Application Research and Thermal Economic Evaluation of Low-Pressure Economizer on Coal-Fired Units

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Abstract. The energy saving principle, layout and key parameters of low-pressure economizer on coal-fired units are introduced. Taking a 220MW unit as an example, the thermal economy of low pressure economizer is evaluated by equivalent enthalpy drop method.

1. Introduction

At present, the designed flue gas temperature of coal-fired boilers is generally between 120-140 ℃, but the average exhaust temperature of a large number of coal-fired boilers is above 160 ℃, and a large amount of heat is lost with the high-temperature exhaust flue gas. Therefore, it is of great significance to reduce the exhaust gas temperature and make deep use of the waste heat of flue gas to improve the economy of the unit and to reduce the coal consumption of power generation. The low-pressure economizer is a system which is widely used to reduce the exhaust gas temperature to recover waste heat, using flue gas to replace part of steam extraction to heat part of condensate water by squeezing out steam extraction to do work to realize energy saving.

Wanchao Lin of Xi'an Jiaotong University has made a thorough analysis of the thermal economy of low-pressure economizer system by using the theory of equivalent enthalpy drop [1]; Zhenqi Zhou of Northeast Electric Power University has used the principle of equivalent enthalpy drop to analyze the thermal economy of coal-fired units equipped with low-pressure economizer [2]; Xinyuan Huang of Shandong University has also made an analysis of the low-pressure economizer of coal-fired power plants. The optimum design and operation of the low-pressure economizer in coal-fired power plants are studied in depth, and a general mathematic model for optimum design of the low-pressure economizer in coal-fired power plants is proposed [3-4].

This paper introduces the energy-saving principle, layout mode and determination method of key parameters of low-pressure economizer on coal-fired units. Taking a 220 MW unit as an example, the thermal economic evaluation is carried out by using equivalent enthalpy drop method.

2. Energy-saving principle of low pressure economizer

The installation of low-pressure economizer is one of the effective measures to save energy and reduce consumption by utilizing the waste heat of boiler exhaust gas. The low-pressure economizer is installed at the back of the boiler, and its structure is similar to that of the economizer.
The characteristic of low-pressure economizer is that it is directly connected to the regenerative heating system and is a part of steam turbine thermal system. The condensate water in the low-pressure regenerative system of steam turbine enters the low-pressure economizer, and after heat exchange in the heat exchanger absorbing the heat from the high-temperature exhaust gas of the boiler, it returns to the entrance of a certain low-pressure regenerative heater, thereby increasing the temperature of the condensate water and realizing the recovery and utilization of the waste heat from the exhaust gas of the boiler.

After adding low-pressure economizer in the system, a large amount of waste heat from flue gas enters the regenerative system, which will squeeze out part of the extraction steam and reduce the thermal cycle efficiency of the system. At the same time, the exhaust of the condenser will increase and the vacuum of the steam turbine will decrease, which is the main question about the energy saving of low-pressure economizer. Theoretically, after adding a low-pressure economizer, a large amount of waste heat from flue gas enters the regenerative system, but this is the additional heat that is absorbed and reused by the waste heat without increasing the fuel of the system. It must be converted to electrical work with a certain efficiency. This part of the extra thermal work is much larger than the thermal work loss caused by reducing the steam extraction and microdrop of steam turbine vacuum, and the overall economic efficiency of the unit is improved.

3. Arrangement mode

3.1. Installation location

3.1.1. Between ESP and FGD. The low-pressure economizer reduces the flue gas temperature to about 110 °C, enters the desulfurization tower, and the heated condensate enters the regenerative system for circulation. In this arrangement, the low-pressure economizer actually acts as the role of flue gas cooling in the GGH heater. The low-pressure economizer is in low dust area, and the wear degree of fly ash on pipe wall is greatly reduced. Since most of the alkaline particles in the flue gas are trapped by ESP and the flue gas at the outlet is acidic, the corrosion in the low-pressure economizer and the subsequent flue should be considered. In addition, ash deposition in operation will also affect the heat transfer effect of low-pressure economizer. The advantage of this arrangement is that the economizer system and the regenerative system can be safely and reliably separated, and the safe operation of the unit will not be affected when accidents such as the leakage of the economizer occur; the disadvantage is that it can not make use of the advantages brought by the reduction of flue gas temperature to improve the operation efficiency of the electrostatic precipitator and to reduce the power of the induced draft fan and the booster fan.

![Figure 1. Between ESP and FGD.](image)

3.1.2. Before ESP. The heat transfer temperature difference is low, the heat transfer area is large, and the space is large, so when installing low temperature economizer, it is necessary to reasonably consider the location of the flue in the boiler site. The optimization design method of heating surface can be used to reduce the size of low temperature economizer and alleviate the difficulties in
arrangement. For example, the finned tube can be used instead of the smooth tube to increase the heat transfer area, and the number of tube rows can be greatly reduced. The low pressure economizer works in high dust area, so the wear of fly ash on pipe wall must be considered. The greatest risk of this arrangement is corrosion. Because of the flue gas temperature after the low pressure economizer is close to the acid dew point of the flue gas, dust collector, flue, induced draft fan and booster fan may have corrosion risk.

Figure 2. Before ESP.

3.1.3. Two-stage arrangement. The first stage is arranged between the air preheater and the dust collector. The main consideration is that the flue gas outlet temperature is higher than the acid dew point to avoid the corrosion of downstream equipment. The second stage is arranged at the entrance of the desulfurizer. This arrangement generally sets the condensate water bypass of the first low-pressure economizer. When the load is low, part of the condensate water takes the first bypass to reduce the heat absorbed by the flue gas, so that the flue gas temperature at the outlet of the economizer is always above the acid dew point of the flue gas, so as to avoid the corrosion of the dust collector, flue and other equipment.

At present, the three schemes have been successfully applied at home and abroad, while the first one has been adopted more in China.

3.2. Connection mode
According to the position of inlet and outlet point of low pressure economizer in thermal system, it can be divided into series and parallel arrangement.

Series arrangement. As shown in Figure 3 of the series arrangement, all condensate water from the N-1 stage heater enters the low-pressure economizer in the tail flue, and returns to the N stage heater after absorbing the waste heat of the flue gas. The advantage of series system is that the amount of water flowing through low pressure economizer is the largest. When the heating area of low pressure economizer is fixed, the cooling degree of boiler flue gas and the heat load of low pressure economizer are larger, and the utilization degree of waste heat of flue gas is higher. The drawback is that the resistance of condensate water increases, and the condensate pump may have to be replaced because of insufficient pressure head of condensate pump.

Figure 3. Series arrangement.

3.2.1. Parallel arrangement. Parallel system, as shown in Figure 4, can divert water across one or more heaters. The water flow through low-pressure economizer is defined as Dd, and the ratio of Dd to D0 is defined as the water dividing coefficient β. For parallel systems, heat Q not only squeezes out
N-stage steam extraction, but also squeezes out all heaters around N-stage steam extraction. The advantage of parallel system is that it is unnecessary to replace condensate pump, because the resistance reduced by bypassing one or more heaters is enough to compensate for the increased resistance of low-pressure economizer and connecting pipes. Besides, it is also convenient to realize the cascade development and utilization of waste heat energy. The disadvantage is that the heat transfer temperature-pressure ratio of parallel system is lower than that of series system. Because the diversion flow is less than the total flow, the outlet water temperature of parallel system will be higher than that of series system, and the utilization degree of exhaust waste heat is relatively lower.

![Figure 4. Parallel arrangement.](image)

4. Parameter determination

4.1. Water diversion flow
In parallel system, the temperature of exhaust gas can be controlled by adjusting the operation of low pressure economizer, that is, by changing the influent flow rate of low pressure economizer. However, changing the inlet water flow rate in operation will affect the outlet water temperature and thermal economy of low pressure economizer. According to the equivalent enthalpy drop theory, when the water flow of low pressure economizer increases, the water partition coefficient increases, which is favorable to the increase of equivalent enthalpy drop increment. But at the same time, the increase of water flow reduces the enthalpy of outlet water of low pressure economizer, and decreases the equivalent enthalpy drop increment. Therefore, there is a problem of determining the optimal feed water flow rate in the operation of low pressure economizer.

4.2. Inlet water temperature
The inlet water temperature of low-pressure economizer also has a question of selecting the best value. In addition, the thermal corrosion and ash plugging of low pressure economizer should be considered. When the two can not be coordinated, the thermal corrosion problem can only be given priority. In most cases, the optimal inlet temperature is much lower than the inlet temperature required by thermal corrosion. Therefore, the actual inlet temperature of low pressure economizer is restricted by thermal corrosion factors. According to the mechanism of low temperature corrosion and the relationship between corrosion and wall temperature, the annual corrosion rate of metal is less than 0.2mm. The temperature of the tube wall of the low pressure economizer shall be within the following range: t_{ld} + 25°C < t < 105°C, in which t_{ld} is the dew point of vapor in the flue gas, which can be calculated according to the elemental analysis of the fuel.

4.3. Outlet position
Condensate from the outlet of low-pressure economizer can be introduced into different low-pressure heaters, and the increment of equivalent enthalpy drop is different when the position of the inlet of low-pressure economizer is different. The higher the enthalpy value of condensate water at the outlet of low pressure economizer is, the greater the cooling degree of exhaust smoke and the utilization of exhaust heat are, and the better the economy of low pressure economizer is. The higher the waste heat
level of exhaust smoke is, the better its economy is. Obviously, while raising the waste heat level of exhaust gas, it will raise the exit gas temperature of low-pressure economizer and reduce the utilization degree of waste heat of exhaust gas. Because of these two contradictory factors, it can be inferred that there is an optimal outlet position for low pressure economizer. This position can be determined by thermodynamic calculation or thermal test.

5. Economic evaluation of low pressure economizer

The thermal economic evaluation methods of low pressure economizer include equivalent enthalpy drop method, heat consumption transformation coefficient method, heat balance method, local quantitative analysis method and thermal test method. Among them, the equivalent enthalpy drop method can obtain the economic effect of the change of the whole thermal system only by quantitatively calculating the extraction steam flow and heat of certain stages. Therefore, it has become the mainstream method for the economic evaluation of low pressure economizer. Equivalent enthalpy drop method regards exhaust waste heat recovered from low pressure economizer as pure heat input system, while the energy consumption of boiler producing 1 kg new steam remains unchanged. Under this premise, all the additional power generated by exhaust steam in the system will improve the efficiency of steam turbine.

5.1. Calculation of coal consumption reduction in power generation

Total work done by 1 kg new steam is called equivalent enthalpy drop of the new steam (recorded as $H$, kJ/kg). The additional work of the exhaust extraction is called equivalent enthalpy drop increment (recorded as $\Delta H$, kJ/kg). It is calculated as follows:

$$H = \frac{3600}{\eta_{jd}} \cdot d$$  \hspace{1cm} (1)

Where: $d$ is the steam consumption rate of the unit, kg/(kW·h); $\eta_{jd}$ is the electromechanical efficiency of the turbine, %.

$$\Delta H = \beta(h_d - h_{m-1})\eta_m + \sum \left( \beta_j \tau_j \eta_j \right)$$  \hspace{1cm} (2)

Where: $\beta$ is flow coefficient of low pressure economizer, %; $h_d$ is the specific enthalpy of low pressure economizer, kJ/kg; $h_{m-1}$ is the specific enthalpy of inlet water of lower stage heater at outlet of low pressure economizer, kJ/kg; $\eta_m$ is extraction efficiency of m-low pressure heater, %; $\beta_j$ is the flow coefficient of j low pressure heater bypassed, %; $\tau_j$ is the enthalpy rise of the refrigerant of j-low pressure heater bypassed, kJ/kg; $\eta_j$ is the extraction efficiency of j-low pressure heater bypassed, %.

The low pressure economizer makes the thermal economy of the unit relatively improve:

$$\delta \eta = \frac{\Delta H}{H + \Delta H}$$  \hspace{1cm} (3)

The reduction of steam consumption of the unit is:

$$\Delta D = D \times \Delta \eta_i$$  \hspace{1cm} (4)

Where: $D$ is the steam consumption rate of the unit, kg/s.

Relative reduction of unit heat consumption $\Delta q$ (kJ/(kW·h)) is:

$$\Delta q = q \times \Delta \eta_i$$  \hspace{1cm} (5)
Where: $q$ is the heat consumption rate of the unit, kJ/(kW·h).

Reduction of coal consumption for power generation $\Delta b$ (kg/(kW·h)) is:

$$\Delta b = \frac{\Delta q}{\eta_g \times \eta_b \times 29271}$$

Where: $\eta_g$, $\eta_b$ is pipeline efficiency and boiler efficiency, %.

![Figure 5. Schematic diagram of low pressure economizer system of a 220MW coal-fired unit.](image)

Table 1. Energy saving calculation results of low pressure economizer of a 220MW unit.

| Item                                      | value     |
|-------------------------------------------|-----------|
| Inlet flue gas temperature/°C             | 165.39    |
| Outlet flue gas temperature/°C            | 103.65    |
| Heat exchange/kW                          | 21700     |
| Outlet water temperature/°C               | 120.09    |
| Equivalent enthalpy drop/kJ/kg            | 1215.77   |
| Equivalent enthalpy drop increment/kJ/kg  | 14.22     |
| Reduction of heat consumption/%           | 1.16      |
| Reduction of coal consumption for power generation/g/(kW·h) | 3.56      |

5.2. Calculation of vacuum effect of steam turbine

For wet cooling units, the relationship between turbine back pressure increment $\Delta P_c$ and condensate increment $\Delta D_c$ can be calculated by means of variable working condition of condenser or by the following formula:

$$\Delta P_c = 2.059 \times \Delta D_c / D_c$$

(7)
\[ \Delta D_c = \sum D_j - dD_0 \]  

Where: \( D_c \) is condensing capacity of condenser, t/h; \( \Delta D_c \) is the decrease value of new steam flow caused by adding low pressure economizer, t/h, which can be calculated by \( \Delta b \); \( \Sigma D_j \) is the total amount of extraction to condenser, t/h, which is reduced by low pressure economizer. Where the reduction of class j is based on the following formula:

\[ D_j = 3.6G\gamma_j \tau_j / q_j \]  

Where: \( G \) is flow rate of low pressure economizer, kg/s; \( \gamma_j \) is reduced coefficient, %, which refers to the proportion of the steam extraction from j class arriving at the condenser.

The test and calculation on load 220MW show that the total extraction volume reduced to the condenser is 14.12t/h, the low pressure economizer saves 5.64t/h of new steam, the net condensate increases 8.48 t/h, and the back pressure of steam turbine increases 0.0404kPa. The specific enthalpy of steam turbine exhaust is increased by 0.457kJ/kg, which accounts for only 0.038% of the equivalent enthalpy drop of the new steam. Therefore, the effect of reducing extraction on steam turbine vacuum and steam turbine work can be neglected.

6. Conclusion

Low temperature corrosion and flue gas wear should be taken into account in the layout of low pressure economizer. The material of low pressure economizer should be chosen according to the working conditions of the unit. Because of the lower water resistance in the parallel system, there is no need to replace the condensate pump, and the reconstruction project is favorable to the construction, when the economizer failure will not cause accidents affecting the safe operation of the unit, the parallel mode is given priority. Through the calculation of energy saving after installing low pressure economizer, it can be seen that adding low pressure economizer has practical and feasible significance in reducing flue gas exhaust temperature, saving energy and reducing consumption, and improving the thermal economy of the unit.

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