The Application of Heat Pipe to Flue Gas Residual Heat System in Thermal Organic Media Furnace with Coal as Fuel

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Abstract: To resolve the problem of reclaiming residual heat of the flue gas for thermal organic media furnace with coal as fuel, a technique project of reclaiming residual heat of the flue gas using heat pipe technology is put forward, and the technology of heat exchanger network is optimized. 1.25MPa steam produced by the heat pipe steam generator reclaiming residual heat of the flue gas can supply supplement steam of the rapid installation steam boiler, and the boiler operation time can be reduced and the energy can be saved. The heat pipe air pre-heater further recycles residual heat of the flue gas, preheating up the air from the normal temperature to 130 ℃ or so, as heating furnace's oxidizing air. And the efficiency of heating furnace can be improved. The project application example indicated that the economic benefit of the system of reclaiming residual heat of the flue gas using heat pipe technology is put forward. Technical targets are that the heat pipe steam generators reclaiming residual heat of the flue gas produce steam of 1.25MPa and 1.6MPa, as supplement steam of the rapid installation steam boiler the added steam (DZL4-1.25- AⅡ) and assembly water-pipe steam boiler (SZL20-1.6- AⅡ) in enterprise production, reduce the heat load of steam boiler, achieve the goal of saving energy and increase the enterprise economic benefits; and heat pipe air pre-heater can recycle further residual heat of the flue gas to heat air from normal temperature to about 100 ℃, as the combustion air of furnace to improve the efficiency of the furnace, reduce the dust of unburned coal in fuel gas. These play a very important role for enterprise's energy conservation and emission reduction.

I THE WORKING PRINCIPLE OF HEAT PIPE

A thermal organic media furnace with coal as fuel is a special industrial furnace which based on coal as the main fuel, use indirect heating mode, the heat generated by burning of coal fuel transfer to organic carrier and the organic carrier was forced to liquid-phase circulate by circulating pump, the heat will be transfer to the heat transfer equipment, then the organic carrier return to the heating furnace to reheating. Therefore, the thermal organic media furnace belongs to high energy consumption equipment in petroleum, chemical, textile, printing, dyeing industries.

The fuel gas temperature of a thermal organic media furnace is generally above 300 ℃, some as high as 400 ℃. Although the heating furnace manufacturers usually equipped with a normal tube-shell air pre-heater recycling the heat of fuel gas, in practice running the following problems still exist: (1)The residual heat of flue gas is far from being recycled and utilized adequately.(2)The life of conventional tube-shell air pre-heater is short.(3)The air outlet temperature of tube-shell air pre-heater surpasses the design temperature of chain grate for 130 ℃ of thermal organic media furnace, so it has an impact on the life of the chain grate.

According to the problems of 8000 kW and 9600 kW thermal organic media furnace of Jiangsu huulun chemical industry Co.Ltd, a technique project of reclaiming residual heat of the flue gas using heat pipe technology is put forward. Technical targets are that the heat pipe steam generators reclaiming residual heat of the flue gas produce steam of 1.25MPa and 1.6MPa, as supplement steam of the rapid installation steam boiler the added steam (DZL4-1.25- AⅡ) and assembly water-pipe steam boiler (SZL20-1.6- AⅡ) in enterprise production, reduce the heat load of steam boiler, achieve the goal of saving energy and increase the enterprise economic benefits; and heat pipe air pre-heater can recycle further residual heat of the flue gas to heat air from normal temperature to about 100 ℃, as the combustion air of furnace to provide the efficiency of the furnace, reduce the dust of unburned coal in fuel gas. These play a very important role for enterprise's energy conservation and emission reduction.

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I THE WORKING PRINCIPLE OF HEAT PIPE

The working principle of heat pipe, as shown in figure 1, the heat pipe is generally compose by shell, capillary porous materials and working medium. The working media after being purified will be filled into tube with capillary wick material and being pumped into the high vacuum, then being sealed from the front end. One end of the heat pipe is evaporator section and the other is condenser section. When the evaporator section is heated, the working media of the capillary wick material absorb heat and be vaporized into steam, and the steam will flow to condenser section, be cooled in condenser section, release latent heat of vaporization of steam and be condensed into liquid. The liquid goes back to the evaporator section along the porous material under the action of capillary force, and then is reheated to evaporator into steam again. And this process is circulated like this again and again. The heat will be transmitted continuously from evaporator section of heat pipe to condenser section. In the recycle and utilization of industrial waste heat, the heat pipes
generally have no wicks, working medium from the condenser section back to the evaporator section by gravity, this kind of heat pipe is called gravitational heat pipe. The working principles and structure of the heat pipe steam generator and the heat pipe air pre-heater which made by gravitational heat pipe of filled with special medium are shown in figure 2 and figure 3.

2 THE OPTIMIZATION OF THE SYSTEM OF RECLAIMING RESIDUAL HEAT OF THE FLUE GAS FOR THERMAL ORGANIC MEDIA FURNACE WITH COAL AS FUEL.

2.1 The System of Reclaiming Residual Heat of The Flue Gas with a Traditional Tube-shell Air Pre-heater

The original flue gas residual heat system of thermal organic media furnace of Jiangsu hualun chemical industry Co.Ltd is using a traditional tube-shell air pre-heater, the process is shown in figure 4. The project has the following deficiencies: (1) a part of the residual heat of 380 °C high temperature flue gas is only recovered and used to preheat the air entering the heating furnace, and the exit flue gas temperature is still about 300 °C. The residual heat of flue gas is far from being recycled and utilized adequately. (2) The tube-shell air pre-heater is located at the front of dust separator, dust particles in the flue gas has not been removed, the tube-shell heat exchanger is often scoured to be invalidation in practical operation, so the life of equipment is very short, tube-shell air pre-heater will almost be replaced in two years. (3) Because thermal organic media furnace with coal as fuel is a special industry furnace with chain grates, if preheated air temperature is too high, the life of chain grates will be shorten. In the process, a fuel gas bypass regulator valve is set to regulate the fuel gas quantity of access to tube-shell air pre-heater. Since the regulator valve is not automatic, the air temperature is often exceeding 130 °C of design requirement, and it will shorten the life expectancy of chain grates.

2.2 The System of Reclaiming Residual Heat of the Flue Gas with Heat Pipe Exchangers

Since the system of reclaiming residual heat of the flue gas with a traditional tube-shell air pre-heater has many deficiencies, it is optimized by heat pipe technology. The optimized system of reclaiming residual heat of the flue gas is as shown in figure 5. This system has the following advantages: (1) Heat pipe exchangers are located in the back
dust separator, reduce the scour damage of flue gas on heat transfer components - heat pipes, while reducing dust stratification in heat pipe. These will be beneficial to long-term high-efficiency operation of heat pipes.(2) The heat pipe steam generator first reclaims residual heat of the 380°C flue gas to produce steam of 1.25MPa and 1.6MPa, as supplement steam of the rapid installation steam boiler the added steam (DZL4-1.25- A II) and assembly water-pipe steam boiler (SZL20-1.6- A II) in enterprise production, reduces the heat load of steam boiler, achieves the goal of saving energy and increases the enterprise economic benefits.(3) The heat pipe air pre-heater will further reclaim residual heat of the flue gas to pre-heater air entering furnace to about 130°C and improve combustion efficiency of furnace. (4) Due to working principle and structure of heat pipe are special, the heat pipe exchangers can improve the reliability of the system. The traditional tube-shell air pre-heaters used by enterprises usually have a short life of an average of two years, affect the normal operation of the device, while heat pipe devices can improve the reliability of the system, even if the some heat pipes are

<table>
<thead>
<tr>
<th>No.</th>
<th>item</th>
<th>unit</th>
<th>heat pipe steam generator</th>
<th>heat pipe air pre-heater</th>
<th>tube-shell air pre-heater</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>inlet temperature of flue gas</td>
<td>℃</td>
<td>380</td>
<td>240</td>
<td>380</td>
</tr>
<tr>
<td>2</td>
<td>outlet temperature of flue gas</td>
<td>℃</td>
<td>240</td>
<td>180</td>
<td>298.3</td>
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<td>3</td>
<td>inlet temperature of air</td>
<td>℃</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>outlet temperature of air</td>
<td>℃</td>
<td>201</td>
<td>99.5</td>
<td>130</td>
</tr>
<tr>
<td>5</td>
<td>volume flow of flue gas</td>
<td>Nm³/h</td>
<td>20550</td>
<td>20550</td>
<td>20550</td>
</tr>
<tr>
<td>6</td>
<td>mass flow of vapor</td>
<td>kg/h</td>
<td>1563</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>7</td>
<td>volume flow of air</td>
<td>Nm³/h</td>
<td>—</td>
<td>17000</td>
<td>17000</td>
</tr>
<tr>
<td>8</td>
<td>vapor pressure</td>
<td>Pa</td>
<td>1.6</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>9</td>
<td>heat recovery</td>
<td>kW</td>
<td>1153.8</td>
<td>487.7</td>
<td>677.7</td>
</tr>
</tbody>
</table>
damaged in heat pipe heat exchanger, the cold and hot fluids of both sides of the heat pipe heat exchanger will not blend, So it won’t affect production operation and do not need to stop working for maintenance. And the heat pipes have a long life, no moving parts, few breakdowns and convenience maintenance and so on.

3 THERMODYNAMIC PARAMETERS COMPARISON

The system of reclaiming residual heat of the flue gas of 9600kW thermal organic media furnace with coal as fuel of Jiangsu Hualun chemical industry Co.Ltd is took as an engineering example, the contrast of thermodynamic parameters is shown in Table 1 among heat pipe steam generator, heat pipe air pre-heater and tube-shell air pre-heater.

4 ECONOMIC BENEFITS ANALYSIS AND COMPARISON

4.1 Tube-shell air pre-heater

From table 1, we find that the heat reclaimed from flue gas by tube-shell air pre-heater is 677.7kW.

From the handbook [2] [3] we find 1kW.h=860kcal.

Hence:

\[ Q = 677.7 \times 860 \text{kcal/kW.h} = 5.83 \times 10^5 \text{kcal/h} \]
\[ = 5.83 \times 10^4 \text{kcal/h} \times 24h = 1.4 \times 10^7 \text{kcal/d} \]

From the handbook [2] [3] we find that the production of 1 ton 1.6MPa steam need to consume 64.5 × 104 kcal heat, assuming water temperature is 20 °c, so we can convert the heat reclaimed from flue gas into quantity of steam, we get

\[ \frac{1.4 \times 10^7 \text{kcal/d}}{64.5 \times 10^4 \text{kcal/t}} = 21.7 \text{t/d} \]

(2)

The current market price of steam is 190 Yuan / ton, so the economic benefits generated by the reclaimed residual heat per-day are:

\[ 21.7 \text{t/d} \times 190 \text{Yuan/t} = 4123 \text{Yuan/d} \]

(3)

Assuming a year has 300 working days, so the economic benefits generated by the reclaimed residual heat per-year are:

\[ 4123 \text{Yuan/d} \times 300 \text{d} = 123.69 \text{Million Yuan} \]

(4)

4.2 Heat pipe steam generator and heat pipe air pre-heater

From table 1, we find that the heat reclaimed from flue gas by heat pipe steam generator and heat pipe air pre-heater is:

\[ Q = 1153.8 \text{kW} + 487.7 \text{kW} = 1641.5 \text{kW} \times 860 \text{kcal/kW.h} \times 24h = 3.4 \times 10^7 \text{kcal/d} \]

(5)

Similarly, we can convert the heat reclaimed from flue gas into quantity of steam, we get

\[ \frac{3.4 \times 10^7 \text{kcal/d}}{64.5 \times 10^4 \text{kcal/t}} = 52.71 \text{t/d} \]

(6)

Similarly, the economic benefits generated by the reclaimed residual heat per-day are:

\[ 52.71 \text{t/d} \times 190 \text{Yuan/t} = 10013 \text{Yuan/d} \]

(7)

Similarly, so the economic benefits generated by the reclaimed residual heat per-year are:

\[ 10013 \text{Yuan/d} \times 300 \text{d} = 300.39 \text{Million Yuan} \]

(8)

4.3 Economic benefits comparative and analysis

By calculating the economic benefits of energy-saving can be seen: for 9600kW thermal organic media furnace, using traditional tube-shell heat exchanger reclaiming residual heat of flue gas, economic benefits generated per year is 123.69 Million Yuan, while using heat pipe steam generator and heat pipe air pre-heater reclaiming residual heat of flue gas, economic benefits generated per year is 300.39 Million Yuan, It is 2.4 times of tube-shell heat exchanger. Under the background of the current economic crisis, the use of high efficient heat transfer equipment can bring greater economic benefits to the enterprise.

5 CONCLUSION

Using heat pipe technology reclaiming residual heat of the flue gas for thermal organic media furnace with coal as fuel, the engineering example proved, energy-saving effect of heat pipe technology is superior to the traditional tube -shell heat exchanger, the economic benefits are significant.

REFERENCES