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Study on Structural Optimization Design of Heat Exchangers of Hot air furnace

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Abstract

Spraying heat exchanger and tubular radiation recuperator are common equipment of the drying hot air furnace. To study the way of reducing the investment cost for the heat exchanger of high-temperature and high-capacity hot air furnace, the heat exchange area of the two heat exchangers was calculated by LMTD method when air temperature rose from 0℃,100℃and 200℃ to different temperature points, and the figure of the relationship between the temperature difference and average heat exchange area was given. According to the analysis, the economical temperature range of the heat exchangers is narrower as the inlet air temperature rises. When the air temperature difference keeps constant, the average heat exchange area increases as the inlet air temperature rises. When the inlet air temperature keeps constant, the average heat exchange area increases gradually as the air temperature difference rises. Then the average heat exchange area exceeds the economical temperature range and approaches infinity quickly. The analytical method of economic performance can be applied to the design and model selection of two-stage heat exchanger of high-temperature and high-capacity hot air furnace.

Keywords：drying; hot air furnace; spraying heat exchanger; tubular radiation recuperator; economic performance

1. Design and Study Status of Heat Exchanger of Hot air furnace

Drying is to remove the moisture and other volatiles of materials. With the development of science, technology, agriculture and industry, there are more and more materials needing drying. Drying technology is applied to food, ceramics, medicine, minerals, paper, wood processing and even instrument processing. Hot air furnace is the auxiliary equipment for pneumatic drying, spray drying, fluidized

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drying and tower drying, etc. Indirect hot air furnace is comprised of combustion chamber and heat exchanger. Heat exchanger is the core of hot air furnace heat exchange system, with the thermodynamic characteristics different from surplus heat utilization heat exchanger [1]. The common heat exchangers of hot air furnace include tube type heat exchanger [2], spraying heat exchanger and tubular radiation recuperator [3], etc. As for high-temperature and high-capacity hot air furnace, single-stage heat exchanger is either oversized or fails to meet the production requirements. Limited by installation, transportation and the heating temperature of drying medium, the high-temperature and high-capacity hot air furnace generally adopts two-stage composite heat exchanger.

As for the design and selection of heat source exchanger or hot air furnace of drying system, generally, the thermal load (i.e. heat exchange rate), temperature difference between and flow of cold and hot fluid at inlet and outlet are known, the heat exchange area needs to be determined. Then LMTD method shall be adopted. The basic calculating procedures of LMTD method are integral of a differential equation of heat transfer process of cold and hot fluid. The formula for the overall heat exchange rate of the heat exchanger is derived as follows:

$$q = KF \frac{\Delta t_{\max} - \Delta t_{\min}}{\ln \Delta t_{\max} / \Delta t_{\min}} \tag{1}$$

In the formula: $\frac{\Delta t_{\max} - \Delta t_{\min}}{\ln \Delta t_{\max} / \Delta t_{\min}} = \Delta t_m$

We call Δt_m the logarithmic mean temperature difference (LMTD) (℃), whose physical conception is the maximum temperature difference minus the minimum temperature difference and then divide by the natural logarithm of the ratio between the temperature difference. q is the heat exchange rate of the heat exchanger (J/s), k is the overall heat transfer coefficient of the heat exchanger (W/m^2•℃), and F is the heat exchange area of the heat exchanger.

The design requirements for the heat exchanger are to obtain the maximum enhanced heat transfer efficiency with the minimum investment cost. That is to say, on the condition that high heat transfer coefficient can be obtained, the heat exchange area and the flow resistance of the heat exchanger shall be minimized to get the highest heat exchange efficiency. Currently, the study on heat exchanger often proceeds from heat exchange function formula (1). Under given condition, the heat exchange rate q and LMTD Δt_m are known, the heat exchange area F can be reduced if only the heat transfer coefficient K rises. Then the manufacturing cost for heat exchanger can be reduced. As for hot air furnace with single-stage heat exchanger, the main way of reducing heat exchange area is to increase the gas velocity and turbulence intensity to intensify the convection heat transfer at air side and flue gas side, increase the heat transfer coefficient. The higher the heat transfer coefficient is, the smaller the heat exchange area (volume) needed to exchange the same quantity of heat is, the lower the investment cost is. However, the measure of increasing heat transfer coefficient often causes more losses of air and flue gas flow resistance. Therefore, the hot air furnace should have strong blast capacity and smoke extraction capacity, which increases the investment cost and power consumption. As for hot air furnace with two-stage heat exchanger, the designer often allocates the quantity of heat of single-stage and two-stage heat exchanger based on past experience. The heat allocation method is in lack of evaluation criterion and may cause the increase and waste of investment cost for heat exchanger.

2. **Economical Analysis of Heat Exchanger of Hot air furnace**

2.1. Economical Analysis of Spraying Heat Exchanger

We take spraying heat exchanger as an example to discuss the heat exchange characteristics of the heat exchanger of high-temperature and high-capacity hot air furnace and work out the effective method for optimum allocation of the quantity of heat of two-stage hot air furnace. The spraying heat exchanger of hot air furnace often has flue gas at the shell side. The flue gas flows from the pipe hole under the action of heated air. According to the comprehensive analysis of spraying heat exchanger [4-8] , the structural parameters are as follows: the inner barrel and the outer barrel adopt Φ159×4.5mm and Φ219×6mm seamless steel pipe respectively; 3.5mm round holes are uniformly distributed on the inner barrel; 8×8＝64 spraying pipes are in gallery layout and form a rectangle. The pipe spacing is shown in Fig 1. The parameters of spraying pipe are shown in Fig.2 and Table 1.

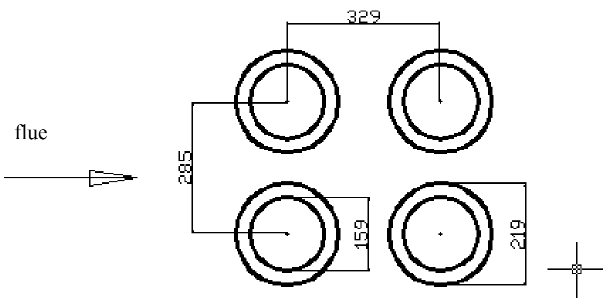
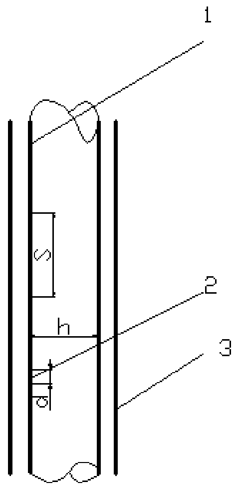


Fig 1. Arrangement diagram of the spraying pipes



1. Spraying pipe 2. Orifice 3. Heat exchange pipe

Fig.2.parameters of spraying pipes of the Spraying heat exchanger

Table 1. Parameters of spraying pipe

Name	Code	Value
Hole diameter (mm）	d	3.5
Relative distance of orifice (mm)	S	33
Non-dimensional spray spacing	S/d	9.42
Non-dimensional spray	h/d	6.8
Number of orifices		41920
Area of orifices（m^2）		0.4

On the condition that the air amount V_K＝26000m^3/h, the flue gas volume Vy＝10000m^3/h and the inlet flue gas temperature is 1100℃, the air with temperature t1=0℃, 100℃ and 200℃ is introduced into spraying heat exchanger respectively. When t1 rises to t2, LMTD method is applied to conduct heat transfer computation for spraying heat exchanger [9-11] to conclude the temperature difference Δt=t2-t1/℃ and the heat exchange area needed to increase the temperature for 1℃ (average heat exchange area) F/(t2-t1)， the relation curve is shown in Fig.3. According to Fig.3, when the inlet air temperature is 0℃, the average heat exchange area needed increases sharply after the temperature difference Δt≥400℃ and approaches infinity quickly. When the spraying heat exchanger operates under the condition that Δt≤ 400℃, the heat exchange area needed to increase the temperature for 1℃ and the overall heat exchange area are small. That is to say, when the inlet air temperature is 0℃, the economical temperature range of the spraying heat exchanger is 400℃. When the heat exchanger operates under the condition that Δt＞ 400℃, the heat exchange area needed increases rapidly, which causes the substantial increase of materials used and investment costs. In designing and selecting heat exchanger, the exchanger shall be kept operating within the economical temperature range. As for the curve with the initial air temperature t1=100℃, the average heat exchange area needed increases sharply after Δt≥360℃ and approaches infinity quickly. That is to say, when the inlet air temperature is 100℃, the economical temperature range of the spraying heat exchanger is 360℃. As for the curve with the initial air temperature t1=200℃, the economical temperature range of the spraying heat exchanger is 320℃. To sum up, the economical temperature range is narrower as the inlet air temperature rises. When the inlet air temperature varies, the average heat exchange area is different even if the heated air temperature difference keeps constant. As the initial air temperature rises, the average heat exchange area increases. When the inlet air temperature keeps constant, the average heat exchange area changes with the temperature rise. As the air temperature difference rises, the average heat exchange area increases gradually and sharply and approaches infinity after going beyond the economical temperature range.

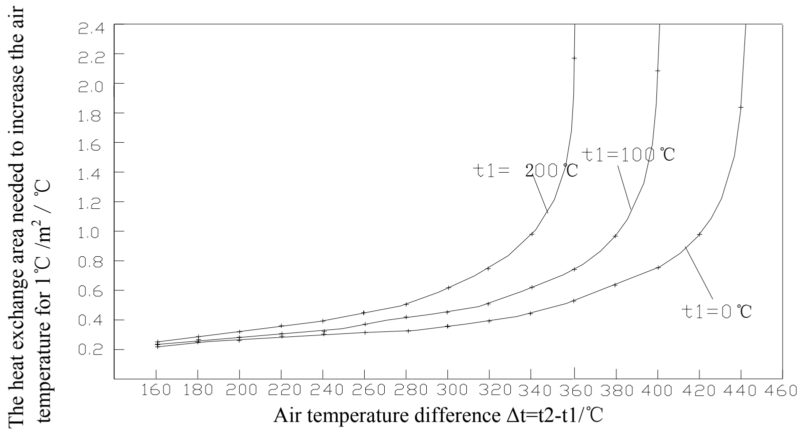


Fig.3. Figure of the spraying heat exchanger

2.2. Economical Comparison Between Tubular radiation recuperator and Spraying Heat Exchanger

When the tubular radiation recuperator adopts the same initial conditions of spraying heat exchanger, the variation trend of the figure [3] has few differences with the curve concerning heat exchanger characteristics of spaying heat exchanger. According to Fig.4, the average heat exchange area needed by the spaying heat exchanger is apparently smaller, 50% of that by tubular radiation recuperator. As for heat exchanger of high-temperature and high-capacity hot air furnace, spraying heat exchanger is small-sized. Comparing spraying heat exchanger with tubular radiation recuperator, the heat exchange area needed to increase the same temperature is smaller, which reduces the cost for material manufacturing and heat exchanger.

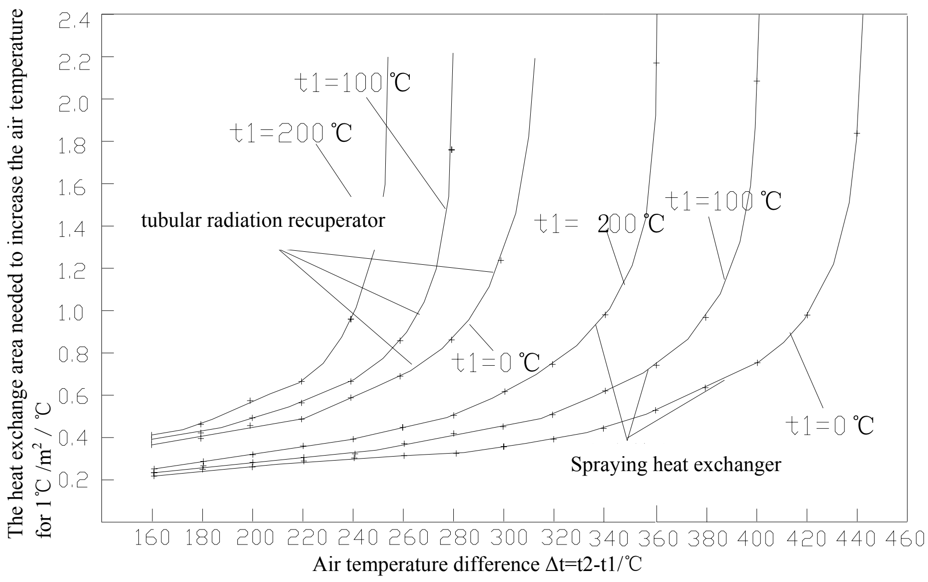


Fig.4.Comparision in figure of the spraying heat exchanger and the tubular radiation recuperator

3. Conclusion

Spraying heat exchanger and tubular radiation recuperator are applicable for single-stage heat exchanger low-temperature hot air furnace or two-stage heat exchanger high-temperature hot air furnace. Through the economical analysis of the heat exchange curve of two heat exchangers, the economical temperature range of spraying heat exchanger is concluded when the inlet temperature is 0 ℃, 100℃ and 200℃. By comparison, spaying heat exchanger is smaller than tubular radiation recuperator in size on the same condition. As for the design and selection of heat source exchanger or hot blast stove of drying system, the heat exchanger shall be kept operating within the economical temperature range. As for two-stage high-temperature and high-capacity hot air furnace, the heat exchange area of heat exchanger and the investment cost for hot air furnace can be reduced if the two heat exchangers operate within the economical temperature range.

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