

Experimental Study on Heat Recovery Technology of Industrial Furnace Wall

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ABSTRACT: Aiming at the characteristics of large volume and dispersed heat-dispersing surfaces of the industrial furnace, the adoption of air guide sleeve can effectively organize the air flow and the heat recovery of the industrial furnace wall. This paper introduces the heat recovery principle of air guide sleeve, and establishes a visible heat recovery heat engineering experiment table of air guide sleeve so as to test the clearances of the four different working modes and different stream guidance gaps when the furnace wall's temperature is 80°C, 120°C, 160°C and 200°C, which measures the distribution rule of temperature and velocity in the flow passages on the cross sections with different heights and the temperature change outside the flow guide baffle, and adopts a surface heat exchanger to carry out experiments on heat recovery. The result shows that the adoption of the air guide sleeve improves the capability of the furnace wall in temperature preservation and the heat recovery can reduce the discharge amount of heat pollutants by 83% or so, which betters the environment.

Keywords: Industrial furnace, air guide sleeve, thermal pollution, convection, radiation

1. INTRODUCTION

The large quantity of heat produced around by the industrial furnace wall makes the workshop rather sweltering, which seriously worsens the operating ambient of the site operators and affects the normal operations of the electronic components around the furnace as well. To improve the environment quality around the industrial furnace, it is necessary to take some effective measures to reduce heat discharged by the industrial furnace wall to the surroundings so as to improve the working environment in the workshop ^{[1] [2]}. This paper proposes a method that a protection device is additionally installed outside the furnace body, namely the method that the air guide sleeve is set to organize the air flow and the suggestion that a furnace wall heat discharge simulator be built to conduct experimental study on the air flow distribution in the flow passage and the heat recovery of the furnace wall.

2. HEAT RECOVERY CHARACTERISTICS OF AIR GUIDE SLEEVE AND EXPERIMENTAL DEVICE

2.1 Heat Recovery Characteristics of Furnace Wall of Air Guide Sleeve

Flow direction of the heat radiated by the furnace wall with air guide sleeve is shown as Figure 1. Heat radiation Q_w of the furnace wall has two ways, namely convection and radiation. As the air is a diathermic body which does not have the ability to absorb the radiant heat, so the heat Q_{wr} from the heat radiation part of the furnace wall is completely transmitted to the air guide sleeve baffle, which heats up the baffle and forms a natural convection heat exchange Q_{cd} between the inner side of baffle and the air. Q_{cd} , together with the convection heat exchange Q_{wd} of the furnace wall, ascends to the top and then enters into the surface heat exchanger, with the total amount being $Q_{td} = Q_{wd} + Q_{cd}$. The other part of heat Q_{ct} passes through the baffle and then is radiated into the atmosphere in a form of natural convection and radiation, while the heat discharge energy equation of furnace wall is shown as follows [3]:

$$Q_w = Q_{td} + Q_{ct} \quad (1)$$

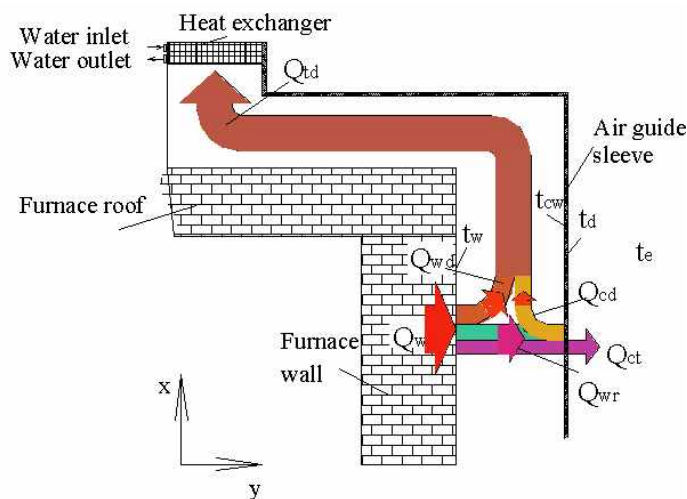


Figure 1: Flow direction of heat radiated by furnace wall



Figure 2: Heat recovery experimental device of furnace wall

2.2 Formation of Experimental Device

According to the symmetrical characteristic of the industrial furnaces, a two-dimensional space can be simplified, which is to say that a part of the furnace body and the air guide sleeve is clipped from the industrial furnace, and the experimental device is made for the experimental study on heat recovery^{[4][5]}.

Simulated furnace body of the experimental device is 1800mm high and 1200mm in half width, and the length of the clipped furnace body is 600mm, and the front and the back both utilize a heat insulating material to isolate the heat. The device body adopts five electric heating plates(with the size of 600*600mm*mm and electric power of 1.5kW) to simulate the heat radiation of the furnace wall, wherein, three of the plates are used as the sidewall heat radiation and two are used to simulate the heat radiation of furnace roof. The five electrical heating plates are respectively arranged on a temperature probe of a heating plate so as to achieve the automatic temperature control of the furnace wall. Based on the blackness of the simulated furnace body, the heating plates can be painted with coatings with different blackness coefficient. The air guide sleeve and the baffle are in a moveable structure and can adjust the clearance width of the flow passage according to the experiment condition. The materials of the air guide sleeve and the baffle can also be changed, and light building materials can be used, such as the asbestos slate and the thin metal iron plate. The device is shown as Figure 2.

2.3 Experimental Device Detection System

Experimental device detection system includes a temperature measuring system and a velocity measuring system, wherein, the temperature measuring system mainly consists of a fixed temperature probe and a moveable flow passage temperature distribution measuring stick. The fixed temperature probe is equably buried under the ground and outside the air guide baffle and used to measure the heat radiation of the baffle, and the moveable flow passage temperature distribution measuring stick is used to measure the temperature distribution on the different sections of the flow passage. The base material of the measuring stick is wedge hard wood and 16 thermal couples are fixed on the measuring stick with the equal distance of 20mm and are communicated with a PC via two multi-way sampling cards of WP series to record the test data. The velocity measuring system utilizes the CALC Plus digital meter which tests the velocity distribution on the section of the flow passage at the same place of the flow passage's temperature test. See Figure 3---Figure of the heat recovery experimental device detection system of the air guide sleeve.

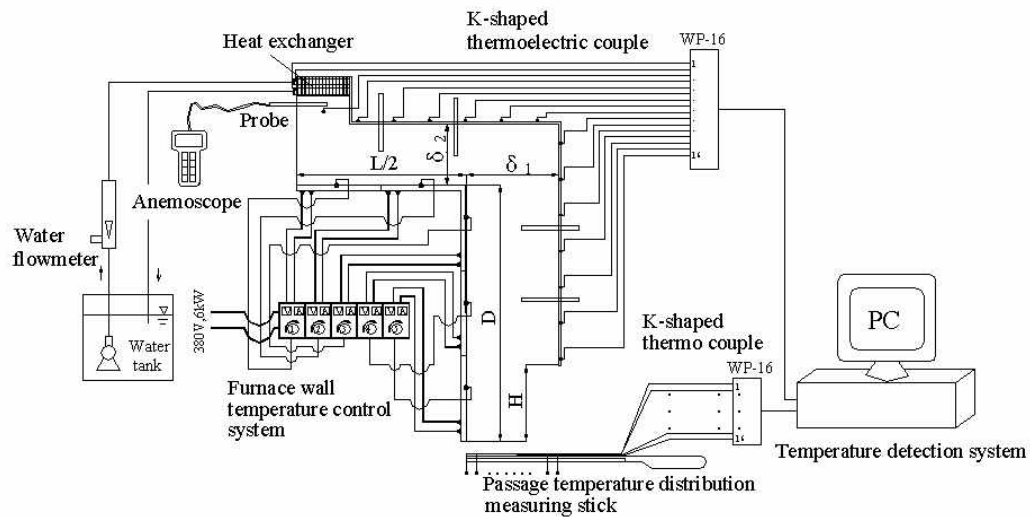
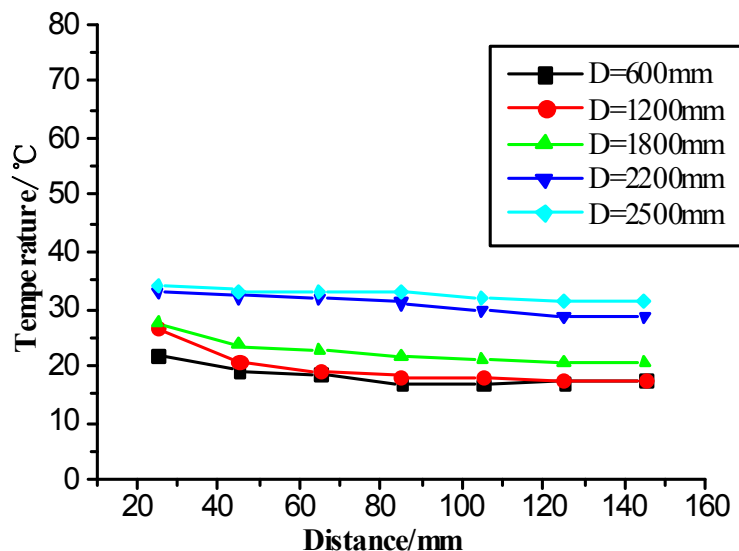


Figure3: Figure of the heat recovery experimental device detection system of the air guide sleeve

3 AIR GUIDE SLEEVE HEAT RECOVERY EXPERIMENT AND RESULT ANALYSIS

3.1 Temperature and Velocity Distribution of Air Flow in Flow Passage

After the condition changes each time, the test begins when the furnace wall temperature and the temperature outside the air guide sleeve baffle become stable. During the experiment, the indoor temperature is 14.3 °C, and the experiment result is as the Figure 4 to 8.



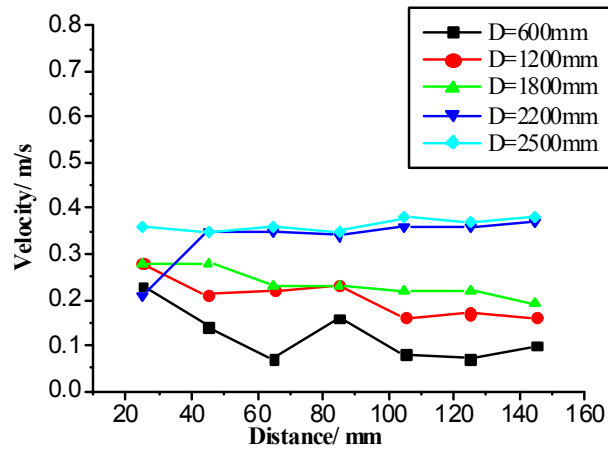


Figure 4: Relations between the change of the air flow's temperature and velocity and the furnace wall's distance in the flow passage ($t_w=80^\circ\text{C}$, $H=400\text{mm}$, $\delta_1=\delta_2=150\text{mm}$)

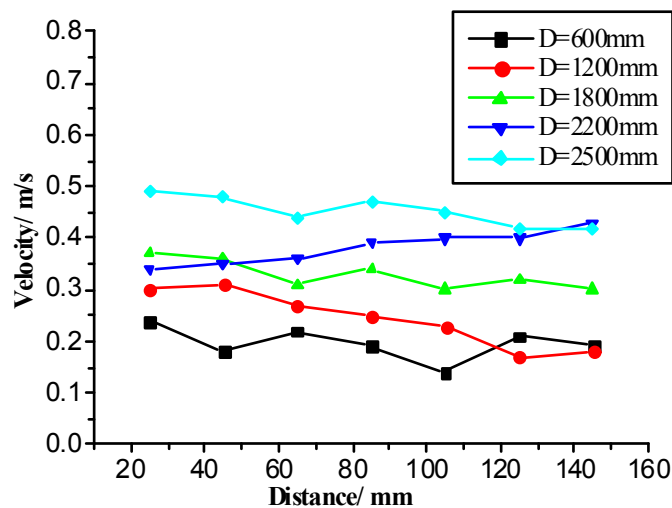
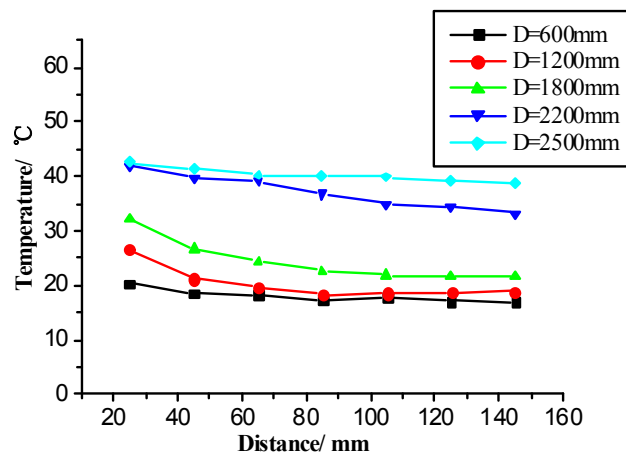


Figure 5: Relations between the change of the air flow's temperature and velocity and the furnace wall's distance in the flow passage ($t_w=120^\circ\text{C}$, $H=400\text{mm}$, $\delta_1=\delta_2=150\text{mm}$)

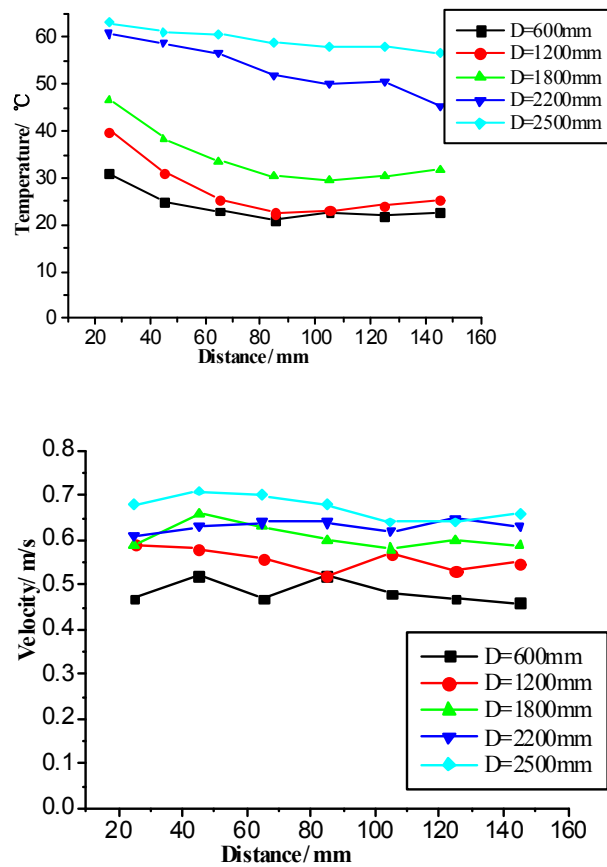
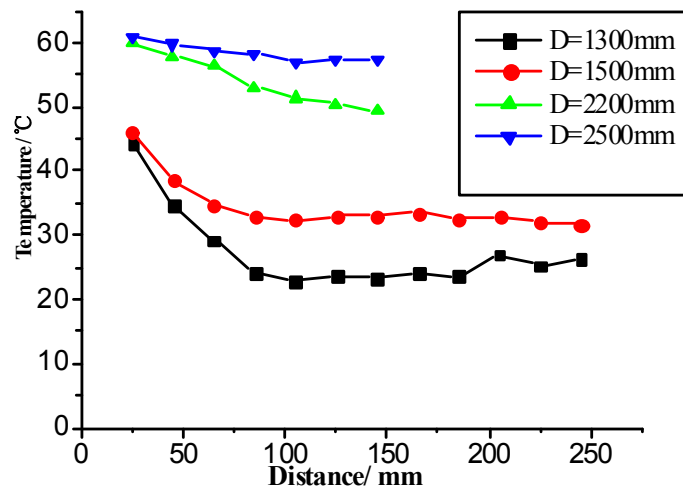


Figure 6: Relations between the change of the air flow's temperature and velocity and the furnace wall's distance in the flow passage ($t_w=200^\circ\text{C}$, $H=400\text{mm}$, $\delta_1=\delta_2=150\text{mm}$)



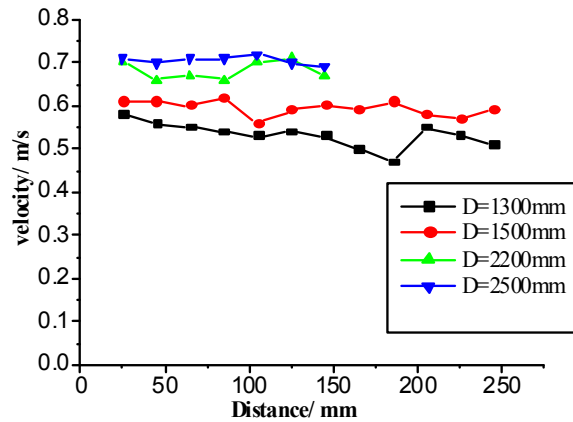


Figure 7: Relations between the change of the air flow's temperature and velocity and the furnace wall's distance in the flow passage($t_w=200^\circ\text{C}$, $H=1000\text{mm}$, $\delta_1=250\text{mm}$, $\delta_2=150\text{mm}$)

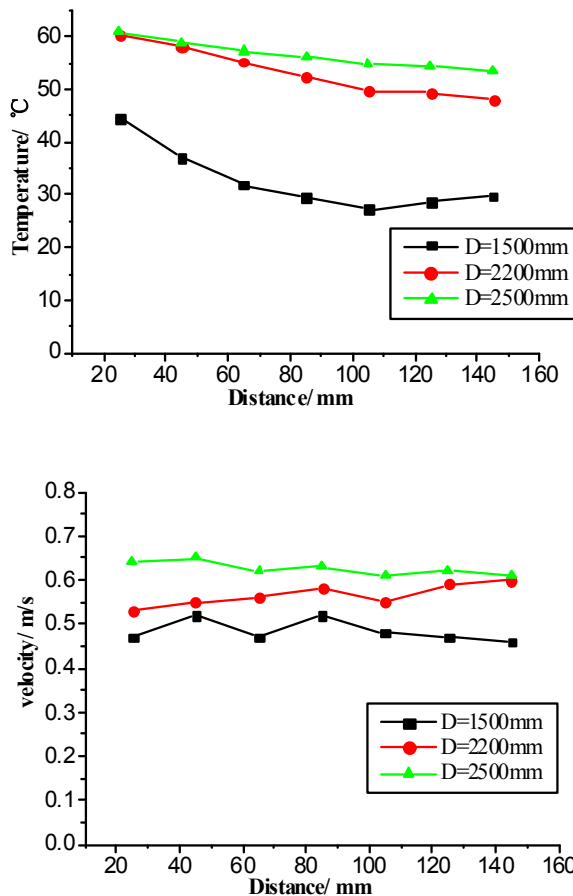


Figure 8: Relations between the change of the air flow's temperature and velocity and the furnace wall's distance in the flow passage($t_w=200^\circ\text{C}$, $H=1300\text{mm}$, $\delta_1=\delta_2=150\text{mm}$)

The experiment result shows that the temperature of the air flow in the flowing passage is closely related to that of the furnace wall and the higher the temperature of the furnace wall is, the higher the temperature of the air flow in the flow passage at the corresponding place is; the greater the velocity of the air flow is. Seen from the figure, under the action of the attached

surface of the furnace wall, as for the baffle with lower raising height, the attached surface generates short distance and is thin, so the temperature of the cross section at this place is small in change. With the increase in the raising height, the thickness of the attached surface increases and the temperature change increases constantly. However, the velocity changes are all great under the different raising heights, which is similar to the effect of the pipe inlet. At the crossing place between the sidewall and the furnace top(namely the 90° corner), as the natural convection on the sidewall is stopped by the air guide sleeve baffle(the partial resistance), the air flow distribution at this place is changed, the flowing velocity at the place close to the sidewall is increased, the natural convection heat exchange coefficient is improved, and the heat exchange strength is enhanced, so the average grade in the air flow temperature in the raising of the air flow temperature is greater than the other places of the flow passage. In the horizontal flow passage, the ascending air flow under the influence of the sidewall becomes the horizontal air flow after the direction change and then mixes with the ascending air flow resulted from the influence of the furnace top, which improves the equality of the air flow temperature on the cross section of the outlet and can improve the inlet condition of the heat side of the surface heat exchanger [6], [7], [8].

Air guide sleeve baffle guides the air flow and separates it from the external environment. Seen from Figure 7 to 9, with the increase of the raised height of the baffle, much more outside air is absorbed into the flow passage, so the separating ability of the baffle is decreased, and then the outlet temperature of the flow passage is lowered. What is specially pointed out by the experiment is that the raised height should not be higher than the plane of furnace roof, or else the hot air flow will spill out, and the flowing velocity at the rear part of the flow passage is decreased, which is not favorable for the furnace wall's heat recovery.

The increase of the width at the vertical part of the flow passage increases the air sucked from the inlet of air guide sleeve, the width is smaller after the corner and the flow amount is increased. When the width is increased to an appropriate degree, the airflow in the flow passage is increased by a certain degree, which is helpful for increasing the exchanged heat of the surface heat exchanger.

3.2 Temperature of Baffle and Thermal Pollutant Discharge

During the measurement of the temperature and velocity distribution in the flow passage, the temperature of the outer surface of the air guide sleeve baffle is tested and the test result is shown as Figure 9.

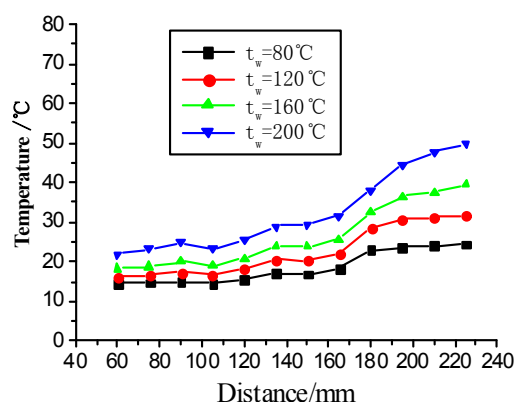


Figure 9: Relationship the temperature of the temperature of the air guide sleeve's external

wall and distance under different furnace wall temperatures ($H=400\text{mm}$, $\delta_1=\delta_2=150\text{mm}$)

Calculation of the heat radiation Q_{sb} of the furnace wall and the outside of the baffle, the available formula being ^[9]

$$Q_{sb} = \sum A_i \left\{ 4.88\varepsilon \left[\left(\frac{273+t_d}{100} \right)^4 - \left(\frac{273+t_e}{100} \right)^4 \right] + A(t_d - t_e)^{1.25} \right\} \quad (1)$$

Wherein: A_i is the heat radiation surface area m^2 ; ε is the blackness coefficient of the corresponding heat radiation surface material; t_d is the temperature of the heat radiation surface, $^{\circ}\text{C}$; t_e is the environment temperature, $^{\circ}\text{C}$; A is the coefficient, with the commonly adopted wall being $A=2.2$, horizontal upper adopted wall being $A=2.8$, and the heat radiation calculation result is as the following Table 1:

Table 1 Heat radiation calculation of the furnace wall

Furnace wall temperature ($^{\circ}\text{C}$)	Heat radiation capacity		Decreased heat discharge	
	Exposed wall (W)	With baffle (W)	Heat amount (W)	Percentage (%)
80	1664.9	265.5	1399.4	84.1
120	3118.8	511.0	2607.8	83.6
160	4893.7	799.9	4093.8	83.7
200	7024.1	1179.6	5844.5	83.2

Note: the simulated furnace wall is 1.8m high, 1.2m long, 0.6m wide

The result of the Table 1 shows that, after the adoption of the air guide sleeve, the heat discharge of the heat radiated from the furnace wall is reduced by about 83%, and the heat preservation capacity of the furnace wall is improved and the thermal pollution caused by the heat radiation of the furnace wall to the environment is decreased greatly.

3.3 Heat Recovery

Known from the test of air flow's temperature and velocity distribution, the average velocity at the outlet of the smooth flow passage which is not provided with a surface heat exchanger is: 0.3~0.4m/s when furnace wall temperature is 80°C ; 0.6~0.7m/s when furnace wall temperature is 200°C . After the surface heat exchanger is installed, there is a certain resistance loss that shall be compensated by using an exhaust fan so as to guarantee the higher heat exchange efficiency of the surface heat exchanger. After the experiment, too large pumping force will pump away a great amount of heat at a low-temperature status; meanwhile, the energy consumption of the electric motor is increased, which is not helpful for the normal work of the surface heat exchange. Through the adjustment of the input power of the exhaust fan, the flow rate at the inlet on the heating side of the surface heat exchanger is close to the flow rate at the state of original natural convection, which is the best status. After the measurement, the power consumption of the exhaust fan is 20W. Now the test on furnace wall heat recovery under the different working conditions is carried on. Figure 10 and Figure 11 are respectively the contrast of experimental calculation results of the heat recovery of the surface heat exchanger when the exhaust fan is started or stopped.

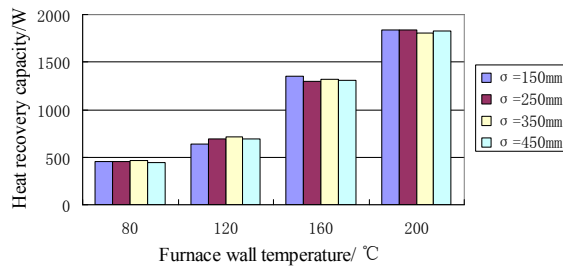


Figure 10: Relationship between the heat recovery, furnace wall temperature and the flow passage width (with exhaust blower started)

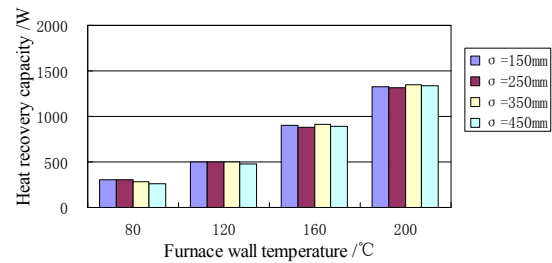


Figure 11: Relationship between the heat recovery, furnace wall temperature and the flow passage width (with exhaust blower stopped)

Heat recovery capacity is closely related to the furnace wall temperature and the existence of the exhaust fan. Seen from Figure 11-1, the heat recovery amount is large under the action of the exhaust fan, which is quite related to the magnitude of furnace wall temperature and is basically unrelated to the flow passage width. According to Figure 11-2, in case the natural pumping force is applied (that is, no blower is adopted), the heat recovery amount is small, which has bearing on such factors as the furnace wall's temperature and the baffle width. Wherein, with the same furnace wall temperature, the pumping force in the flow passage will see gradual decline, which leads to the decrease of the hot airflow of the surface heat exchanger and finally to the continual decline of its heat recovery amount. Both Figure 11-1 and Figure 11-2 shows that under the same condition; the recollected heat when the exhaust fan is started is 44% greater than that when exhaust fan is stopped. The absolutely increased heat recovery amounts are respectively 168.4、204.8、429.1、509.3W, if the electricity consumption 20W of the exhaust fan is deducted, greater heat recovery amount can be obtained.

3 CONCLUSION

1) After the arrangement of the air guide sleeve, the higher the furnace wall temperature is, the higher the air flow is in the flow passage of the corresponding place and the greater the velocity of the air flow is, which is also related to the raised height of the air guide sleeve baffle. Especially when the raised height is higher than the furnace roof, the air in the flow passage will spill out, which weakens the air flow's organizing ability, affects the outlet temperature and flow rate of the air flow and reduces the heat recovery capacity.

2) After the furnace wall is installed with the air guide sleeve, the heat radiation loss is greatly reduced, the heat preservation capacity of the furnace wall is increased and the pollution to the environment can be reduced as much as 83%.

3) The surface heat exchanger is installed and the exhaust fan is started so as to keep the air flow in the flow passage at natural convection velocity when the flow passage is smooth and effectively recycle the heat. Although a certain amount of electricity is consumed, extra heat amount of 44% can be recycled.

This paper conducts experiment on the influences of the furnace wall temperature and raised

height of the baffle toward heat recovery, after the air guide sleeve is installed, and needs to conduct a further experimental study on other factors such as furnace wall blackness, flow passage width at the horizontal section of the air guide sleeve and the change of baffle material.

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