Application of Energy-saving Technology on Furnaces of Oil Refining Units

Wang Ping, Xie Changfang, Xu Shiming, Ge Yulin

Abstract

The level of energy consumption is an integrated oil refinery economics and important indicator of the level of process technology, how to reduce the energy consumption of atmospheric and vacuum distillation unit refinery energy conservation has become a top priority. Atmospheric and vacuum distillation unit energy consumption can be achieved through a variety of ways. With the continuous development of energy conservation, demand lower and lower exhaust gas temperature furnace. But often in the steel pipe waste heat recovery equipment, heat exchangers and other heat transfer surface will produce strong low-temperature dew point corrosion. As so, we focus on is the furnace flue gas waste heat recovery technological applications, and discuss how to prevent low-temperature dew point corrosion, as well as the effect of waste heat recovery.

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1. Reduction

Refinery furnace is the main energy conversion equipment, about 1/3 of the comprehensive energy consumption of refinery conversion and consumption through the furnace; thereby increasing refinery furnace thermal efficiency has become the main measures tapping the potential synergies. Reduce heat losses can improve the thermal efficiency. Exhaust gas loss accounts for a large proportion in furnace heat loss. When the furnace thermal efficiency is high (e.g. 90%), exhaust gas loss accounts for 70% to 80% of
total loss, When the furnace thermal efficiency is low (e.g. 70%), the proportion of exhaust gas loss in total loss reaches up to 90% [1].

Usually increasing air preheater when the energy-saving reform can obtain obvious effect on the efficiency, however, due to change in heavy of fuel oil and increase in sulfur content, the dew point corrosion temperature of flue gas is increasing. With the extension of time of continuous operation, low dew point corrosion on the long period of furnace normal operation already pose a serious threat. Some devices are forced to shutdown to change equipment every year which cause great economic losses. Hot tubular air preheater although can adjust wall temperature, still there are 13% severely corrosive [2].

Install air preheater. By recycling flue gas heat to preheat air can accelerate the gasification of atomized droplets, improve fire condition of fuel, and improve combustion reaction rate, which directly reduce heating fuel consumption. The main forms of air preheater in our country are rotary air preheater, pipe-type air preheater and heat pipe air preheater and so on. In a domestic chemical plant a crude oil distillation unit of burning heavy oil furnace installed a large scale heat pipe air preheater which use to recovery exhaust waste heat, the design recovery of heat load 5232 kW, the air temperature is 20 ~ 250 ℃, flue gas temperature of 330 ~ 170 ℃, the application of the heat exchanger achieve success, and saving of 3600t of crude oil every year. The current heat pipe air preheater are used widely in the domestic refineries [3].

With the continuous development of energy conservation, the required exhaust gas temperature gets lower and lower. But on the heat transfer surface of the air preheater or other waste heat recovery equipments often has a strong low-temperature dew point corrosion, even in the running time of less than a year, the heat transfer surface to severe corrosion perforation, so that furnace does not work correctly. This paper reaches the furnace flue gas waste heat recovery technology, discusses the prevention of low dew point corrosion, and discusses how to recycle waste heat in order to achieve the purpose of improving the furnace efficiency.

2. Conceptual design

2.1 Heat Recovery System

This article takes the Atmospheric and vacuum unit vacuum furnace for example. The vacuum furnace uses the vertical furnace and the convection chamber and the chimney of it is located in the upper chamber of radiation. The heat recovery system consists of air preheater, air blowers, flue gas inducted draft fan, an independent steel chimney and flue and duct. The air preheater is placed on the basis of the furnace side of the ground. Its main advantage is that the replacement and maintenance of the exchange is convenient and easily operated, but the covers, steel maintenance and investment are more.

The merit of the air preheater which flue gas warms air directly is that it is self-contain and frees from process constraints. If the air temperature increases 20℃, the thermal efficiency of the furnace will improve about 1%.

The flue gas temperature of the gas out of the convection section is about 347℃. Use the program of recover waste heat with exchange to reduce the temperature to 160℃ and discharges to atmosphere. And air temperature is warmed from 80℃ to 290℃. Because of the gas-gas heat transfer coefficient of the steel heat exchanger is low, the volume of the air preheater is large and the efficient of heat exchanger is low. Using heat pipe heat exchanger can solve the problems of the waste heat recovery and exchange bulky and improve the efficiency of waste heat recovery.
2.2 The Operation of the Air Preheater

If the furnace burning fuel gas and air inlet temperature $t_1^C$ (shown in Figure 1) = 80 °C, gas outlet temperature $t_2^H = 160 ^\circ C$, take the heat pipe flue gas inlet temperature $t_1^H = 285 ^\circ C$ (minimum condition), the operating parameters shown in Table 1; Use water as the heat pipe working fluid, shell material is 20 # the boiler seamless steel, fin material is low carbon steel, the connection of fin and shell is high-frequency welding. When the flue gas inlet temperature $t_1^H = 354 ^\circ C$ (maximum condition), in order to prevent the occurrence of burst pipes, before the heat pipe heat exchanger series a heat exchanger (steel heat exchanger), the outlet temperature of 285 °C, the gas temperature difference between import and export keeps 69 °C, making the series heat exchanger small.

| Operating Parameters | Normal Condition | Minimum Condition | Maximum Condition |
|----------------------|------------------|------------------|------------------|
|                      | Gas   | Air   | Gas   | Air   | Gas   | Air   |
| Quantity/ (kg/s)     | 12.53 | 18.17 | 7.03  | 13.07 | 13.18 | 18.87 |
| Inlet temperature/ °C| 347   | 80    | 285   | 80    | 354   | 80    |
| Outlet temperature / °C| 160  | 223   | 160   | 155   | 165   | 225   |
| Pressure drop/ Pa     | <1000 | <1500 | <1000 | <1500 | <1000 | <1500 |

3. Measures to prevent the corrosion of flue gas dew point

3.1 Corrosion Mechanism

Because of the chemical incompatibility of the pipe and the refrigerant, making the steel-water heat pipe corroded and produce non-condensable gas hydrogen. The more hydrogen, the heat transfers the worse. If the hydrogen accumulates to a certain degree, heat pipe will lost heat transfer capabilities.

1) Chemical corrosion

Heat pipe works at high temperatures for a long time; steel and water occur chemical reaction and make change in the pipe. The main chemical reaction process is as follows:

$$Fe + H_2O = FeO + H_2$$

$$2Fe + 3H_2O = Fe_2O_3 + 3H_2$$

$$3Fe + 4H_2O = Fe_3O_4 + 4H_2$$

The result of the reaction makes wall corrode, result in FeO, Fe$_2$O$_3$ and Fe$_3$O$_4$ and produce a certain amount of non-condensable gas hydrogen.

Addition to Fe$_3$O$_4$, the other two oxide layer (FeO and Fe$_2$O$_3$) can not prevent water intrusion; continue to react with the iron makes hydrogen.

2) Electrochemical reaction
In the steel-water heat pipe, iron, impurities and water constitute a primary battery. The iron is anode and the impurities are cathode. Impurities generally are FeC3 and graphite, which contained in carbon steel and the water. Ionization of water is small, but there is still a small amount of OH\(^{-}\) and H\(^{+}\) generation. The main electrochemical reaction in the tube as follows:

\[
\begin{align*}
2H^+ + 2e^- & = H_2 \\
Fe - 2e^- & = Fe^{2+} \\
Fe^{2+} + 2OH^- & = Fe(OH)_2 \\
3Fe (OH)_2 & = Fe_3O_4 + 2H_2O + H_2
\end{align*}
\]

Under the conditions of at high temperature of water, the reactions is proceeding very quickly and generally think that this is the main reason which cases incompatible between water and carbon steel.

3) The mechanism of heat pipe dew point corrosion

When the heat pipe heat exchanger used at low temperature flue gas, heat pipe of heat exchanger often have low dew point corrosion. Sometimes even in the normal exhaust temperatures, flue gas outlet side (in the absence of pre-heater case) there are a few low-temperature dew point corrosion on the last heat pipe.

According to heat transfer, side wall temperature of gas is mainly related to cold and hot fluid temperature, heat transfer coefficient and heat transfer area. It is proportional to hot fluid temperature, heat transfer coefficient, area and temperature of cold fluid and is inversely proportional to the heat transfer coefficient and area. When the cold and hot side heat transfer coefficient and heat transfer area is certain, and when the cold temperature is low, the gas side wall temperature is likely to occur the dew point corrosion below the dew point temperature [4].

3.2 Methods

1) Exhaust gas temperature control

According to the dew point temperature of flue gas reasonably determine the exhaust gas temperature, the exhaust gas temperature should be higher 20 ~ 30 °C than the dew point temperature. In addition, because summer and winter temperature difference too much, should control the different exhaust gas temperature, exhaust gas temperature should be raised in winter.

2) Addition pre-heater

Addition pre-heater can increase the temperature of the air entering the preheater, so as to effectively prevent the dew point corrosion

3) Adjusting the structure parameters

By adjusting the hot and cold side of the structural parameters, can improve the lowest wall temperature of heat pipe, to prevent low temperature corrosion. In the structural parameters, cold and hot length change is the most sensitive to change the wall temperature, but the hot end of the length can not increase too much, otherwise it will result in the flue gas outlet temperature too high, the single heat pipe heat capacity decreases, and the air-side flow Resistance increases. The current most widely used is to adjust the height and fin spacing. In the structure Parameter adjustment, the proposal to change a parameter the cold, hot side at the same time, so that wall temperature changes rapidly and the single-row heat pipe heat transfer essentially the same, without increasing the original tube row can ensure heat transfer performance. When the difference between the wall temperature and dew point temperature is small, choice fin height or spacing as thermostat parameters firstly, when the wall temperature and dew
point temperature difference is large, the length of the cold end should be selected as a thermostat adjusting parameters or adjust multiple parameters simultaneously.

Using this method change the structure of the last few rows of heat pipe which the wall temperature is lower than the dew point of flue gas, can effectively prevent the low-temperature heat pipe corrosion [4].

4) Method using hot air reflow

Warm air with flue gas is the primary method to recover waste heat and improve thermal efficiency, and it is also the most commonly used method. Reduce exhaust gas temperature in technical is mainly limited by the flue gas dew point. The temperature of the waste heat recovery heat exchanger surface must be higher than the flue gas dew point temperature, or the heat transfer surface will be damaged by dew point corrosion. In addition, the heat transfer surface accumulation of dust under the dew point will be “sticky gray”, which is difficult to remove. The sticky gray piled up, the gas side resistance increases quickly and even the waste heat recovery system difficult to operate and forced outages.

In this paper the hot flue gas from the top of the convection cell of furnace flows through the hot gas channel of a separate steel chimney into air preheater, the hot flue gas transfers heat with cold air and is sent into the cold gas channel of the independent steel chimney into atmosphere by flue draft fan. Cold air flows into air preheater by air blowers, transfers heat with hot flue gas and enters wind channel at the bottom of the furnace for the burner to use. To avoid the cold end of low-temperature dew point corrosion of air preheater, the use of hot air reflow method, send a part of the warm-hot air to the entrance of the air blower to improve the inlet temperature of the air side.

It is worth noting that, with the air temperature increasing, the NOx of the combustion products increase, if no appropriate measures to reduce NOx, then for environmental protection is bad. In addition, if the air temperature is too high, it may cause the fuel nozzle coking or deformation of the excessive burner or other issues, unless you change the burner structure and materials, the general air preheating temperature should not exceed 300 °C [5].

Be sure of Gas recovery is efficient. Dirt stickiness of the heat exchange tube is low and dry because the dew point corrosion is removed. So it is Conducive to cleaning, at the same time fouling on the surface of heat exchange tube can also be removed in time. Through the above measures the heat exchange tube can in good sate for a long time .It can also reduce exhaust gas temperature, full recovery of waste heat, improve the thermal efficiency of furnace and to achieve the purpose of energy saving [6]

3.3 Using Low Sulphur Heavy Oil

From a technology view, using low sulphur heavy oil can avoid corrosion due to smoke of the dew point or adding some additives which can occur combination reaction with sulfur trioxide and produce No corrosion materials into heavy oil can also reduce the concentration of sulfur trioxide to a large extent. At the same time, reduce corrosion. In the process of design and operation, the exhaust gas temperature should do not drop too low in order to save energy blindly. Reducing dust in the flue gas and treating dirt on the equipment surface in time during downtime etc [7]

3.4 Structure of the Heat Pipe Air Preheater

Heat pipe air preheater structure is shown in Figure 1. This heat pipe air preheater is mainly made up by hot tubes, the upper box, the lower box, the baffle and the cap. The upper box and the lower box are tightened on median partition. Air flows through the upper box and the flue gas flows through the lower box, air and flue gas reverse flow in their circulation space. Each heat pipe is an independent component of heat transfer. Heat pipe evaporator section outside and condenser section outside have fins. The middle of each section welds conical connection and match with the cone of the middle plate. They have the function
of seal. The upper and lower boxes use frame structure which is welded with channel steel and steel box. The front and the back of the lower box have two doors and makes it easy to repair and check and disassembly blowing device. There are two drains at the bottom; they are used for washing exchange on the overhaul time. There is also an air preheater composed by iron and glass, and it if good for low-temperature corrosion resistance. To make entire exchange has good insulation properties, both sides of the top, bottom and around of the exchange are filled with insulation layer [8].

![Figure 1. The heat pipe air preheater construct](image)

4. Conclusion

This paper according to the status of production technology of atmospheric and vacuum unit vacuum furnace and optimizes the design by simulation to get to the purpose of plant expansion and saving with less investment. With the continuous development of energy conservation, demand lower and lower exhaust gas temperature furnace. But often in the steel pipe waste heat recovery equipment, heat exchangers and other heat transfer surface will produce strong low-temperature dew point corrosion. It is to improve the thermal efficiency of vacuum furnace and achieve the requirements of energy saving by using new technologies. The prerequisite of improving furnace thermal efficiency and energy conservation should ensure the safe operation of heating and normal life. If you ignore this, it often results in greater waste.

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