|------|-------|-----------------------|------|-------|
| $h_0$                     | kJ/kg| 3396.0 | $D_0$                 | t/h  | 1830.67 |
| $h_1$                     | kJ/kg| 3062.5 | $D_1$                 | t/h  | 94.82  |
| $h_2$                     | kJ/kg| 2989.4 | $D_2$                 | t/h  | 152.82 |
| $h_{x_1}$                 | kJ/kg| 2989.4 | $D_{x_1}$             | t/h  | 1566.46 |
| $h_{x_2}$                 | kJ/kg| 3595.8 | $D_{x_2}$             | t/h  | 1566.46 |
| $h_3$                     | kJ/kg| 3405.1 | $D_3$                 | t/h  | 73.88  |
| $h_4$                     | kJ/kg| 3194.0 | $D_4$                 | t/h  | 85.71  |
| -                         | -    | -     | $D_x$                 | t/h  | 84.39  |
| $h_5$                     | kJ/kg| 2972.4 | $D_5$                 | t/h  | 90.53  |
| $h_6$                     | kJ/kg| 2741.0 | $D_6$                 | t/h  | 43.22  |
| $h_7$                     | kJ/kg| 2630.9 | $D_7$                 | t/h  | 58.47  |
| $h_8$                     | kJ/kg| 2481.0 | $D_8$                 | t/h  | 54.31  |
| $h_c$                     | kJ/kg| 2314.7 | $D_c$                 | t/h  | 1077.51|
| $h_c'$                    | kJ/kg| 136.3 | -                     | -    | -      |
| Inlet drainage            | Unit | Value | Outlet drainage       | Unit | Value |

Table 1. The original parameters.
|       |       |       |       |       |       |       |       |
|-------|-------|-------|-------|-------|-------|-------|-------|
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The notes:
- \( h_0 \) — Main steam enthalpy, kJ/kg;
- \( h_c \) — Exhaust steam enthalpy of condenser, kJ/kg;
- \( h_i \) — No. i steam extraction enthalpy, kJ/kg;
- \( h_{di} \) — Inlet drainage enthalpy, kJ/kg;
- \( h_{d(i+1)} \) — Outlet drainage enthalpy, kJ/kg;
- \( h_{w1} \) — Outlet water enthalpy, kJ/kg;
- \( h_{w1} \) — Intlet water enthalpy, kJ/kg;
- \( h_{c} \) — Condensation water enthalpy, kJ/kg;
- \( h_{z1} \) — The cold section enthalpy of reheat steam, kJ/kg;
- \( h_{zr} \) — The hot section enthalpy of reheat steam, kJ/kg;
- \( h_{w4} \) — Outlet water enthalpy of pump, kJ/kg;
- \( D_0 \) — Main steam mass, t/h;
- \( D_c \) — Waste steam mass, t/h;
- \( D_x \) — Exhaust steam mass of small turbine, t/h.

2.1 The calculation of simple heat balance method

The main content of simple heat balance method is as follows:\(^{[2]}\):

This should be viewed as the sum of multipart coordinate steam. Each part of steam follow the main path into the turbine and out from the different location. The path of steam in turbine is the inlet of main steam to the location of steam extraction. In this paper, the turbine have eight-stage steam extraction. With the steam which is not extracted, there are nine stage steam shown in Fig.1. \( \alpha_i \) is extraction steam ratio. The sum for each content of extraction steam ratio should be equal to 1, such as formula (1):

\[
\alpha_c + \alpha_1 + \alpha_2 + \alpha_3 + \cdots + \alpha_8 = 1
\]  

(1)
Fig. 1. Steam extraction of the turbine.

The external work of the turbine is the sum of steam extraction work:

\[ H_i = \sum \alpha_i \Delta h_i \]  \hspace{1cm} (2)

\[ H_T = \sum H_i \]  \hspace{1cm} (3)

The steam mass in turbine can be calculated by formula (4):

\[ D_i = D_{i-1} - D_{el} \]  \hspace{1cm} (4)

\( D_i \) is NO.i steam mass in turbine, t/h; \( D_{i-1} \) is NO.i-1 steam mass in turbine, t/h; \( D_{el} \) is NO.i steam extraction mass in turbine, t/h.

NO.i steam enthalpy-drop in turbine can be calculated by formula (5):

\[ \Delta h_i = h_i - h_{i+1} \]  \hspace{1cm} (5)

\( \Delta h_i \) is NO.i steam NO.i steam extraction enthalpy-drop, kJ/kg; \( h_i \) is NO.i steam extraction enthalpy, kJ/kg; \( h_{i+1} \) is NO.i+1 steam extraction enthalpy, kJ/kg.

NO.i steam extraction efficient can be calculated by formula (6) and the main steam extraction efficient can be calculated by formula (7):

\[ \eta_i = \frac{\sum_{i=1}^{n} \Delta h_i D_i}{\sum_{i=1}^{n} \Delta h_i D_i + D_n (h_c - h'_c)} \times 100 \]  \hspace{1cm} (6)

\[ \eta_m = \frac{\sum_{i=1}^{n} \Delta h_i D_i}{\sum_{i=1}^{n} \Delta h_i D_i + D_n (h_c - h'_c) + \Pi} \times 100 \]  \hspace{1cm} (7)
\( \eta_i \) is NO.\( i \) steam extraction efficient,\%; \( h_c \) is Steam extraction enthalpy of condenser,kJ/kg; \( \Pi \) is Steam supply mass of small turbine,kJ/h; \( h_c' \) is Condensation water enthalpy,kJ/kg.

The calculations of steam mass and enthalpy-drop in turbine are shown in Table.2.

**Table 2.** The calculations of steam mass and enthalpy-drop in turbine.

| Steam mass | Unit | Value | Enthalpy-drop Unit | Value |
|------------|------|-------|---------------------|-------|
| \( D_1 \)  | t/h  | 1732.25 | \( \Delta h_1 \)  kJ/kg | 73.1  |
| \( D_2 \)  | t/h  | 1579.43 | \( \Delta h_2 \)  kJ/kg | 132.66|
| \( D_3 \)  | t/h  | 1505.55 | \( \Delta h_3 \)  kJ/kg | 211.1 |
| \( D_4 \)  | t/h  | 1335.45 | \( \Delta h_4 \)  kJ/kg | 221.6 |
| \( D_5 \)  | t/h  | 1244.92 | \( \Delta h_5 \)  kJ/kg | 231.4 |
| \( D_6 \)  | t/h  | 1201.70 | \( \Delta h_6 \)  kJ/kg | 110.1 |
| \( D_7 \)  | t/h  | 1143.23 | \( \Delta h_7 \)  kJ/kg | 149.9 |
| \( D_8 \)  | t/h  | 1088.92 | \( \Delta h_8 \)  kJ/kg | 166.3 |

The steam extraction efficiencies are shown in Table.3

**Table 3.** The steam extraction efficiencies

| The steam extraction efficiencies | Unit | Value |
|----------------------------------|------|-------|
| \( \eta_0 \)                     | %    | 48.51 |
| \( \eta_1 \)                     | %    | 41.28 |
| \( \eta_2 \)                     | %    | 39.52 |
| \( \eta_3 \)                     | %    | 36.37 |
| \( \eta_4 \)                     | %    | 30.90 |
| \( \eta_5 \)                     | %    | 24.57 |
| \( \eta_6 \)                     | %    | 16.97 |
| \( \eta_7 \)                     | %    | 12.94 |
| \( \eta_8 \)                     | %    | 7.09  |

**2.2 The calculation of equivalent enthalpy drop method**

The equivalent enthalpy drop method is widely used to calculate the steam extraction efficiencies, So the principles won't be covered in this paper. The equivalent enthalpy drop of new steam can be calculated by formula (8) and the steam extraction efficiencies can be calculated by formula (9)[3]:

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The calculation of steam extraction efficiencies by equivalent enthalpy drop method are shown in Table.5.

Table 5. The steam extraction efficiencies

| Equivalent enthalpy drop | Unit   | Value  | The steam extraction efficiencies | Unit | Value |
|--------------------------|--------|--------|-----------------------------------|------|--------|
| $H_1$                    | kJ/kg  | 795.37 | $\eta_1$                         | %    | 41.17  |
| $H_2$                    | kJ/kg  | 796.65 | $\eta_2$                         | %    | 38.86  |
| $H_3$                    | kJ/kg  | 948.49 | $\eta_3$                         | %    | 36.56  |
| $H_4$                    | kJ/kg  | 804.49 | $\eta_4$                         | %    | 30.94  |
| $H_5$                    | kJ/kg  | 621.13 | $\eta_5$                         | %    | 24.67  |
| $H_6$                    | kJ/kg  | 402.98 | $\eta_6$                         | %    | 17.04  |
| $H_7$                    | kJ/kg  | 306.96 | $\eta_7$                         | %    | 12.99  |
| $H_8$                    | kJ/kg  | 166.30 | $\eta_8$                         | %    | 7.10   |

3 Conclusion

The calculate differences of steam extraction efficiencies between simple heat balance method and equivalent enthalpy drop method are shown in Table.6. As the table shows, there is little differences between simple heat balance method and equivalent enthalpy drop method. The equivalent enthalpy drop method has higher precision. So equivalent enthalpy drop can be replaced by simple heat balance method to calculate steam extraction efficiencies in order to reduce calculation amount.

Table 6. The difference value of steam extraction efficiencies between simple heat balance method and equivalent enthalpy drop method

| The difference value | Value  | The difference value | Value |
|----------------------|--------|----------------------|-------|
| $\Delta \eta_1$      | -0.00108 | $\Delta \eta_5$ | 0.00093 |
| $\Delta \eta_2$      | -0.00662 | $\Delta \eta_6$ | 0.00075 |
| $\Delta \eta_3$      | 0.00187  | $\Delta \eta_7$ | 0.00056 |
| $\Delta \eta_4$      | 0.00036  | $\Delta \eta_8$ | 0.000051 |

References

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| 103.8 | 82 | - | - | - | 193.1 | 8b |
| 181.4 | 82 | 74 | 191.4 | 8b | 2050.0 | 8b |
| 22.4 | 82 | 74 | 128.9 | 8b | 2594.6 | 8b |
| 177.9 | 82 | 74 | 216.9 | 8b | 2600.4 | 8b |
| 161.6 | - | - | - | - | 2518.1 | 8b |
| 171.9 | - | - | - | - | 2600.4 | 8b |
| 122.4 | - | - | - | - | 2594.6 | 8b |
| 181.4 | - | - | - | - | 2050.0 | 8b |

Table 4. The feed-water enthalpy, steam released heat in heater, drainage released heat in heater.