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Experimental Study on Thermal Discharge Performance of A Phase Change Thermal Storage Material

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Abstract: Thermal energy storage (TES) equipment utilizing phase change material (PCM) was designed and built. The PCM was sealed inside metal tubes and exchanged heat with process fluid flowing outside. The storage capacity characteristics of the system were analyzed based on data covering the inlet and outlet temperatures of the process fluid, volumetric flow rate of the process fluid and temperature change of the PCM.

Keywords: Internal fluid, phase change material, thermal discharge performance.

1. INTRODUCTION

Solar energy is being used nowadays in a wide spectrum of applications including heating, air conditioning, refrigeration, power generation and many others [1-5]. There are however limitations on these applications due to the law of solar radiation [6, 7]. Heat storage technology can provide potential solution to these limitations [7-9]. The phase change thermal storage technology has a number of advantages over other thermal storage systems: large heat storage capacity, compactness [10, 11], high thermal efficiency, stable operating temperature during heat exchange process and easy operation. All of these have made it one of the most practical and popular thermal storage systems [12, 13].

Increasing number of literature on solar heating and thermal energy storage (TES) systems using phase change material (PCM) in the recent past has shown the growing interest in this research field. Some reported experimental studies have utilized novel equipment [14] having characteristics of thermal storage systems. By analyzing parameters including temperature change and flow rates of process fluids, useful information can be drawn to understand the performance of the phase change materials in such applications.

In this paper, an experimental investigation of the thermal discharging features of thermal storage equipment using phase change materials is reported. The unit operating with process fluids flowing in coil tubes was submerged in the PCM. The volumetric flow rate, inlet and outlet temperatures of the process fluid together with the temperature change of the PCM were measured and analyzed to evaluate the performance of the equipment.

2. EXPERIMENTAL EQUIPMENT

2.1. Thermal Storage Materials

Greater developments have been made by the researches with regard to phase-change thermal storage material at present. The main research contents include the compositions, thermal properties, preparation technology and utilization methods. As the thermal storage medium, the phase change materials are critical factors for the process of thermal storing and discharging. The favorable thermal storage material should integrate the characteristics as follows:

(1) Thermodynamic conditions: appropriate phase transition temperature, higher latent heat, good heat conduction, large densities and little change of volume.

(2) Chemical conditions: high thermal stability, low corrosiveness, low toxicity, good compatibility with the container, segregation-free, less delamination of melting and solidification.

(3) Economic conditions: rich raw materials, lower cost.

(4) Technical aspect: high efficiency, compactness, high reliability.

The phase-change thermal storage materials are selected according to the above mentioned rules. JDJN-58 was applied as the material is used for solar heating system. The thermo-physical properties of material are shown in Table **1**.

Table 1. Thermo-physical properties of material.

Thermo Physical Properties		Values
Melting point (°C)		56-58
Latent heat (kJ/kg)		230
Specific heat (kJ/kg°C)	Solid	1.50
	Liquid	2.1
Thermal conductivity (W/m°C)	Solid	1.12
	Liquid	0.58
Density (kg/m^3)	25°C	1460
	35°C	1420

2.2. Experimental Equipment

The experimental platform consists of phase-change thermal storage equipment, water system, data acquisition

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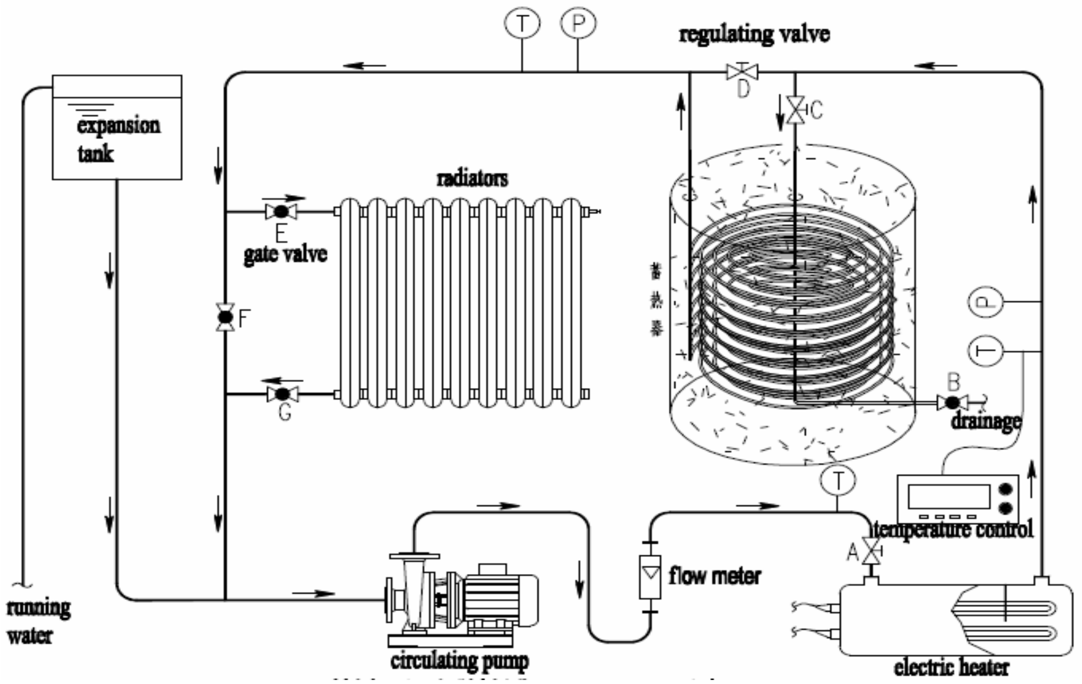

Fig. (1). Schematic diagram of experimental device.

system and temperature control system. The system schematic diagram is shown in Fig. (**1**).

2.2.1. Thermal Storage Devices

The central part of the experimental equipment is the heat storage device, which is principally a vertical cylinder vessel of 700 mm height with an inside diameter of 560 mm. In the center of the vessel, process water flows in seven parallel layers of spiral coil tubes, which share a common inlet leg situated on the center line of the vessel. This arrangement is to obtain minimum water flow resistance at required heat transfer area and also to achieve even temperature distribution of the phase change material which fills in-between the coils. The process water flows into a common manifold located next to the inner wall of the vessel. Each of the seven spiral coil tubes has an inside diameter of 11 mm and an extended length of 4.5 m. The vessel and all external tubes are insulated to minimize heat loss to the environment. Heat exchange takes place between process water and the phase change material though the wall of the coil tubes which are submerged in the latter.

During a test run, temperature is measured by thermocouples of the copper-constantan type. Volumetric flow rates of the process water are measured using a rotameter. The data acquisition systems take all measurements and send to storage simultaneously. The measurement system layout is shown schematically in Fig. (**2**).

2.2.2. The Measurement System

(1) Thermocouples

Nine thermal couples of the copper-constantan type are used to measure the temperature of the phase change material and those at the inlet and outlet of the process water.

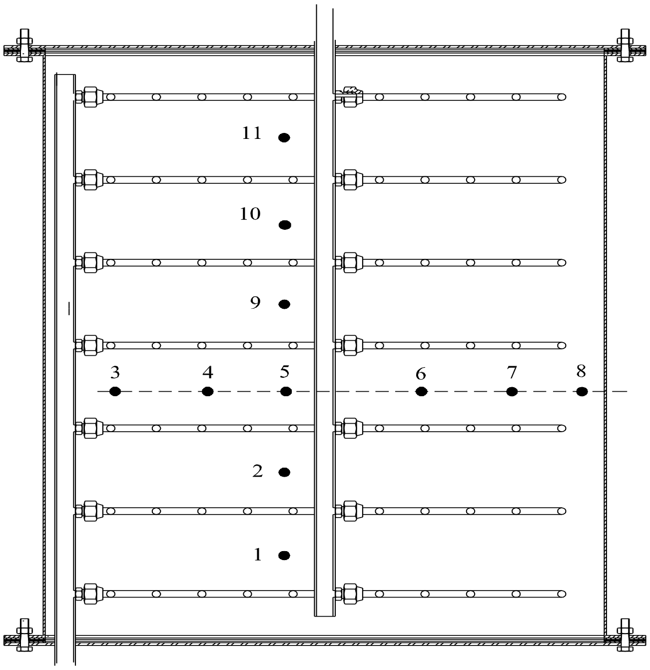

Fig. (2). The arrangement diagram for temperature measuring point.

(2) The flow meter

The rotameters are applied during the process of the experiment.

(3) Data collection system

The system has 19 thermocouples to measure the temperature of thermal storage materials, thermal storage device, the radiator's inlet and outlet. The temperature signs are accessed to the FLUKE 2645A and the temperature is recorded automatically. The flux is measured by float flow meter. The accuracy of the float flow meter is 1.0.

(4) The control cabinet is applied for the temperature control system. The temperature control system includes the digital temperature regulator, the PID digital instrument, the thyristor, the thermal resistance and the PLC extended module.

(5) Electric Heater

Electric heater is an auxiliary heat source in the circulatory system, which is switched on automatically when the outlet water temperature in the heat storage cylinder in the exothermic process cannot reach the heating supply (40°C). In this system, three electric heating rods are put inside the electric heater. The input power of one of them is 1500 w, while the input power of others are 1000 w.

2.3. Experimental Procedure

(1) Firstly, hot water is circulated through the spiral coils till the PCM temperature is above 70° C, then the temperature distribution is allowed to settle until evenly distributed. The inlet valve C is turned off and the by-pass valve D is opened.

(2) The inlet temperature is set to be 40°C. Opening the inlet valve C, the by-pass Valve D is turned off. The rotameter is adjusted to reach a stable flow rate of 140 L/h. The recording is then started.

(3) The temperature change of the PCM and also of the process water is monitored. At the point where the temperature change of the process water between inlet and outlet is fairly small and all measurement points on the PCM show minor temperature change, the process is terminated and one test run is then finished.

(4) The inlet temperature of fluid is hold onto 40°C and the flow rates are adjusted to 200 L/h, 300 L/h by the regulating valve. The experiment of discharge thermal is repeated.

(5) The inlet temperature of fluid is adjusted to 45°C by the electric heat. After the system is stable, the change of parameter is less than 0.2°C, the above procedure is repeated and the flow rates are 140 L/h, 200 L/h, 300 L/h respectively.

3. EXPERIMENTAL RESULTS

3.1. The Influence of Inlet Temperature on the Thermal Discharge Performance

The temperature changes of the phase change material during the thermal discharge process are given in Figs. (**3**, **4**), for process water at flow rate of 200 l/h and inlet temperature of 40 °C and 45°C, respectively.

It can be seen that the temperature variation of the phase change material includes three different stages during the process of thermal discharge. The process of thermal discharge includes the solid sensible thermal discharge stage, the phase change latent heat discharge stage and the liquid sensible heat discharge stage. At the time of the phase change, latent heat discharge is far away than that of the solid sensible heat discharge and the liquid sensible heat discharge. The temperature of the phase change material decreases rapidly during the stage of solid sensible heat discharge. Consequently, the process of thermal discharge comes into the stage of phase change latent heat discharge. And the temperature variation of phase change material is smaller relatively. The temperature of phase change material decreases slowly during the stage of liquid sensible heat stage.

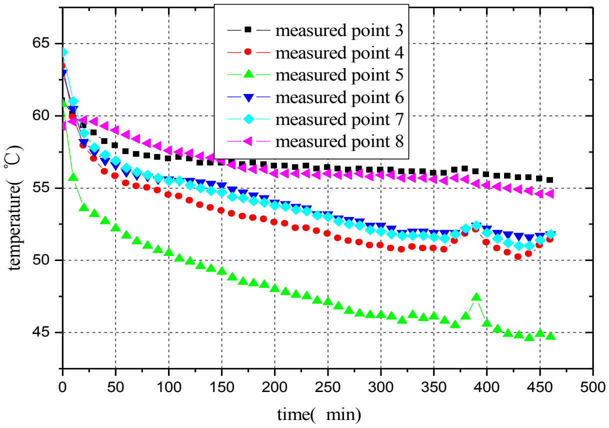

Fig. (3). The temperature variation of phase change material with time (40°C, 200 L/h).

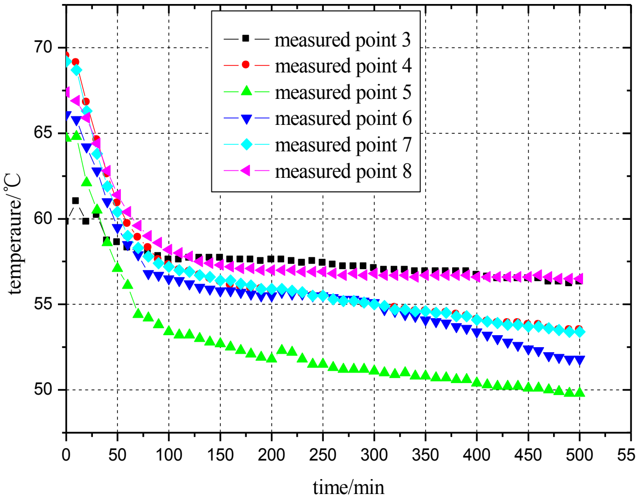

Fig. (4). The temperature variation of phase change material with time (45°C, 200 L/h).

The temperature variation of different measuring points decreases gradually along with the axial direction during the process of thermal discharge. The maximum temperature variation of all measuring points is 5, that is close to the riser. And the phase change temperature of measuring point 5 is lowest, 51.2°C. The temperature of heat transfer fluid increases gradually along with the spiral pipe from the inlet to the outlet when heat transfer fluid flows into the spiral pipe from the riser. The heat transfer temperature difference between the fluid and the phase change material decreases gradually. So the temperature variation of different measuring points is different.

The process of thermal discharge when the inlet temperature of fluid is 45°C is slower than that when the inlet temperature of fluid is 40°C. The reason is that the heat transfer difference is different due to the difference in the inlet temperature of fluid.

3.2. The Influence of Flow Rate on the Thermal Discharge Performance

The temperature variation of the thermal storage material with time in the process of thermal discharge is shown in Fig. (**5**) when the inlet temperature of fluid is 45°C and the flow rates are 140 L/h, 200 L/h, 300 L/h respectively. It can be seen that the heat release law of different flow rates is consistent basically. But an increase in flow rate can result in higher rate of heat release. And the phase change temperature of thermal discharge is different when the flow rate is different. The phase change temperature is 50.8°C, 49.5°C, 47.6°C when the flow rate is 140 L/h, 200 L/h, 300 L/h, respectively. The reasons are that thermal discharge process is enhanced due to the increasing flow rate. Furthermore, the temperature of phase change material decreases remarkably when the flow rate increases. The time of thermal discharge is shorter as the flow rate increases.

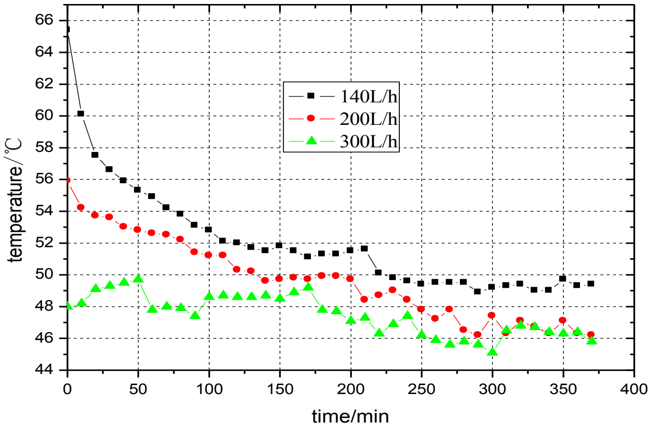

Fig. (5). The temperature variation with time at different flow rates.

3.3. The Influence of Inlet Temperature and Flow Rate on the Outlet Temperature of Heat Transfer Fluid

Fig. (**6**) shows the outlet process water temperature at flow rate of 200 l/h and various inlet temperatures. It is clear that the outlet temperature changes correspondingly with inlet temperature, and drops more rapidly at lower inlet temperature, due to a higher heat transfer temperature difference which again promotes heat transfer rate.

When the inlet temperature of heat transfer fluid is 45°C, the influence of flow rate on the outlet temperature of heat transfer fluid is shown in Fig. (**7**). It can be seen that the outlet temperature of heat transfer fluid is depressed with the increasing flow rate. The reason is that the heat transfer time is shorter when the flow rate is larger. And the heat transfer fluid achieves the less thermal stability, so the outlet temperature of heat transfer fluid is relatively low.

The inlet temperature influence of heat transfer fluid on the performance of thermal discharge is greater significantly than that of the flow rate as shown by comparison of Figs. (**6**, **7**).

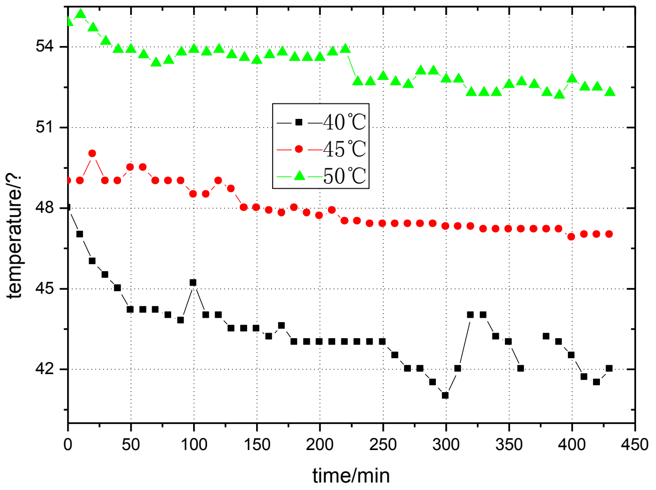

Fig. (6). The outlet temperature variation with time at the difference in inlet temperature.

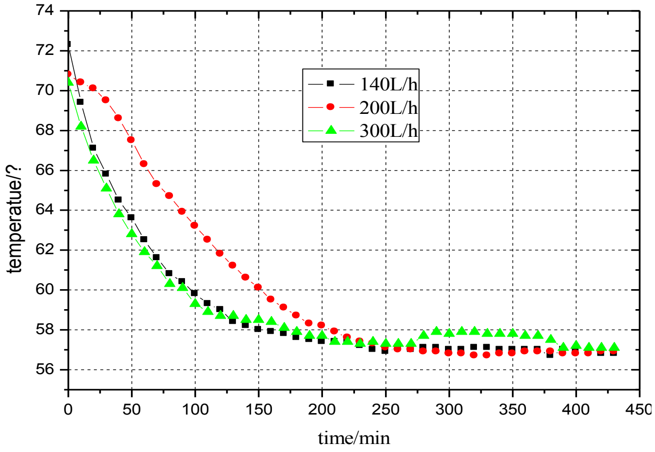

Fig. (7). The outlet temperature variation with time at the difference in flow rates.

CONCLUSION

Experimental data on the thermal discharging features of a phase change material cooled by process water were presented. The PCM used was JDJN−58 which is a relatively new material but recently, has been gaining increasing applications due to a number of desirable properties. The effect of the inlet temperature and volumetric flow rate of the process water on the thermal discharging rate of the PCM was investigated in the range of 40-50°C and 140-300 l/h, respectively. In the testing range, the PCM underwent three stages during the thermal discharging process, namely single liquid phase stage, two-phase and single solid phase stage, in the sequence of occurrence. Thermal energy released during the two-phase change accounted for approximately 75% of the total heat exchange, in all cases. Both flow rates and inlet temperature change showed significant influence upon the heat transfer rates.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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