Study on the performance of Double-pipe phase heat exchangers in waste heat recovery with heat storage and discharge

Quanying Yan, Yuan Guo*, Chao Ma
Beijing Municipality Key Lab of Heating, Gas Supply, Ventilating and Air Conditioning Engineering, Beijing University of civil Engineering and Architecture, Beijing, 100044, China

*Corresponding author’s e-mail: 961160025@qq.com

Abstract. The heat transfer performance of the double-pipe phase change heat storage and exothermic device and its cycle system for waste heat recovery was studied experimentally. 10 different experimental conditions were set by adjusting the inlet temperature, inlet flow rate and heat storage time of the phase change heat storage and exothermic device to study the changes of the outlet temperature, heat exchange and the inlet and outlet temperature of the heat sink of the heat-using device. The experimental results show that the higher the inlet temperature, the higher the flow rate and the longer the heat storage time, the higher the average heat exchange and the longer the heat release time of the heat exchanging device. The phase heat exchanger designed and used in this experimental research provides a certain experimental basis and data reference, which can be used for waste heat recovery in industrial and other fields.

1. Introduction
In recent years, the importance of energy conservation and environmental protection issues has become increasingly prominent. However, the abundant low-temperature waste heat in the industrial field has led to serious waste due to its instability and other restrictive factors, and the waste heat recovery technology urgently needs to be developed. At present, the research on phase change materials is progressing rapidly [1, 2], and the application in phase change energy storage devices can improve the utilization rate of industrial low-temperature waste heat recovery and further improve the energy development structure, thus phase change energy storage devices have a broad development and application prospect in the field of low-temperature waste heat recovery.

Some scholars have conducted related studies. Saydam [3] et al. conducted numerical simulations of the PCM melting process using ANSYS software and analyzed its effect on the heat exchanger performance. Saeed [4] et al. experimentally evaluated the thermal characteristics of a plate heat exchanger using PCM as the energy storage medium.

In this research, a self-designed double-pipe phase change heat storage and heat release device is used to form a circulating system for waste heat recovery and use in radiator heating. The mainly studies the influence of factors such as the inlet temperature of the device on the heat transfer performance of the phase change device, and provides a reference for the application of phase change heat technology and phase change heat device in industrial low-temperature waste heat recovery.
2. Design of the Experimental System

2.1 Experimental Devices

Experimental material: The PCM was a mixture of 20%62# paraffin-80% stearic acid with graphite added in the ratio of 85%:15%. The phase change temperature was 62.73 ℃ and the latent heat of phase change was 205.53 J/g [5].

Experimental device: Considering the relative independence of the PCM in the heat storage and release heat carrier and the hot water. At the same time, it is necessary to meet the safety, stability and cost of the experimental system, and the sleeve type phase change heat storage and release device is selected. Medium A and B are PCM and water respectively, outer pipe 168×3mm and inner pipe 89×2mm are 304 stainless steel, inlet and outlet flanges are DN80, two ends of the phase change heat (PCH) device are pipes Connected with a constant temperature water tank and a steel column radiator, the system uses a circulating water pump to provide circulating power, the pipes and equipment are strictly insulated with rubber and plastic insulation cotton. The detailed dimensions (mm) and structure are shown in Fig. 1.

![Figure 1. Structure of double-pipe PCH storage and exothermic device](image)

2.2 Experimental Conditions

The experiments were carried out in No. 2 Experimental Building of Beijing University of Engineering and Architecture from Nov. 15, 2019 to Jan. 20, 2020. The inlet/outlet of the phase change device and the inlet/outlet of the column radiator adopt thermocouple thermometers to measure the temperature, and use the electromagnetic flowmeter to measure the flow on the side of the phase change device and the radiator. The heat exchange $Q$ is defined in equation (1):

$$Q = \frac{Gc\Delta t}{3600}$$

Where, $c$—Thermal medium specific heat capacity, $c=4187$ J/kg·K; $G$—Thermal medium flow rate, kg/h; $\Delta t$—Import/export temperature difference of phase conversion heat device, K.

By varying the inlet temperature, inlet flow rate and storage time of the PCH storage and exothermic device, the influence of different factors on the heat transfer of the double-pipe PCH storage and release device and its system was studied. The experimental conditions are: (1) keep the hot water circulation flow rate of 100 kg/h in the PCH storage and exothermic device unchanged, and set the inlet temperature to 70 ℃, 75 ℃ and 80 ℃; (2) keep the inlet temperature of 80 ℃ unchanged, and set the hot water circulation flow rate of the PCH exchanger to 65 kg/h, 80 kg/h and 100 kg/h, respectively; (3) the inlet temperature of the hot water of the PCH exchanger is 70 ℃, the flow rate of 100 kg/h, change the heat storage time of 220min and 320min; (4) PCH exchanger hot water inlet temperature of 80 ℃, the flow rate of 100 kg/h, heat storage time of 110min and 190min.
3. Experimental Results and Analysis

3.1 Performance Analysis of the Heat Storage Process

The experimental outcomes of the outlet water temperature and heat exchange amount of the PCH device in the heat storage process change with time are shown in Figs. 2~5. When the hot water flow of the PCH storage and heat release device is 100kg/h and the inlet temperature is 70, 75 and 80℃, the change of the outlet water temperature and the heat exchange amount of the PCH device with time (Fig. 2).

![Figure 2](image1)

**Figure 2. Variation curve of water temperature and heat transfer at the outlet of heat exchanger**

![Figure 3](image2)

**Figure 3. Variation curve of water temperature and heat transfer at the outlet of heat exchanger**

Fig. 2 (The curve with an increasing trend is the outlet water temperature, and the curve with a decreasing trend is the heat exchange) shows that the water temperature at the outlet of the PCH exchanger shows a rising trend with time, and the slope of the curve is high and the rise rate is large in the first and middle period, and the rise rate gradually slows down in the later period; the heat exchange curve of the PCH exchanger shows a decreasing trend with time, and the change law of the decline rate is similar to the rise rate of the water temperature. The reason is that in the first and middle stages of the experimental test, the compound PCM filled with the phase change heat exchanger continuously absorbs the heat of hot water, its volume is more, the latent heat change is larger, and the heat exchange is higher, thus causing the heat exchanger outlet water temperature to decrease more.

Figure 3 shows the variation of water temperature and heat transfer with time when the hot water inlet temperature is 80℃ and the PCH exchanger inlet flow rate is 65, 80 and 100kg/h. The variation of outlet water temperature and heat exchange curve with time for the PCH exchanger is similar to Figure 2. It can be seen from the figure that the water temperature and heat transfer at the outlet of the heat exchanger under different flow conditions have a significant difference in the first 120 minutes of the heat storage process, because the temperature difference between the inlet and outlet of the phase-change heat exchanger is large at the initial stage, and the phase-change latent heat storage is mainly. After 120 minutes, the trend of outlet water temperature and heat exchange rate gradually approached and eased. After the PCM is completely melted in the final stage, sensible heat is mainly used for heat storage. With the increase of heat exchanger inlet flow, the flow rate of heat medium in the device becomes faster, the speed of PCM melting is accelerated, the time required for heat storage process is shortened, and the average heat exchange of PCH exchanger increases, and finally the outlet water temperature approaches 80℃.

When the inlet water temperature is 70℃, the flow rate is 100kg/h, the heat storage time is 220min and 320min respectively, the heat exchanger outlet water temperature and the heat transfer curve with time (Fig. 4). And the inlet water temperature is 80℃, the flow rate is 100kg/h, the heat storage time is 110min and 190min respectively, the heat exchanger outlet water temperature and the heat transfer curve with time (Fig. 5).
It can be seen from the above two figures that the heat storage time under the same working condition is different, and the outlet temperature and heat exchange amount are not affected much in the initial stage of the heat storage process, and the curve fitting is good. However, when the heat storage time is short, neither the water temperature at the outlet of the heat exchanger nor the heat transfer curve can reach the relatively flat curve segment in the late phase change heat storage, indicating that the heat storage is insufficient, that is, when the heat storage time is insufficient, the heat supply. The heat cannot meet the complete phase change requirement of the PCM. For the PCH device, as the heat storage time increases and is sufficient, the PCM can be completely melted to complete the heat storage, the water temperature curve at the outlet of the heat exchanger can reach a flat stage, and the heat exchange amount increases.

3.2 Performance Analysis of the Exothermic Process

The PCH device stores heat during the hot water circulation phase, after which the hot water circulation is stopped and the radiator return water enters the device for exothermic circulation instead. Figures 6–7 show the variation curves of the inlet/outlet temperatures of the circulating water of the radiator during the exothermic stage when the hot water inlet temperature of the PCH device is 70, and 80 °C in the heat storage phase.

In the exothermic process under various conditions, the heat stored in the phase conversion heat device is constantly released in the indoor environment through the radiator, and the low-temperature return water from the radiator outlet is constantly circulated with the heat exchanger, so the import and export temperatures of the radiator are constantly reduced with the exothermic time. In the initial stage of heat release, the temperature difference between the entrance and exit of the radiator is slightly larger.
and the heat release is greater. At this point, the PCM in the device is converted from liquid to solid. In the later stage of exotherm, the temperature difference of the heat sink decreases, but in the overall exotherm process, the temperature difference of the heat sink does not change much, and the heat exchange does not change significantly in magnitude.

The variation curves of the radiator inlet/outlet water temperature with time for the heat storage process unit inlet temperature of 80°C and flow rates of 65 kg/h and 80 kg/h are shown in Fig. 8 and 9.

Comparing the analysis of Fig. 7, 8 and 9, it is known that as the hot water flow rate of the device in the heat storage process increases, the longer the time of the exothermic process of the radiator, that is, the longer the time of complete solidification of the PCM.

In the heat storage process hot water circulation flow rate of 100kg/h, inlet temperature of 70°C, heat storage time of 220min and inlet temperature of 80°C, heat storage time of 110min two conditions, the radiator inlet/outlet water temperature change curve with time are shown in Fig. 10 and 11.

In the exothermic process, analysis and comparison of Fig. 6 and Fig.10, Fig. 7 and Fig. 11 can be seen: PCH exchanger inlet temperature of 70°C, heat storage time of 220min and 320min, respectively, the average temperature difference between the radiator inlet/outlet is about 6.7°C and 7°C, the radiator outlet temperature to 27°C exothermic time of about 215min and 265min, respectively; PCH exchanger inlet temperature of 80°C, heat storage time of 110min and 190min, the average temperature difference between the radiator inlet/outlet is about 5.7°C and 6.1°C, the radiator outlet temperature to 27°C exothermic time of about 310min and 358min, heat storage time of 110min and 190min, respectively,
the average temperature difference between the import and export of the radiator is about 5.7°C and 6.1°C, the radiator exit temperature to 27°C exothermic time of about 310min and 358min, respectively. When the PCH storage and release device inlet temperature and flow rate is constant, with the extension of the heat storage time, the average temperature difference between the entrance and exit of the radiator increases slightly, the longer the heat release time.

4. Conclusion
In order to improve the utilization rate of industrial waste heat recovery, a double-pipe phase change heat storage and exothermic device is designed. By adjusting the inlet temperature of the device and other influencing factors, the experimental research of 10 working conditions is carried out. Finally, under different parameter settings, the change rules of the outlet temperature and the amount of heat exchange of the heat exchanger, and the inlet and outlet temperature of the radiator are obtained. The main conclusions are as follows:

(1) Changing the hot water inlet temperature, flow rate and heat storage time can have different effects on the heat transfer performance of the double-pipe PCH storage and exothermic device.

(2) With the heat storage process of PCH device hot water inlet water temperature increases, the PCM can carry out the storage and exothermic heat of sensible and latent heat, the average heat exchange of the storage process is larger, the phase change device heat storage faster; and the exothermic process of PCH device in the material phase change is slower, the exothermic time increases.

(3) In the process of heat storage with the PCH device hot water inlet flow rate increases, the hot water flow rate becomes faster, the average heat exchange in the process of heat storage is larger, the storage time is shortened. And exothermic process radiator inlet and outlet temperature difference increases, the exothermic time increases.

(4) The heat storage time is shortened, and the PCM in the heat storage process cannot be completely phase change, thus the heat exchange performance of the PCH exchanger is reduced, and the average heat exchange is smaller; the temperature difference between the import and export of the radiator in the exothermic process is reduced, and the exothermic time is then shortened.

Acknowledgment
The project was supported by the Science and Technology Key Program of Beijing Municipal Education Commission (KZ201710016011) and Beijing Scholars Program (2015NO.022).

References
[1] Yang L, Jin X, Zhang Y, et al. (2020) Recent development on heat transfer and various applications of phase-change materials. Journal of Cleaner Production.
[2] Nazir H, Batool M, Osorio F J B, et al. (2019) Recent developments in phase change materials for energy storage applications: A review. International Journal of Heat and Mass Transfer, 129(FEB.):491-523.
[3] Abdulrahman R S, Ibrahim F A, Dakhil S F. (2019) Development of paraffin wax as phase change material based latent heat storage in heat exchanger – ScienceDirect. Applied Thermal Engineering, 150:193-199.
[4] Saeed R M, Schlegel J P, Sawafa R, et al. (2019) Plate type heat exchanger for thermal energy storage and load shifting using phase change material. Energy Conversion and Management, 181(FEB.):120-132.
[5] Fan Q Z, Yan Q Y, Liu C. (2020) Study on Heat Storage Properties of Fatty Acid and Paraffin Composite Phase Change Materials with Graphite Added. New Chemical Materials, 48(09):145-147+151.