Application and Benefit Calculation of Waste Heat Recovery of Power Plant Boiler

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Abstract. In the boiler combustion of power plants, the smoke loss is the main combustion heat loss of the boiler. Reducing the exhaust gas temperature is one of the main means to reduce the heat loss of the exhaust gas, and it is also the main measure for improving the thermal efficiency of the boiler in each power plant. This paper summarizes and discusses the application and economics of installing composite phase change heat exchangers for coal-fired boilers.

1. Introduction
With the intensification of competition among enterprises and increasingly strict energy conservation, emission reduction and environmental protection requirements, further fuel consumption has become one of the top priorities for the future development of enterprises, which makes it possible to make full use of the heat generated by coal combustion and improve the utilization efficiency of heat energy, it is very important [1].

In thermal power plants, there are many ways to use the waste heat of boilers [2-5]. This paper focuses on the economics of a 330MW subcritical parameter boiler after the installation of composite phase change heat exchangers.

2. Working principle of composite phase change heat exchanger
In the context of different applications, the composite phase change heat exchanger can design and combine many variations, but the basic working principle is unchanged. Its structural form is shown in Figure 1. The composite phase change heat exchanger structure is mainly divided into two parts: the evaporation section and the condensation section. The combined phase change heat exchanger upper and lower heat exchangers are connected by the steam-water separation device, saturated steam and saturated water naturally circulates in a closed system [6]. When the phase change heat device is applied to the flue of the boiler tail, the evaporation section of the phase change heat absorber absorbs the heat of the flue gas at the tail of the boiler, the internal medium of the heat exchanger is in a phase change state, and enters the steam drum along the riser pipe for steam and water separation, and then the steam enters the condensation section of the phase change heat. In the condensation section, the internal steam of the phase change heat exotherms the external medium (air or condensate, etc.), the
steam is condensed into a liquid, and is circulated along the loop to the evaporation section to complete a cycle. In this cycle, the wall temperature can be adjusted and controlled by adjusting the flow rate of the heat exchange medium.

Figure 1. Compound phase changer schematic.

3. Application of compound phase change heater in power plant boilers

3.1. Boiler operation status
A unit in Tianjin area is HG1102/17.5-YM33 coal boiler. The boiler is 330MW subcritical parameter, one intermediate reheating, single-axis two-cylinder double-row steam heating and steaming coal-fired unit, synchronous installation of desulfurization and denitration equipment, balanced ventilation, Solid-state slagging, semi-open-air layout, all-steel framed drum furnace.

Under the normal operating conditions of the unit in summer, the exhaust gas temperature is as high as 155°C. The power plant operators can not achieve the expected effect by changing the traditional method of reducing the exhaust gas temperature by burning coal quality and regular soot blowing. Excessive exhaust gas temperatures result in a drastic reduction in the life of the unit bag. In a minor repair of the unit in a certain year, it was found that the bag of the dust collector had been damaged in a large area, and it was no longer able to continue to use it after being identified. After extensive analysis and investigation, the conclusion is that the exhaust gas temperature is too high. From the start-up to the replacement, the service life of the bag has only lasted for 2 to 3 years. Reducing the exhaust gas temperature will inevitably increase the service life of the bag and reduce the maintenance and operation costs.

3.2. Transformation plan
The heat absorption section of the composite phase change heat is placed in the flue after the air preheater, the waste heat of the flue gas of the tail flue is recovered, the exhaust gas temperature is lowered, and the heat recovery is transferred to the heat release section by the phase change of the water medium. In summer, it is used to heat the condensate from the #8 low pressure heater inlet to the #7 low pressure heater outlet, thereby reducing the steam recovery and steam extraction of the steam turbine, increasing the power generation and reducing the coal consumption for power supply; in winter, it is used to heat the heating and return water, saving energy and reducing consumption. The device flexibly configures the heat absorption section and the heat release section geometry of the heat exchanger, on the one hand, it satisfies the requirement that the minimum wall temperature is higher than the flue gas acid dew point; on the other hand, the efficiency of the phase change heat transfer is
fully exerted, and the wall temperature is the exhaust gas temperature maintains a small temperature
difference. Under the premise of ensuring that the heated surface is not dew condensation, the exhaust
gas temperature is lowered, and the "maximum amplitude" is effective for cooling and energy saving,
improving boiler thermal efficiency and corrosion resistance.

3.3. Transformation effect

After the transformation, the exhaust temperatures of the inlet and outlet of the composite phase
change heat exchanger were tested in the summer and winter by grid method. The data are
summarized in Table 1 and Table 2:

| Measuring hole Numble | Phase change heat exchanger inlet exhaust temperature ℃ | Phase change heat exchanger outlet exhaust temperature ℃ |
|-----------------------|--------------------------------------------------------|--------------------------------------------------------|
| 1                     | 154.5                                                  | 129.5                                                  |
| 2                     | 154.0                                                  | 129.2                                                  |
| 3                     | 154.6                                                  | 129.4                                                  |
| 4                     | 154.2                                                  | 129.1                                                  |
| Average value         | 154.33                                                 | 129.30                                                 |

| Measuring hole Numble | Phase change heat exchanger inlet exhaust temperature ℃ | Phase change heat exchanger outlet exhaust temperature ℃ |
|-----------------------|--------------------------------------------------------|--------------------------------------------------------|
| 1                     | 144.5                                                  | 120.6                                                  |
| 2                     | 144.4                                                  | 120.2                                                  |
| 3                     | 144.7                                                  | 120.3                                                  |
| 4                     | 144.3                                                  | 120.4                                                  |
| Average value         | 144.48                                                 | 120.38                                                 |

It can be seen from the test data after the transformation that the outlet temperature of the summer
phase change heat exchanger is 25.0°C lower than the inlet temperature, and the outlet temperature of
the winter phase change heat exchanger is 24.1°C lower than the inlet temperature, and the exhaust gas
temperature is successfully controlled at the design value. In the range of 130°C, the cooling effect
after the transformation is remarkable.

4. Phase conversion heat exchanger benefit calculation and economic analysis

The coal quality data, annual average load, annual running time and exhaust gas temperature used in
the calculation are all calculated according to the operation records before the transformation of the
power plant; the reference of each low-added extraction enthalpy, hydrophobic enthalpy and turbine
exhaust enthalpy Turbine steam-water balance diagram under THA conditions; flue gas flow using
measured values; according to power generation coal consumption of 350g/(kw.h), standard coal price
is 700 yuan/ton, annual operating time is calculated to be 7013 hours (winter The heating time is four
and a half months, that is, 3240 hours and summer 3773 hours).

4.1. Summer energy saving

4.1.1. Phase change heat recovery heat calculation.

$$Q = \frac{V \times \rho \times G \times \Delta T \times \varphi}{3600} \quad (1)$$
4.1.2. Equivalent standard coal quantity.

![Diagram](image)

**Figure 2.** Schematic diagram of increasing pipeline reform in summer heat recovery system.

Since the water temperature at the outlet of the composite phase change heat exchanger is lower than the water temperature of the unit No.7 low pressure heater and the design outlet water temperature is 105.4°C, the low extraction of the No.6 low pressure heater needs to increase the partial extraction steam flow to continue heating the condensed water. No.6 low pressure heater needs to increase the steam extraction heat:

\[
Q_h = \frac{C_p \times \Delta h_h \times m}{3.6} \tag{2}
\]

The No.6 low pressure heater extraction enthalpy = 2893.7kJ/kg, and the hydrophobic enthalpy value is =465.5kJ/kg. According to the heat balance calculation, the No.6 low pressure heater needs to increase the extraction steam flow:

\[
G_e = \frac{Q_h}{h_e - h_in} \tag{3}
\]

By heating the partially condensed water by the composite phase change heat exchanger, the extraction flow rate of the No.7 low pressure heater and the No.8 low pressure heater can be reduced. The inlet water temperature of No.7 and No.8 low pressure heater design is 84.4°C and 33.8°C respectively, and the composite phase change heater effluent (temperature is 100°C) enters No.6 low pressure heater, so the extraction heat of No.7 low pressure heater reduction is:

\[
Q_7 = \frac{C_p \times \Delta h_7 \times m}{3.6} \tag{4}
\]

No.7 low pressure heater extraction enthalpy = 2767.2kJ/kg, hydrophobic enthalpy = 377.2kJ/kg, No.6 low pressure heater due to increased extraction flow 0.227kg/s, will also increase the hydrophobic flow 0.227kg/s used Heating No.7 low-pressure heater, No.6 low-pressure heater hydrophobic enthalpy = 465.5kJ/kg, according to heat balance calculation No.7 low-pressure heater to reduce extraction steam flow:

\[
G_7 = \frac{Q_7 + G_e \times (h_e - h_7)}{h_1 - h_7} \tag{5}
\]
The reduced steam heat of the No.8 low pressure heater is: 
\[ Q_h = Q - Q_s = 6748.9 - 1589.4 = 5159.5 \text{(kW)} \]

According to the heat balance calculation, the No.8 low-pressure heater reduces the extraction flow rate is:

\[ G_s = \frac{Q_a - (G_s - G_a) \times (h_{a_2} - h_{a_1})}{h_a - h_{a_1}} \]  
(6)

The pumping flow reduced by the No.7 and No.8 low-pressure heaters is used for power generation, and the equivalent power drop is used to calculate the increased power generation:

\[ N_e = (H_h \times G_h + H_i \times G_i - H_a \times G_a) \times \eta_e \times \eta_m \]  
(7)

Calculated by the summer running time of 3773 hours and the coal consumption of coal power of 350g/(kW•h), the amount of standard coal saved by heating condensate is: 1015.7t/a.

4.2. Winter energy savings

Phase change heat recovery heat:

\[ Q = \frac{V_g \times \rho_g \times \Delta T \times \varphi}{3600} \]  
(8)

Equivalent standard coal quantity:

\[ G_r = \frac{860 \times Q \times HR}{Q^2 \times \eta_e \times 1000} \]  
(9)

4.3. Calculation of increased energy consumption after adding a composite phase change heat exchanger

The added energy consumption after the addition of the composite phase change heat exchanger includes the increased energy consumption of the induced draft fan, the increase of energy consumption by the booster pump in summer, and the increase of energy consumption by the booster pump in winter.

4.4. Energy saving and benefit calculation

From this, it can be calculated that the amount of standard coal saved in one year is 3465.9t/a.

According to the average calculation of 700 yuan per ton of standard coal, it can be concluded that the annual savings of 2.43 million yuan. At the same time, it can reduce about 8,640 tons of carbon dioxide, 2,357 tons of carbon, 2,357 tons of dust, 260 tons of sulfur dioxide and 130 tons of nitrogen oxides.

5. Conclusion

The use of phase change heat to recover the waste heat of the boiler exhaust can greatly reduce the discharge temperature of the flue gas, resulting in considerable economic and social benefits. Therefore, the phase change heat exchanger can be widely applied to other power plants to exert its excellent characteristics of recovering low-temperature residual heat.

References

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