Analysis on the change of coal consumption of low-pressure (low temperature) economizer unit

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Abstract. This paper discusses the calculation of coal consumption for power generation when the unit uses steam extraction as a low-pressure (low temperature) heat recovery source. The calculation of coal consumption for power generation when the unit uses low-pressure (warm) economizer as a low-pressure (low-temperature) heat source, the heat source is not recovered. At the same time, the coal consumption of power generation was compared, and finally the reduction of the heat rate of the turbine was discussed as a decrease in coal consumption.

1. Introduction

Previously, most domestic power plants and some power industry research institutes relied on experience accumulation for low-pressure economizer performance tests. There was no uniform standard. Due to the inconsistent content, methods and processes of different technicians, the test results lacked credibility. Therefore, to improve the scientific and reliability of the test results, it is particularly urgent to prepare a standardized unified test method for low-pressure economizer performance. The "Low Pressure Economizer Performance Test Guidelines" (DL/T 1885-2018) industry standard clarifies the basic conditions and requirements of the low-pressure economizer performance test, standardizes the measurement and calculation methods, unifies the principle of result correction, and fills up the. The industry gap has important guiding significance for standardizing and guiding the energy consumption evaluation of thermal power plant energy-saving equipment [1, 2].

2. Assumptions

In order to facilitate discussion of the main issues and simplify the secondary links, here are some assumptions: 1. Only discuss the coal consumption of power generation of the unit; 2. Assume that the heat loss of the pipeline has no heat loss. The actual calculation of coal consumption should also consider the impact of heat loss on the heat generation efficiency of the unit; 3. Steam turbines, generators, and heat recovery systems. Included in a system, referred to as a turbine, the heat loss of the generator cooling should be included in the heat loss of the turbine; 4. Hypothesis: Due to the two cases discussed, the power generation of the unit is constant, so the mechanical efficiency of the turbine can be considered. The efficiency of the generator and the heat transfer efficiency of the thermal system are inconvenient, and only the heat loss of the exhaust steam of the steam turbine changes. 5. Some auxiliary machines will bring back some heat from the thermal system, but because of the small magnitude, the input heat
of these systems is ignored here. 6. Only the low-pressure economizer is placed at the entrance of the precipitator and there is no bypass flue; other arrangements, the heat balance will be different, but the analysis is the same, and the conclusions are similar [3, 4].

3. Calculation of coal consumption for power generation when pumping steam is used as low-pressure (low temperature) heat recovery source

In order to facilitate the comparison of the two cases, the heating of the turbine is divided into two parts, namely \( \Sigma Q_{dy} \) and \( \Sigma Q_1 \); the total loss of the boiler is also divided into two parts, namely \( \Sigma L_{lqt} \) and \( \Sigma L_1 \):

- \( \Sigma Q_{dy} \)—the low-pressure heat recovery heat supply when the unit uses extraction steam as a low-pressure (low temperature) heat source, kJ/h;
- \( \Sigma Q_1 \)—When the unit uses extraction steam as a low-pressure (low-temperature) heat source, the turbine system supplies heat other than the low-pressure heat recovery heat supply, kJ/h;
- \( \Sigma L_{lqt} \)—the total heat loss of the boiler system in addition to the total exhaust heat loss and the physical heat loss of the fly ash, including solid and gas incomplete combustion, heat dissipation, slag physical heat loss, kJ/h;
- \( \Sigma L_1 \)—total heat loss from flue gas system and other heat loss from physical heat loss of fly ash, kJ/h;

(1) Heat balance of the entire unit

a. thermal equilibrium relationship

\[
E \cdot a + (\sum L_j + (\sum L_{lqt} + \sum L_i)) = B_h \cdot Q_{bu}\]  \hspace{1cm} (1)

b. Unit power generation efficiency

\[
\eta = \frac{E \cdot a}{B_h \cdot Q_{bu}} \hspace{1cm} (2)
\]

(2) Thermal balance of the turbine system

a. thermal equilibrium relationship

\[
E \cdot a + \sum L_j = (\sum Q_1 + \sum Q_{dy}) \]  \hspace{1cm} (3)

b. Turbine system power generation efficiency

\[
\eta_j = \frac{E \cdot a}{(\sum Q_1 + \sum Q_{dy})} \]  \hspace{1cm} (4)

(3) Heat balance of the boiler system

a. thermal equilibrium relationship

\[
(\sum Q_1 + \sum Q_{dy}) + (\sum L_{lqt} + \sum L_i) = B_h \cdot Q_{bu} \]  \hspace{1cm} (5)

b. Boiler system power generation efficiency

\[
\eta_i = \frac{\sum Q_1 + \sum Q_{dy}}{B_h \cdot Q_{bu}} \]  \hspace{1cm} (6)
(4) Power generation coal consumption of the unit

\[ \eta = \frac{E \cdot a}{B_b \cdot Q_{bn}} = \frac{E \cdot a}{\sum Q_i + \sum Q_{dy}} \frac{\sum Q_i + \sum Q_{dy}}{B_b \cdot Q_{bn}} = \eta_j \cdot \eta_i \]  \hspace{1cm} (7)

\[ b_j = \frac{0.123}{\eta} = \frac{0.123}{\eta_j \cdot \eta_i} \]  \hspace{1cm} (8)

4. Calculation of coal consumption for power generation when the unit uses low-pressure (warm) economizer as low-pressure (low-temperature) regenerative heat source

1. The case of low-pressure (warm) economizer as equipment in the boiler boundary

   Symbol Description:
   \( \Sigma L_{j1} \) — uses low time, the total heat loss of the turbine system is kJ/h;
   \( \Sigma Q_{1} \) — When the unit is used as a low-pressure (low-temperature) heat source, the turbine system heating unit other than the low-pressure residual heat supply heat, kJ/h;
   \( B_{b1} \) — combustion of coal with standard coal in low-saving boilers, kg/h;
   \( \Sigma L_{lqt} \) — total other heat loss with a low-saving boiler system, kJ/h;
   \( \Sigma L_{l1} \) — the heat discharged from the flue gas and fly ash from the low-time boiler air preheater, kJ/h;
   \( \Sigma L_{l1} \) — the sum of the total heat loss from the low-time boiler system and the total heat loss of the fly ash, kJ/h;

   (1) Heat balance of the entire unit
      a. thermal equilibrium relationship

\[ E \cdot a + (\sum L_{j1} + (\sum L_{lqt} + \sum L_{l1})) = B_{b1} \cdot Q_{bn} \]  \hspace{1cm} (9)

b. Unit power generation efficiency

\[ \eta_i = \frac{E \cdot a}{B_{b1} \cdot Q_{bn}} \]  \hspace{1cm} (10)

(2) Thermal balance of the turbine system

a. thermal equilibrium relationship

\[ E \cdot a + \sum L_{j1} = (\sum Q_i + \sum Q_{dy}) \]  \hspace{1cm} (11)

b. Turbine system power generation efficiency

\[ \eta_{j1} = \frac{E \cdot a}{(\sum Q_i + \sum Q_{dy})} \]  \hspace{1cm} (12)

(3) Heat balance of the boiler system

a. thermal equilibrium relationship

\[ (\sum Q_i + \sum Q_{dy}) + (\sum L_{lqt} + \sum L_{l1}) = B_{b1} \cdot Q_{bn} \]  \hspace{1cm} (13)
b. Boiler system power generation efficiency

$$\eta_{bl} = \frac{\sum Q_1' + \sum Q_{dy}}{B_{b1} \cdot Q_{bl}}$$  \hspace{1cm} (14)

(4) Power generation coal consumption of the unit

$$\eta_i = \frac{E \cdot a}{B_{b1} \cdot Q_{bl}} = \frac{E \cdot a}{\sum Q_1' + \sum Q_{dy}} \cdot \frac{\sum Q_1' + \sum Q_{dy}}{B_{b1} \cdot Q_{bl}} = \eta_{j1} \cdot \eta_{l1}$$  \hspace{1cm} (15)

$$b_{j1} = \frac{0.123}{\eta_i} = \frac{0.123}{\eta_{j1} \cdot \eta_{l1}}$$  \hspace{1cm} (16)

2. The case of a low pressure (warm) economizer as a separate device outside the boiler boundary

Heat balance diagram when reheating heat source (lower than outside the boiler boundary)

(1) Heat balance of the entire unit

a. thermal equilibrium relationship

$$E \cdot a + (\sum L_{j1} + (\sum L_{q1} + \sum L_{l1})) = B_{b1} \cdot Q_{bo}$$ \hspace{1cm} (17)

b. Unit power generation efficiency

$$\eta_i = \frac{E \cdot a}{B_{b1} \cdot Q_{bl}}$$ \hspace{1cm} (18)

(2) Thermal balance of the turbine system

a. thermal equilibrium relationship

$$E \cdot a + \sum L_{j1} = (\sum Q_1' + \sum Q_{dy})$$ \hspace{1cm} (19)

b. Turbine system power generation efficiency

$$\eta_{j1} = \frac{E \cdot a}{(\sum Q_1' + \sum Q_{dy})}$$ \hspace{1cm} (20)

(3) Heat balance of the boiler system

$$\sum Q_1' + \sum L_{l1}' + \sum L_{q1} = B_{b1} \cdot Q_{bl}$$ \hspace{1cm} (21)

(4) Thermal balance of low-province systems

$$\sum Q_{dy} + \sum L_{j1}' = \sum L_{l1}'$$ \hspace{1cm} (22)

(5) The combined heating efficiency when the boiler and the low province jointly provide heat to the steam turbine
The joint heating balance equation is:
Adding the left and right ends of "Formula-21" and "Formula-22" respectively, finishing can be obtained:

\[
\sum Q_1 + \sum Q_{dy} + (\sum L_{iq} + \sum L_{yi}) = B_{h1} \cdot Q_{bn} \quad (23)
\]

It can be seen that "Formula-23" is exactly the same as "Formula-13", that is, whether the low temperature economizer is placed in the boiler side or outside the boundary, the resulting joint heating balance is the same.

The combined heat supply efficiency is:

\[
\eta_{lb} = \frac{\sum Q_1 + \sum Q_{dy}}{B_{h1} \cdot Q_{bn}} = \eta_{l1} \quad (24)
\]

(4) Power generation coal consumption of the unit

\[
\eta_{lb} = \frac{E \cdot a}{B_{h1} \cdot Q_{bn}} = \sum \frac{\sum Q_1 + \sum Q_{dy}}{B_{h1} \cdot Q_{bn}} = \eta_{j1} \cdot \eta_{lb} = \eta_{j1} \cdot \eta_{l1} \quad (25)
\]

\[
b_{f_{lb}} = \frac{0.123}{\eta_{lb}} = \frac{0.123}{\eta_{j1} \cdot \eta_{lb}} = \frac{0.123}{\eta_{j1} \cdot \eta_{l1}} = \frac{0.123}{\eta_1} \quad (26)
\]

5. Comparison of coal consumption of power generation when regenerative heat sources are not different

5.1. Comparison of heat balance of steam turbine system when regenerative heat source is different

1. Using extraction steam as a regenerative steam source

   Obtained by (2)

\[
E \cdot a + \sum L_j = (\sum Q_1 + \sum Q_{dy}) \quad (27)
\]

2. Using low province as a regenerative steam source

   By (11)

\[
E \cdot a + \sum L_{j1} = (\sum Q_1 + \sum Q_{dy}) \quad (28)
\]

3. Comparison of heating efficiency of steam turbine power generation in two cases

   Comparing the above two formulas, when using the low-efficiency as the regenerative steam source, the steam flow rate of the steam turbine is reduced, and if the same electricity is generated, the main steam flow rate entering the steam turbine is decreased, and the hot steam flow rate is increased, that is, the main steam work is reduced. The reheat steam is increased in work. At this time, due to the increase in the amount of exhaust steam, the heat loss of the exhaust steam is increased, that is, \( \Sigma L_{j1} > \Sigma L_{j1} \). Since the power generation amount \( E \) is the same in both cases, the left side of the "(2)" equation is larger than the left side of "(11)", so the right side of the "(2)" equation is larger than the right side of "(11)", and the right side of the equation is the total heat generation of the unit. Since the power generation is the same, the heat consumption rate of the steam turbine when using the low-efficiency steam recovery source is larger than that when the steam extraction steam is used as the heat recovery steam source.
Comparing "(3)" and "(12)", it can be seen that the heat consumption rate of the turbine when using the low-recovery steam source is smaller than that when using the steam as the regenerative steam source, that is, The heat generation efficiency of steam turbine power generation is degraded. Therefore, the theory of calculating the increase in thermal efficiency of the entire unit by calculating the reduction of the heat rate of the turbine is wrong from the starting point.

5.2. Comparison of heat balance of boiler system when reheating heat source is different

(1) Using extraction steam as a regenerative steam source, by "(5)"

\[ (\sum Q_1 + \sum Q_{dy}) + (\sum L_{ap} + \sum L_{l}) = B_b \cdot Q_{bn} \]  

(29)

(2) Use low province as regenerative steam source, by "(13)"

\[ (\sum Q_1' + \sum Q_{dy}) + (\sum L_{ap} + \sum L_{l1}) = B_{b1} \cdot Q_{bn} \]  

(30)

It can be launched by "(22)"

\[ \sum L_{l1} = \sum L_{l1}' - \sum Q_{dy} \]  

(31)

As the overall steam extraction volume does not change much, the steam heat loss of the steam turbine does not increase much, so the total heat consumption does not increase much. It can be approximated as follows:

\[ (\sum Q_1 + \sum Q_{dy}) \approx (\sum Q_1' + \sum Q_{dy'}) \]  

(32)

(3) Comparison of boiler heating efficiency in two cases

As the exhaust gas temperature drops, the total other heat losses except the physical heat loss of the flue gas and fly ash are the same in both cases. When the low heat is used as the regenerative steam source, the boiler heat loss $\Sigma L_{11}$ is lower than the boiler heat loss $\Sigma L_1$ when the steam is used as the regenerative steam source. Therefore, the "(13)" formula is proportional to the "(5)" formula. The total heat output on the left side is reduced by the amount of $\Sigma Q_{dy}$. According to the rule that the equation is equal, the heat input to the right side of the equal sign should also decrease by the same amount. Therefore, it can be concluded that $B_{b1}$ is smaller than $B_b$, and $B_{b1}$ can be derived smaller than $B_b$. $Q_{yd}$ The magnitude of $Q_{bn}$. Further, it can be introduced that the heat generation efficiency $\eta$ of the boiler power generation is increased, and the thermal efficiency increase rate of the low-saving time-saving boiler is $\Sigma Q_{yd} \cdot (1/B_{b1}-1/B_b)$. Therefore, it is completely due to the improvement of boiler efficiency that the unit's power generation efficiency is increased, which results in a decrease in coal consumption for power generation.

2. Comparison of coal consumption of power generation in two cases

By comparing "(8)" and "(16)", the heat efficiency of steam turbine power generation decreased slightly, but the decline rate was not large, and the boiler power generation efficiency increased, and the increase rate was large, so the whole unit power generation The thermal efficiency has increased, resulting in a decrease in coal consumption for power generation.

6. Conclusion

Regarding the reduction of steam heat rate as a discussion of coal consumption loss, only if $\Sigma Q_{yd}$ is not used as part of the heat supply of steam turbines, the conclusion that the heat consumption rate of steam turbine power generation will decrease will be obtained, and the left and right sides of "(11)" will be treated in this way. If the relationship is lost, the heat balance between input and output is not established.
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