Energy Efficiency Analysis of Hot Oil Heater System with Waste Heat Recovery Device

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Abstract. In this paper, the energy efficiency analysis of a hot oil heater system with waste heat recovery device is carried out by using the counter balance method. The influence of different excess air coefficient and different flue gas recirculation percentage on the energy efficiency is studied. Through comparative analysis, it is concluded that: as excess air coefficient increases, the exhaust gas heat loss increases, the dissipation heat loss decreases, the overall heat loss increases, and the system thermal efficiency decreases; as flue gas recirculation percentage increases, the exhaust gas heat loss increases, the dissipation heat loss decreases, the overall heat loss increases, and the system thermal efficiency decreases. These conclusions provide some reference for improving the design and operation of hot oil heater system with waste heat recovery device.

1. Preface

With the rapid development of society, energy saving and emission reduction[1] become more and more important in the field of industrial furnace.

Energy saving is the primary consideration. A more energy-saving design can greatly reduce the operating cost of industrial furnace. For gas-fired industrial furnace, the thermal efficiency is generally improved by reducing exhaust gas heat loss and dissipation heat loss, so as to reduce the operation cost. The specific measures are: reducing the exhaust gas temperature, reducing the excess air coefficient, optimizing the equipment insulation and so on.

China has entered the middle and late stage of industrialization, and the severe environmental situation promotes the rapid development of energy conservation and environmental protection industry in China. The national emission standards for industrial furnaces are more and more strict. For gas-fired industrial furnaces, the emission standards for nitrogen oxides are more and more strict. The emission standards for nitrogen oxides in many local standards have reached 30mg / m3. For gas industrial furnace, in addition to the design of special low NOx burner, flue gas recirculation technology is generally used to assist in reducing NOx emission. When using flue gas recirculation technology, the higher the percentage of flue gas recirculation, the better the effect of reducing nitrogen oxides. However, when the percentage of flue gas recirculation is higher than 30%, the effect will not be better, instead it will increase the operation cost, so the percentage of flue gas recirculation is generally lower than 30%.

This paper mainly studies the influence of excess air coefficient and flue gas recirculation percentage on system energy efficiency.

According to TSG G0003-2010 " Energy Efficiency Test and Evaluation Regulation for Industrial Boiler " and GB/T 10180-2017 " Thermal Performance Test Code For Industrial Boilers ", the thermal efficiency of the hot oil heater system can be calculated by the counter balance method[2][3]. For the
hot oil heater system, when the fuel is natural gas, the calculation formula of its thermal efficiency is as follows:

$$\eta = 1 - q_2 - q_3 - q_5$$

Among them:

- $\eta$ is the thermal efficiency of hot oil heater system,\%;
- $q_2$ is the exhaust gas heat loss,\%;
- $q_3$ is the fuel gas incomplete combustion heat loss,\%;
- $q_5$ is the dissipation heat loss,\%.

The calculation formula of exhaust gas heat loss is as follows:

$$q_2 = (0.5 + 3.45 \cdot \alpha_{py}) \cdot \left(\frac{t_{py} - t_{ik}}{100}\right)\%$$

Among them:

- $\alpha_{py}$ is the excess air coefficient of exhaust gas;
- $t_{py}$ is the exhaust gas temperature, °C;
- $t_{ik}$ is the cold air temperature, °C.

When the fuel is natural gas, the fuel gas incomplete combustion heat loss can be selected as $q_3 = 0.2\%$.

The calculation formula of dissipation heat loss is as follows:

$$q_5 = \frac{1670F}{BQ_{in}} \times 100\%$$

Among them:

- $F$ is the total heat dissipation area, including the heater body, waste heat recovery device, flue gas duct and other components in the system, m²;
- $B$ is fuel gas consumption, Nm³/h;
- $Q_{in}$ is the low calorific value of fuel, kJ/Nm³.

2. Introduction of hot oil heater system with waste heat recovery device

Figure 1. Schematic diagram of hot oil heater system with waste heat recovery device
The hot oil heater system with waste heat recovery device studied in this paper include hot oil heater, air preheater and flue gas duct. They are shown in Figure 1.

The design indexes of hot oil heater system with waste heat recovery device are as follows:

| Parameter name               | Value                          |
|------------------------------|--------------------------------|
| Heat load /kcal/h            | 1600×104                       |
| Fuel                         | Natural gas (low calorific value is 8417 kcal/Nm3) |
| Exhaust gas temperature/℃   | ≤130                           |
| Thermal efficiency/%         | ≥93                            |

According to the above design indexes, the parameters of the designed hot oil heater system with waste heat recovery device are as follows:

| Equipment name   | Parameter name                    | Value |
|------------------|-----------------------------------|-------|
| Hot oil heater   | Type                              | Vertical cylindrical furnace |
|                  | Heat exchange area / m²            | 942   |
|                  | Heat dissipation area / m²         | 200   |
|                  | Excess air coefficient             | 1.15  |
|                  | Furnace outlet flue gas temperature /℃ | 359.6 |
|                  | Fuel gas consumption/Nm³/h         | 2026  |
| Air preheater    | Type                              | Tubular air preheater         |
|                  | Heat exchange area / m²            | 1310  |
|                  | Heat dissipation area / m²         | 160   |
|                  | Inlet flue gas temperature /℃     | 359.6 |
|                  | Outlet flue gas temperature /℃    | 130   |
|                  | Inlet cold air temperature /℃     | 20    |
|                  | Outlet hot air temperature /℃     | 299   |
| Flue gas duct    | Heat dissipation area / m²         | 60    |

### 3. Factors affecting system energy efficiency

During the operation of hot oil heater system with waste heat recovery device, excess air coefficient and flue gas recirculation percentage both have great influence on the thermal efficiency of the system. This paper mainly discusses the influence of excess air coefficient and flue gas recirculation percentage on the energy efficiency of the system.

#### 3.1. Influence of excess air coefficient on system energy efficiency

Based on the above-mentioned hot oil heater system with waste heat recovery device, and in the condition that the structure of hot oil heater and air preheater remains unchanged, the calculated operation parameters under different excess air coefficient are shown in the table below:

| Excess air coefficient | Flue gas recirculation percentage /% |
|------------------------|--------------------------------------|
| 1.15                   | 0                                    |
| 1.2                    | 0                                    |
| 1.25                   | 0                                    |
Furnace outlet flue gas temperature/°C 359.6 363.7 369.2
Exhaust gas temperature /°C 130 132 134
Fuel gas consumption/Nm3/h 2026 2032 2040
Exhaust gas heat loss \( q_2 /\%\) 4.914 5.197 5.486
Fuel gas incomplete combustion heat loss \( q_3 /\%\) 0.2 0.2 0.2
Dissipation heat loss \( q_5 /\%\) 0.983 0.980 0.976
Thermal efficiency \( \eta /\%\) 93.903 93.623 93.338

The curves of heat loss (\%) and thermal efficiency (\%) with excess air coefficient are shown in Figure 2 and Figure 3. With the increase of excess air coefficient, the heat loss of exhaust gas increases, the heat dissipation loss decreases, the overall heat loss increases, and the thermal efficiency of the system decreases. Therefore, from the perspective of energy saving, we should try to reduce the excess air coefficient of heater.

**3.2. Influence of flue gas recirculation percentage on system energy efficiency**

Based on the above-mentioned hot oil heater system with waste heat recovery device, and in the condition that the structure of hot oil heater and air preheater remains unchanged, the calculated operation parameters under different flue gas recirculation percentage are shown in the table below.

| Flue gas recirculation percentage/% | 0   | 10  | 20  |
|------------------------------------|-----|-----|-----|
| Excess air coefficient             | 1.15| 1.15| 1.15|
| Furnace outlet flue gas temperature/°C| 359.6| 367.5| 378 |
| Exhaust gas temperature /°C        | 130 | 146 | 162 |
| Fuel gas consumption/Nm3/h         | 2026| 2052| 2070|
| Exhaust gas heat loss \( q_2 /\%\)  | 4.914| 5.629| 6.344|
| Fuel gas incomplete combustion heat loss \( q_3 /\%\) | 0.2| 0.2| 0.2|
| Dissipation heat loss \( q_5 /\%\)  | 0.983| 0.970| 0.962|
| Thermal efficiency \( \eta /\%\)    | 93.903| 93.201| 92.494|
The curves of heat loss (%) and thermal efficiency (%) with flue gas recirculation percentage are shown in Figure 4 and Figure 5. With the increase of flue gas recirculation percentage, the heat loss of exhaust gas increases, the heat dissipation loss decreases, the overall heat loss increases, and the thermal efficiency of the system decreases. Therefore, from the perspective of energy saving, we should try to reduce the flue gas recirculation percentage of heater. However, from the perspective of emission reduction, the percentage of flue gas recirculation should be increased. At this time, we should consider both energy saving and emission reduction, and choose the appropriate percentage of flue gas recirculation.

4. Conclusion

- With the increase of excess air coefficient, the heat loss of exhaust gas increases, the heat dissipation loss decreases, the overall heat loss increases, and the thermal efficiency of the system decreases. Therefore, from the perspective of energy saving, we should try to reduce the excess air coefficient of heater.

- With the increase of flue gas recirculation percentage, the heat loss of exhaust gas increases, the heat dissipation loss decreases, the overall heat loss increases, and the thermal efficiency of the system decreases. Therefore, from the perspective of energy saving, we should try to reduce the flue gas recirculation percentage of heater. However, from the perspective of emission reduction, the percentage of flue gas recirculation should be increased. At this time, we should consider both energy saving and emission reduction, and choose the appropriate percentage of flue gas recirculation.

- We should consider energy saving, emission reduction, investment cost and other factors to reasonably design the hot oil heater system with waste heat recovery device, and select reasonable operation parameters.

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