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Activated coke moving bed heat exchanger performance study

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ABSTRACT

This study is attached to the SO_2 adsorption stripping experiment, which makes a experiment activated coke heat exchange performance in analytic tower. Through calculation and analysis of experimental data, the overall heat transfer performance of activated coke moving bed and the heat transfer law will be obtained. By adopting the combination of experimental study and theoretical research method, the tube wall temperature and heat exchange tube are given quantitatively, which provides the foundation for future research of the moving bed heat exchanger heat transfer and particle system heat transfer research and provides reference for moving bed heat exchanger design optimization.

Keywords: moving bed; activated coke desulfurization; heat transfer performance; particle.

INTRODUCTION

Moving bed was developed on the basis of the fixed bed with excellent properties, which is often used in gas-solid reaction and heat transfer, involves the development of chemical industry, metallurgy, energy, environmental protection and other fields, at present, research on the heat transfer between solid particles and moving bed is less. The movement of particles in the moving bed group than the single particle motion is more complex, and heat transfer characteristics in a certain extent within the bed and moving bed inside the particle flow characteristics related, in actual operation of the moving bed have many unpredictable situation (formation of thermal boundary layer, etc.), combined with the present theoretical research is not very perfect, so need to particles and wall heat transfer mechanism and actual operation mutual contact and mutual combination, to fully understand the heat transfer characteristics of particles in the moving bed, and then to the design and operation of moving bed heat exchanger to do further research and optimization, make the whole heat exchanger design is reasonable and efficient operation[1].

Filled with removable particles moving bed, general particle by the entry into the mobile bed, slow flow inside the bed, finally, discharged from the export of moving bed below this is moving bed and fixed bed is the main difference.

Compared with the fixed bed, fluidized bed[2], the advantage of moving bed are: continuous flow inside particles in the moving bed; With wider range of moving bed can be adapted to the particle size of[3].Solid particles and fluid (gas, liquid) to stay in the bed for a time can be changed in a wide range, this makes the moving bed has good load fluctuations of regulatory and working ability to adapt.

According to the classification of the role and function, moving bed can be divided into moving bed reactor[4] and moving bed heat exchanger. The working principle of moving bed heat exchanger is similar to the tube and shell heat exchanger. general tube heat exchanger divides into tube side and shell side, there are two different fluid temperature in tube side and shell side, fluid with different temperature in the column by column on both sides of the heat exchanger tube heat transfer. Moving bed heat exchanger is to replace the shell side of the tube and shell heat exchanger fluids with solid particles, still passes through the fluid. Moving bed heat exchanger tube passes the fluid inside the shell side of the heating or cooling of solid particles, it is very common in industrial production, such as: the pyrolysis of coal moving bed; recycling of steel slag cooler waste heat of moving bed in the production of steel; granular adsorbent desorption in the environmental engineering of moving bed desorption tower, etc.[5].

Moving bed[6, 7] is a special kind of fixed bed, which is also the separation of liquid mass transfer device using the principle of adsorption. This kind of equipment of production capacity and separation efficiency is higher than fixed bed adsorption, and can avoid moving bed adsorbent wear dust, debris or blockage equipment or pipeline ditch flow between the seam and solid particles.

Particle moving bed particle heat transfer characteristics of experimental research mainly through the experimental method of direct access to the import and export of moving bed cold heat medium temperature, after analysis of particle heat transfer law.

EXPERIMENTAL SECTION

0.1 The experimental system

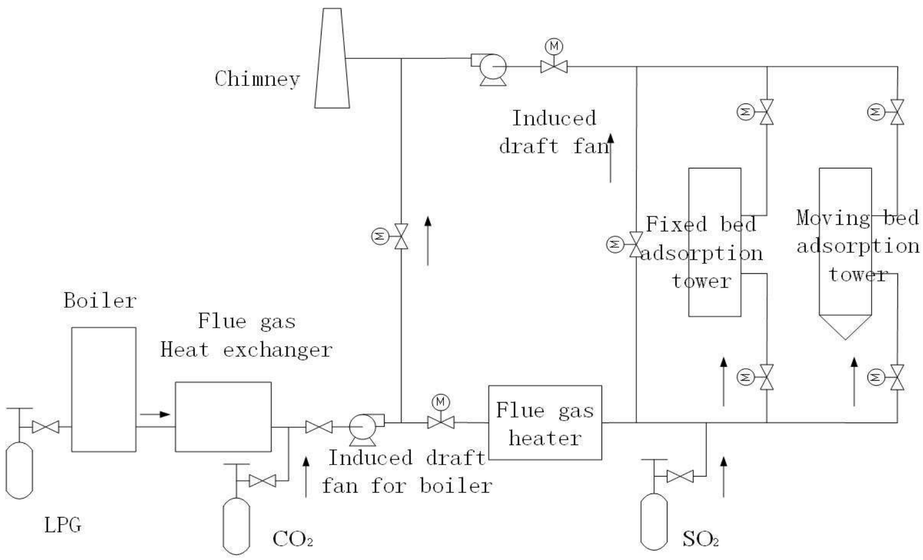


Figure 1 experimental system diagram

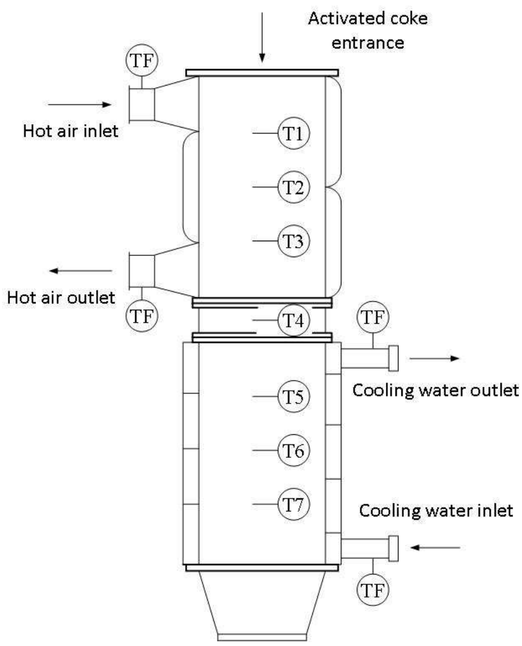


Figure 2 principle diagram of the heat transfer coefficient measurement device

Experiment system is shown in figure 1, hot air pressure cycle through high temperature air blower, form a loop, air heater is used to adjust and control flux into the heat transfer coefficient measurement device to heat activated coke hot air temperature.

The heat transfer coefficient measurement device, which is moving bed activated coke desorption tower, the device principle, see figure 2. This topic experiment is the determination of the desorption tower moving bed all heat transfer parameters of the heating section (section), including temperature, flow, pressure, etc., complete the experimental study of heat transfer characteristic of activated coke moving bed. The temperature needed for the experiment are measured by thermocouple, measuring point located in desorption tower hot air import and export, air import and export temperature measured desorption tower, moving bed heating tube side and tube side between three thermocouple (internal temperature, measurement of activated coke system) moving bed transition section (heating section measuring moving bed particle system temperature) and below the moving bed adsorption tower (activated coke inlet temperature measured desorption tower).Flow by the measurement of the flow meter, measuring point is located in the heating period of hot air import and export. Activated coke particle moving bed movement speed by adjusting the desorption tower feed machine, unloading machine speed frequency (Hz) control decision.

1.2 Laboratory equipment

Desorption tower equipment used parameters are shown in table 1, activated coke physical parameters and heat exchange tube material properties are shown in table 2

1.3 Experimental scheme

According to the moving bed heat exchanger design size and presupposition of activated coke and the inlet temperature of heating medium and the velocity (traffic) and activated coke inlet temperature, calculate the total heat transfer rate and moving bed heat exchanger activated coke export temperature and heating of heat transfer coefficient, based on using the control variable method, calculation and analysis the change of the parameter variables affect the total heat transfer coefficient and heat transfer.Variable parameters and the parameters design values are shown in table 3.

Table 1 Desorption tower equipment used parameters

Device name	specifications
Stripping tower for water pump	Q=16m3/h，H=48m，N=5.5kW
Bucket elevator	Amount of material 0.3-0.6 m3/h,Export height 8.1m,3kW
Heat transfer coefficient measurement device	The dimensions: 724 (length)×480（width）×3800（height）
Determination of heat transfer equipment feeder and unloading machine	Type:YJD-H2, 617×493×410, 0.75kW
Air heater	1200(length)×1100（width）×1200（height）,N=27KW
High temperature air fan	Q=675-2420Nm3/h，△P =9882-10589Pa，N=18.5KW

Table 2 Moving bed design parameters and material parameters

Device name	Project/Unit	Data
Moving bed	Heat preservation coefficient (φ)	0.95
Activated coke	Size /mm	φ9×10
	Specific heat /J.(g·K) $^{-1}$	1.2
	Density /Kg·m^{-3}	918
	Stacking density /Kg·m^{-3}	643
	Poriness	30%
	h /W·(m·K)$^{-1}$	0.23
Heating section	Pipe number	7×25=175
	Number of passes	4
	Activated coke inlet temperature	30
	Heat the air inlet temperature	500
Cooling section	Pipe number	7×6=42
	Number of passes	8
	Cooling water inlet temperature	30

Table 3 Variable parameters and design values

Project	Data		
	10Hz	20Hz	30Hz
Active coke particle velocity /mm·s^{-1}	0.38	0.77	1.15
Heating period of air inlet temperature /℃	180	205	240
Heating period of air flow/m3·h^{-1}	500	550	600

2 Experimental results and analysis

The total heat transfer coefficient K is calculated by means of heat transfer rate equation and heat balance calculation equation, specific as follow.

$$\Phi_1 = q_{m1} \cdot C_1 \cdot \Delta t_1 = \left(\rho_1 \cdot \upsilon_1 \cdot A_1\right) \cdot \mathrm{C}_1 \cdot \left(t_1 - t_1{}'\right) \quad (1)$$

$$\Phi = \varphi \cdot \Phi_1 = \Phi_2 \quad (2)$$

$$\Phi_2 = q_{m2} \cdot C_2 \cdot \Delta t_2 = q_{m2} \cdot C_2 \cdot \left(t_2 - t_2{}'\right) \quad (3)$$

$$\Delta t_m = \left(\Delta t_{\max} - \Delta t_{\min}\right) \Big/ \left(\ln \Delta t_{\max} / \Delta t_{\min}\right) \quad (4)$$

$$K = \Phi \Big/ \left(A_0 \cdot \Delta t_m\right) \quad (5)$$

Table 4 Heat transfer coefficient of the experimental results

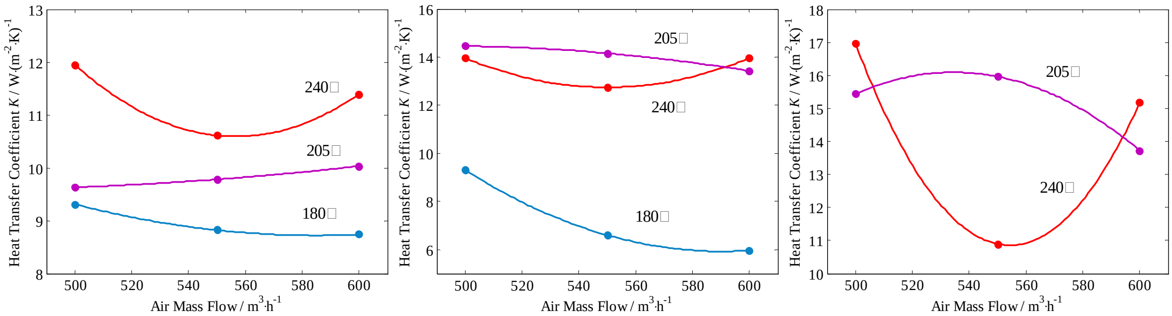
Working condition serial number	Total heat transfer coefficient / $W\cdot(m^{2}\cdot K)^{-1}$	Activated coke export temperature calculated value /℃	calculated and measured values minus/℃	Tube outside heat transfer coefficient $W\cdot(m^{2}\cdot K)^{-1}$
1	10.6	174.2	4.3	13.5
2	11.4	171.3	5.5	14.6
3	12.0	177.8	4.9	15.9
4	12.7	154.0	10.0	17.6
5	14.0	147.0	5.0	20.6
6	14.0	144.2	5.3	19.4
7	10.9	124.0	5.0	14.0
8	15.2	134.0	1.0	21.2
9	17.0	132.1	1.2	26.9
10	15.4	130.0	4.0	23.0
11	16.0	128.0	1.0	23.7
12	13.7	135.0	0.0	18.4
13	13.4	137.7	4.9	18.0
14	14.2	137.4	1.5	19.7
15	14.5	136.6	2.9	21.3
16	9.6	154.4	8.5	12.2
17	9.8	155.7	4.3	12.1
18	10.0	157.8	5.4	12.4
19	8.7	152.5	5.4	10.4
20	8.8	149.4	4.5	10.7
21	9.3	148.2	5.3	11.7
22	9.3	137.8	4.9	11.7
23	6.6	136.1	4.2	7.7
24	6.0	143.7	4.8	6.7

First according to the hot air flow, import and export temperature experiment data and hot air side heat quantity

Φ1calculated by physical property parameters. Φ1 multiplied by the coefficient of heat preservation can get heat absorption Φ2 of activated coke particle system. Then according to the physical parameters and the inlet temperature can get outlet temperature of activated coke in hot section. total heat transfer coefficient can get by calculating the logarithmic mean temperature difference, combined with the total heat transfer. In particular the transition period of temperature measuring point measured temperature data in desorption tower moving bed does not represent the temperature of the segment activated coke, but it is between the outer wall temperature of segment heat exchange tube and actual temperature activated coke particles.

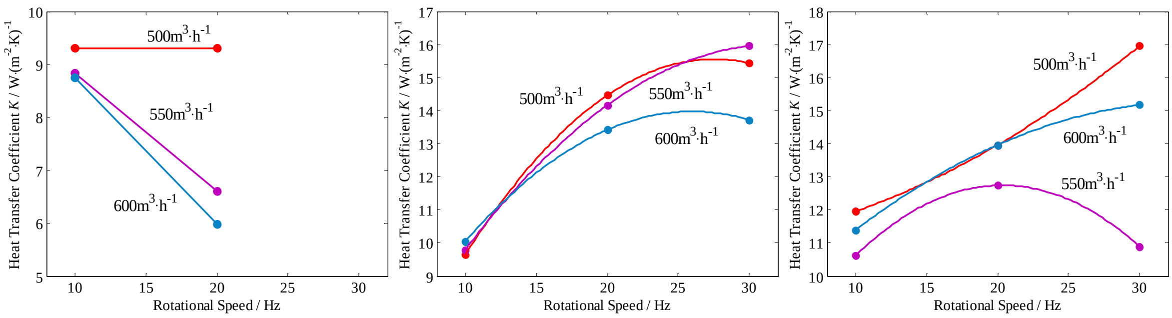
Through processing experimental data, the heat transfer coefficient K, activated coke exports (transition section) temperature calculated value, activated coke export temperature calculated value under various operating conditions and actual value measurement error can be obtained such as table 4.

The coefficient of heat transfer experiment result shows that the valve under different opening the relation between air flow and heat transfer coefficient as shown in the figure below:



(a)10Hz (b) 20Hz (c) 30Hz

Figure 3 Heat transfer coefficient under the speed change with air flow



(a)180℃ (b) 205℃ (c) 240℃

Figure 4 Heat transfer coefficient of air temperature change with speed curve

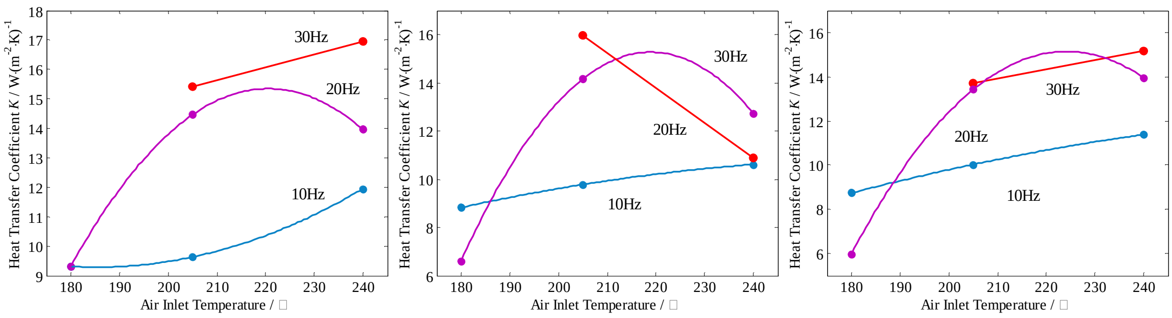


Figure 5 Heat transfer coefficient changing with the air temperature curve under different air flow

According to the experimental results, the following conclusion can be gotten:

(1) the figure 3 shows that moving bed total heat transfer coefficient K vary with the change of the air flow is not big. Because of the hot air to the wall of tube convective heat resistance is small, the air to the active coke particle heat transfer resistance mainly concentrated in the solid particles in the wall to the outside of the tube of the this process. So, simply by changing the hot air flow rate and the intensity of adjusting tube of convective heat transfer, impact on the overall heat transfer process is not much. Data in the working condition of a few points appear larger fluctuation, that is because the experiment condition is not very stable, lead to the error of "balance" as stable condition, caused a certain experimental error, this is unavoidable in the experiment.

(2) the figure 4 shows that when air parameters is constant, activated coke in the decline of variety in the moving bed has a certain influence on the total heat transfer coefficient. Under the current level of the experiment, the results showed that activated coke descent velocity increased from 0.38 mm/s to 1.15 mm/s process, the total heat transfer coefficient K is roughly from 12 $W/m^{2\cdot}$ k to 16 $W/m^{2\cdot}k$ level, obviously rise is bigger also, that shows activated coke movement speed has a great influence on the moving bed heat transfer coefficient. Activated coke movement speed increase can make the moving bed thermal resistance, particle side cooling effect of the improved significantly increased (temperature), raised from the wall to the particle radiation heat transfer coefficient, resulting in the total heat transfer coefficient of the rising trend. To ensure internal particles moving bed exchange heat pipe of scour and the impact wear is small enough and the reasonable structure design on moving bed, the larger activated coke descending speed will lead to higher heat transfer effect.

(3) the figure 5 shows that in the case of activated coke descending speed must have, the higher the air inlet temperature will get greater heat transfer coefficient. Air inlet temperature is higher, the total heat transfer in a moving bed heat exchanger temperature will increase, with the enlargement of activated coke descent velocity can improve the heat transfer coefficient is the same. All in all, activated coke rate of descent and heating air inlet temperature are the main factors affecting the total heat transfer coefficient. Moving bed heat transfer coefficient with activated coke descent velocity and surface hot air inlet temperature changes as shown in figure 6.

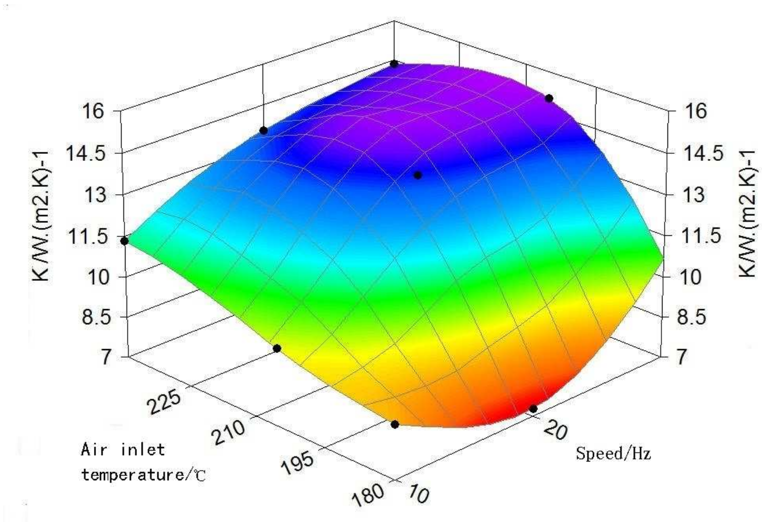


Figure 6 Total heat transfer coefficient K was created

3 Wall temperature and tube outside heat transfer coefficient calculation and analysis

The moving bed under different condition of total heat transfer coefficient and the average tube wall temperature has been obtained, according to the existing data, check the average temperature of the heat pipe tube wall t_{wi} under various working conditions, the check process is as follows:

First, that setting a pipe wall average temperature t_w initial value is equivalent of numerical calculation of the given initial conditions. The experiment of practical calculation process t_w initial value setting of higher than that of activated coke export 30 ℃ temperature measurements, compute a tube with the inner surface temperature heat transfer coefficient h_i:

$$Nu = 0.0214\left(Re^{0.8} - 100\right)Pr^{0.4}\left[1 + \left(D_h/L\right)^{2/3}\right]\left(t_f/t_{wi}\right)^{0.45} \tag{6}$$

$$h_i = Nu \cdot \lambda / D \tag{7}$$

The inner surface temperature is used at the same time, according to the hot air to the heat exchange tube wall of tube in the heat equation.

$$\Phi_i = \Phi = h_i \cdot A_i \cdot \left(\left(t_1 + t_1'\right)/2 - t_{wi}\right) \tag{8}$$

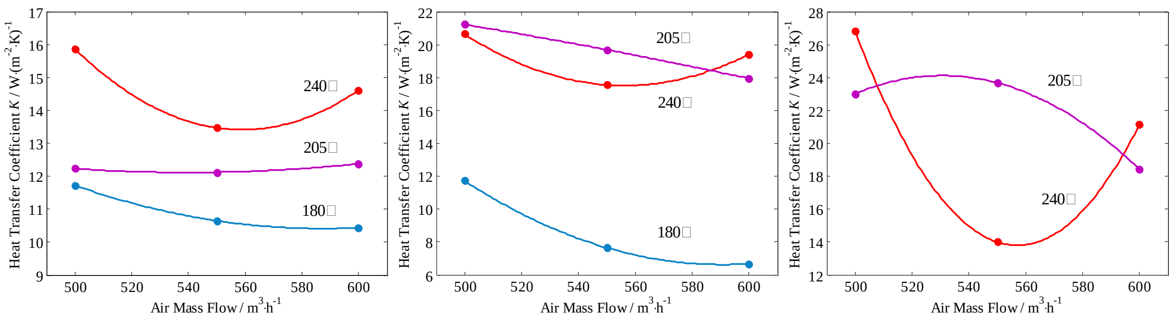
A tube heat transfer coefficient h_i' can be able to get, Compare the values of h_i' and h_i. If a relative error within 1% ~ 1%, the tube wall temperature set is the actual value. If the relative error is out of 1% ~ 1%, to change the value of the t_w make error in the range. After calculating the heat exchange tube inner surface temperature, according to the wall heat transfer formula, it can get tube outer wall average temperature delta t_{w0}.

$$\Delta t_w = \left(\Phi \cdot \ln\left(r_2/r_1\right)\right)/2\pi\lambda l = t_{wi} - t_{wo} \tag{9}$$

By heat transfer coefficient expression of the heat transfer process through a cylindrical wall again, also can get from the outer wall of tube to particle h_0 side the heat transfer effect of the overall heat transfer coefficient.

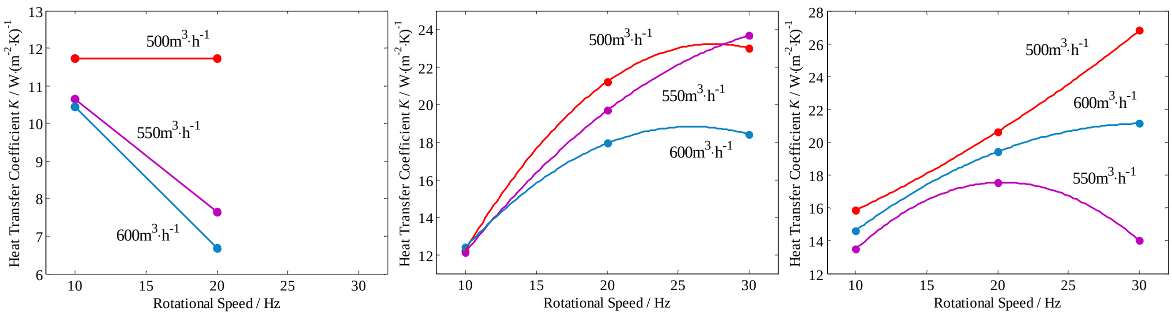
$$K = 1/\left(\left(d_o/d_i\right)\left(1/h_i\right) + \left(d_o/2\lambda\right)\ln\left(d_o/d_i\right) + 1/h_o\right) \tag{10}$$

the outer wall of tube h_0 to the side of the particle heat transfer coefficient is calculated, whose value shown in table 5.



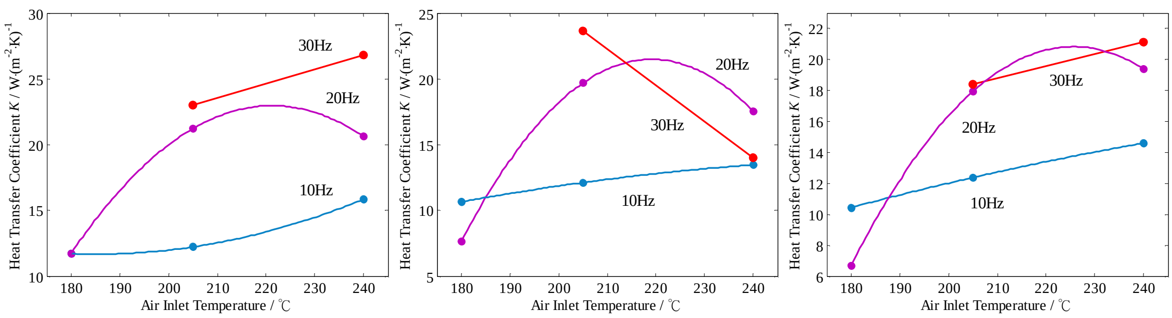
(a)10Hz (b) 20Hz (c) 30Hz

Figure 7 Tube outside heat transfer coefficient changing with air flow curve under different rotational speed



(a)180℃ (b) 205℃ (c) 240℃

Figure 8 Outside the tube heat transfer coefficient changing with speed curve under different air temperature



(a) 500m^{3}·h^{-1} (b)550m^{3}·h^{-1} (c)600m^{3}·h^{-1}

Figure 9 Outside heat transfer coefficient changing with the air temperature curve under different air flow tube

From the result data can be directly see, tube outside heat transfer coefficient change with activated coke movement speed, the tendency of the hot air temperature and flow rate, which is similar to total heat transfer coefficient, specific as follows:

(1) The figure 7 shows that removing the individual outside the point mutation in the experiments, the remained active in coke descending speed and heating air inlet under the condition of constant temperature, tube outside heat transfer coefficient changing with heating air flow change is not big. It is also because tube air flow rate changing make the air to the wall of tube heat transfer conditions different. The total heat transfer resistance most focus on the process of tube, so tube arises the air flow rate changed and tube outside heat transfer coefficient changed little.

(2) The figure 8 shows that air parameters constant, activated coke changes in the rate of decline in the moving bed has a certain influence on tube outside heat transfer coefficient. Under the current level of the experiment, the results showed that activated coke descent velocity increased from 0.38 mm/s to1.15 mm/s process, tube outside heat transfer coefficient K is roughly from 11 $w/m^{2}\cdot k$ to 20 $w/m^{2}\cdot k$, obvious rise and it is bigger also, that activated coke movement speed has a great influence on the moving bed heat transfer coefficient. It is also because activated coke increases movement speed will obviously increase particle side cooling conditions, raise the heat transfer coefficient of the tube.

(3) The figure 9 shows that activated coke descent velocity (inlet and discharge machine speed) is constant, the higher the air inlet temperature will get greater heat transfer coefficient. This is because the air inlet temperature is higher, the corresponding wall can improve the overall temperature, so that to promote the outer wall of the tube to the side of the particle radiation intensity of heat exchange.

Activated coke rate of descent and heating air inlet temperature is the same tube outside heat transfer coefficient is the main influence factors. Tube outside heat transfer coefficient change with activated coke descent velocity and surface hot air inlet temperature as shown in figure 10.

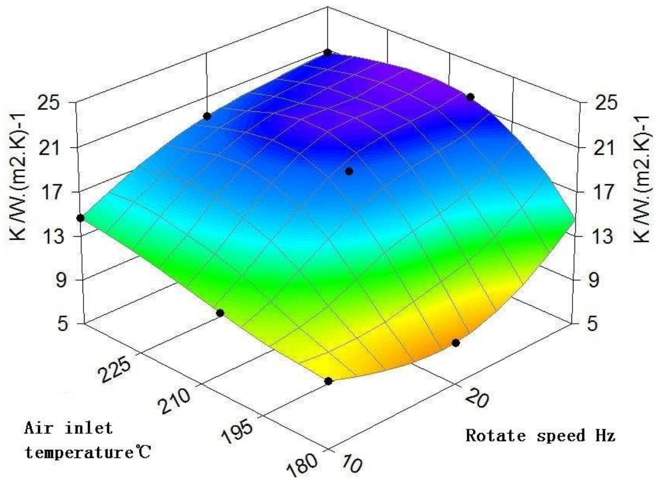


Figure 10 Tube outside heat transfer coefficient of the experimental value

CONCLUSION

(1) This paper introduces the experimental system, equipment, experiment of concrete objects and the experiment plan, through calculation and analysis of the experimental data obtained activated coke heat transfer performance and the overall heat transfer rule of moving bed. Specific rule is: the main influencing factors of heat transfer coefficient are activated coke rate of descent and hot air inlet temperature, within the scope of the experiment, the greater the decline speed of activated coke, hot air inlet temperature is higher, the moving bed heat transfer coefficient is larger.

(2) The heat transfer model of moving bed heat exchanger and the air from the tube to the outside of the tube heat transfer mechanism of the particle systemic are mainly introduced and analyzed. This paper gives the method of heat balance method was used to calculate the tube inside and outside wall temperature, the tube outside heat transfer coefficient is calculated under the working condition of the experiment and analysis the size of the pipe

outside the main factors that influence the heat transfer coefficient is also activated coke rate of descent and hot air inlet temperature, the impact of relationship with the total heat transfer coefficient is the same, this confirms the hot air to the activated coke mainly concentrated in the outer wall of tube in heat transfer resistance to the accuracy of the particle system process. By adopting the combination of experimental study and theoretical research method, the tube outside heat transfer coefficient is obtained the theoretical calculation value roughly coincide with the experimental results, the moving bed heat exchanger heat transfer and particle system heat transfer research of ascend a new step.

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