Up-tube Heat Exchanger Engineering Design and Heat Transfer Analysis

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Abstract: In the coking process, a large amount of 750 ℃-800 ℃ coke-oven gas is produced, and the traditional process is to use circulating water spray to cool the coke-oven gas instantly to 80-90℃, and the sensible heat of the coke-oven gas is wasted. In order to recover sensible heat of coke-oven gas reliably and stably, this paper puts forward a kind of uptube heat exchanger for sensible heat recovery of coke-oven gas based on the problems existing in the past heat exchanger and the characteristics of coke-oven gas itself, and analyzes the heat transfer process equation of heat exchanger.

Keywords: Coke-Oven Gas; Heat Exchanger; Coking

1. Overview

With the development of coking technology, the utilization of waste heat in coal coking process is becoming more and more perfect.The waste heat contained in red coke is recovered for power generation through dry quenching technology, and the waste heat from the flue gas of coke oven is also effectively recovered by heat pipe heat exchanger to produce high temperature hot water or low pressure steam for ammonia evaporation. However, the sensible heat recovery of coke-oven gas is slow due to the reliability problems of coking and heat exchanger. With the increase of the state's support for energy conservation and environmental protection industry, the recovery of sensible heat of coke-oven gas has also been paid more and more attention by the industry. China has developed a rising pipe vaporizing cooling device for the production of low-pressure steam from the 1970s, but the technology is not mature and has not been promoted. Later, some people have adopted waste heat recovery technologies such as thermal oil jacket technology, heat pipe heat transfer technology, and inert gas heat extraction technology, but they cannot operate stably for a long time due to leakage and coking reasons.

Provide equipment design and selection ideas for the company's future recovery of 1 million tons of coke-oven gas sensible heat in coking furnace, from the problems existing in the past uptube heat exchanger and the characteristics of the coke-oven gas itself, put forward a reasonable solution ideas, and through the heat exchanger heat transfer process equation analysis, put forward an uptube heat exchanger[1-2].

2. Characteristics of Coke-Oven Gas and Problems in Sensible Heat Recovery

The coke-oven gas sensible heat recovery heat exchanger is installed at the coke-oven gas outlet at the top of the coke furnace to replace the original coke oven riser, which is usually called the riser heat exchanger. The inner wall of the riser heat exchanger is easy to coking, graphitization, and even completely block the coke-oven gas flow flue, which not only greatly reduces the heat exchange capacity of the heat exchanger, but also may seriously endanger the operation safety of the carbonization chamber and the back-end process. Due to the influence of alternating thermal stress, the uptube heat exchanger is prone to problems such as weld strain, water leakage and air leakage during operation, resulting in short service life and poor reliability, as shown in Figure 1.

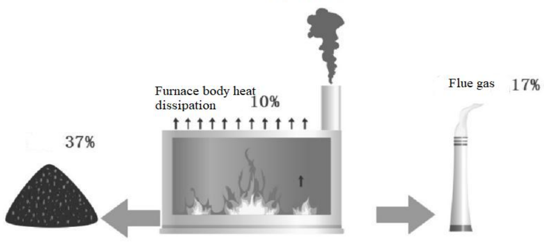

Figure 1. Heat Expenditure Diagram of Coke Oven

2.1 Coking Characteristics of Coke-Oven Gas

Coking of coke-oven gas refers to the process of condensation and graphitization of coke gas in the heat exchanger surface. When the tar droplets condensing in the heat exchange interface of the coke-oven gas riser are encountered with high temperature coke-oven gas, the tar will undergo pyrolysis and thermal condensation reaction and re-vaporize. The higher the temperature of graphite formation, the greater the amount of graphite deposition. The conditions required for coking of coke-oven gas are:

The dew-point temperature of tar in coke-oven gas is 400-500℃ under normal pressure [3]. When the coke-oven gas temperature is lower than the dew-point temperature of tar, the tar gas condensates into mist droplets, and the tar droplets stick to the heat exchanger wall when they collide with it.

The temperature of the heat exchange interface is low, and the tar steam in the coke-oven gas condenses out on the wall of the heat exchanger at a lower temperature. When the heat exchange interface temperature is below 300℃, a large number of tar precipitates, and when the heat exchange interface temperature is greater than 350, the tar precipitates are less.

Convection heat transfer of radiation or high temperature coke-oven gas in coke oven makes the tar precipitated by condensation occur pyrolysis and thermal condensation and solidification.

2.2 Problem of Expansion Deformation and Damage of Heat Exchanger under Alternating Thermal Stress

Coke oven carbonization chamber periodically loaded coal carbonization, each hole carbonization cycle is about 18 hours, coke-oven gas production and temperature change with carbonization time, the drought temperature is as high as 800 ℃, heat exchanger heat exchange medium temperature of about 200℃, heat exchanger internal and external metal temperature difference is large, heat exchanger under the action of this alternating thermal stress, heat exchanger deformation damage, water leakage, leakage, gas leakage. It affects the safe and stable operation of coker[3-4].

3. Solution Ideas

3.1 Aiming at The Problem of Tar Dew Point in Coke-Oven Gas

Reasonable set of sensible heat recovery of coke-oven gas, heat exchanger outlet temperature of coke-oven gas is not less than 520 degrees Celsius, so that the coke-oven gas outlet temperature is 20 degrees higher than the tar dew point temperature. The coke-oven gas is heated from 800℃ to 520℃, and tons of coke can produce low pressure saturated steam of about 90kg.

3.2 For Tar Condensation and Precipitation on the Wall

Through the heat exchanger heat transfer design, ensure the heat exchanger inner wall temperature >350℃, so that the inner wall of the rising flue tar precipitation is less, the coke loose is easy to manually remove. The problem of coking and clogging of rising flue caused by sensible heat recovery of coke-oven gas is fundamentally solved.

3.3 The Heat Exchanger Adopts the Structure Suitable for Alternating Thermal Stress

According to the data obtained from some related literature, the deformation and leakage of the heat exchange medium flow channel of the heat exchanger is the main problem in the heat exchanger. Therefore, the main heat exchange tube elements are designed with spiral coil and free expansion support structure to avoid the tear and leakage of the heat exchange tube caused by the shortage of gas or the temperature change of soft water during the working process.

4. Structural Design of Uptube Heat Exchanger

4.1 Methods for Increasing the Wall Temperature of Heat Exchanger

In order to explain how to improve the temperature of the inner wall of the heat exchanger (twi), through the wall heat transfer diagram to illustrate the problem, as shown in Figure 2, the heat transfer coefficient of the coke-oven gas through the convection heat transfer to the wall of the heat exchanger (area is A, material thermal conductivity λ), the heat transfer coefficient of the coke-oven gas and the wall is hi, the heat exchanger is Φ, the heat is transferred from the inner wall to the outer wall. The heat is then transferred to the water supply by convection heat transfer. The wall temperature during the heat transfer process is expressed as follows.

$$t_{wj} = t_{fj} - \phi / A \times h_j \quad (1)$$

$$t_{wj} = t_{wo} + \phi / (A \times \lambda / \delta) \quad (2)$$

$$t_{wo} = t_{fo} + \phi / (A \times h_o) \quad (3)$$

In order to reduce the coking of coke-oven gas, the temperature of coke-oven gas after heat exchange is 520℃, so the heat exchanger Φ can be determined, and in order to improve the inner wall of the heat exchanger (twi), it can be analyzed from the above three links of heat exchange.

Heat transfer between coke-oven gas and wall surface.

If the heat exchanger Φ of coke-oven gas is determined, tfi has also been determined. In formula (1), increasing hi and the internal surface area A can increase the twi . The specific method is to set vertical fins on the inner wall, so that the area after finning isA0>A; The heat transfer coefficient hi is increased by adding a turbulent device on the inner wall, and the turbulent notch can be set on the vertical fin of the inner wall.

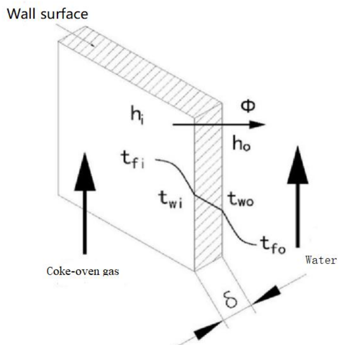

Figure 2. Schematic Diagram of Wall Heat Transfer

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Wall heat conduction.

In formula (2), the heat exchanger (Φ) can be determined by increasing the outer wall temperature (two), reducing the thermal conductivity λ or increasing the wall thickness δ. The specific method is to set a special heat conduction component between the wall and the water, such as heat conduction pad, heat conduction fin and other structures to control heat transfer.

Heat transfer between wall and water.

In formula (3), the method of increasing the outer wall temperature (two) is used to increase the temperature tfo of the heat exchange medium (water). The specific method is to use a high-pressure heat exchange medium flow channel (round tube) to increase the temperature of the water, because it is a soft water heat exchange, the water temperature increases, and the saturated steam pressure level is also increased.

4.2 Heat Exchanger Structure

According to the description of article 3.3 and 4.1 above, we can obtain such a structure of the uptube heat exchanger. As shown in Figure 3, the top and bottom of the uptube heat exchanger are provided with flue interface flanges, cylindrical inner wall is set, vertical fins are provided on the inner wall to increase the internal surface area, there are turbulent grooves on the fins, and spiral coils are used to improve the temperature and pressure of the heat exchange medium. A heat conduction fin is arranged between the coil and the inner wall, and a thermal insulation layer is arranged outside the coil.

For a complete heat exchanger, the temperature of the three heat transfer links in article 4.1 is the average temperature, tfi is the average temperature of the coke-oven gas inlet and outlet;twi is the average temperature of the inner wall of the heat exchanger and the average temperature of the outer wall of the two heat exchanger are actually calculated according to the wall temperature distribution of the heat exchanger. tfo is the average temperature of the heat exchange medium, and for the case that the outlet of the riser heat exchanger is a soft water mixture, tfo is the outlet temperature of the heat exchange medium.

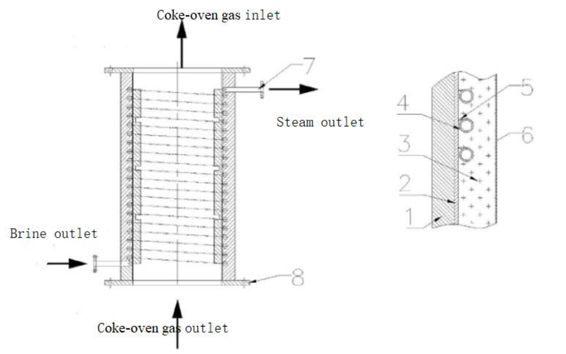

Figure 3. Uptube Heat Exchanger

1- Vertical fin 2- Heat exchanger inner wall 3- Insulation layer 4- Spiral heat exchange tube 5- Thermal fin 6- Stainless steel shell 7- Heat exchange tube interface flange 8- Flue interface flange

It should be noted that the minimum temperature of the inner wall of the heat exchanger should be higher than 350 ° C. For the up-tube heat exchanger used to produce saturated steam, the lowest inner wall temperature point is at the top position of the up-tube heat exchanger, and the highest temperature point is at the bottom position of the up-tube heat exchanger, and the inner wall temperature at the bottom of the up-tube heat exchanger should be avoided, which affects the service life of the heat exchanger. According to the description in article 4.1, we can adjust the bottom of the riser heat exchanger and the bottom inner wall and the heat transfer coefficient of coke-oven gas hi and the internal surface area A, so that the temperature of the lower part of the inner surface of the riser heat exchanger tends to be equal, which also means that the inner fin area of the top and bottom of the riser heat exchanger is not equal.

5. Conclusions

In order to recover the sensible heat of coke-oven gas reliably and stably, the problems existing in the heat exchanger of coke-oven gas in the past and the characteristics of coke-oven gas itself are put forward:

The temperature of the coke-oven gas after sensible heat recovery should be greater than 520 °C, which is 400-500 °C higher than the dewpoint temperature of the tar vapor in the coke-oven gas to avoid the precipitation of tar droplets.

The inner wall temperature of the riser heat exchanger should be greater than 350 ° C to avoid precipitating tar steam on the wall and coking.

Use spiral coil heat exchange to avoid heat exchanger damage and leakage caused by the influence of alternating thermal stress.

A rising tube heat exchanger is proposed to improve the inner wall temperature of the heat exchanger from three aspects of heat transfer:

Longitudinal inner fins and turbulent flow structure are set to enhance heat transfer between the coke-oven gas and the inner wall.

Wall heat conduction is controlled by special heat transfer structure.

Set high pressure heat exchange medium flow path (round tube) to increase the temperature of heat exchange medium (water). The heat exchanger structure can be used for different types of coke furnace, and different sizes of heat exchangers with rising tubes are designed according to the coke-oven gas output of a single rising flue of coke furnace.

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