Experimental study of latent thermal energy storage by using phase change materials (PCM) enclosed in a vertical cylindrical annular space

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Abstract

This paper presents an experimental study of heat transfer during latent heat storage cycle (charging/discharging) in a vertical cylindrical system. The experimental setup consists of two cylindrical tanks filled respectively with hot and cold water, a test bench, and measurement instruments. The test bench, thermally insulated with glass wool, is also composed of two vertical concentric tubes whose annular space contains the paraffin wax as a phase change material (PCM). The heat transfer fluid (HTF) flows in the upward direction of the inner tube (HTF pipe). The storage capacity of the paraffin wax characterized by a melting temperature of 56°C could be quantified. During one cycle of thermal storage (charging/discharging), the instantaneous temperature variation at the specific location will be done. Also, the influence of heat transfer fluid (HTF) mass flow rate on the time average temperature along the radial direction is examined.

KEYWORDS: *Latent heat; Phase Change Material; Thermal Energy Storage; Flow rate.*

1. Introduction

In the last two decades, thermal energy storage (TES) has been received more attention, through its many applications. Thermal energy storage could be done by: sensible heat [1], latent heat and thermochemical heat. While the first technology of TES is mature, the two last ones are in the R&D stage.

The present work focuses on the latent heat storage technology based on the phase change materials (PCMs) which reviewed and reported in many references [2-4]. At specific temperature (melting temperature), PCMs absorb and release thermal energy during melting and solidification processes respectively. Among the different process using the latent heat storage systems there are thermal desalination processes [3, 4], heating and cooling in buildings [5], and in CSP plants [6]. PCMs to be used for TES systems must have a large latent heat and relatively high thermal conductivity. The most used materials for thermal energy storage are paraffin waxes, hydrated salts, fatty acids and eutectics of organic and non-organic compounds.

In this experimental investigation, the storage capacity of the paraffin wax characterized by a melting temperature of 56°C could be quantified. During one cycle of thermal storage (charging/discharging), the instantaneous temperature variation at the specific location will be done. Also, the influence of heat transfer fluid (HTF) mass flow rate on the average of radial and axial temperatures will be examined.

2. Experimental device

2.1 Set-up description

The experimental set-up shown in Figure 1-a was recently performed at RMRE laboratory, of the Faculty of Science, Meknes (Morocco). It mainly consists of two tanks: one of them is filled with hot water and the other one with cold water, a test bench (Figure1-b), a flowmeter for measuring the flow rate of heat transfer flow (HTF), a circulation pump, a data logger with a specific software, a control unit, a microcomputer and an Ethernet connection. Additionally, the test bench, thermally insulated, is composed of two vertical and coaxial tubes made of stainless steel. The storage material (paraffin) is enclosed between the space of the inner tube and the outer one whereas the heat transfer fluid (hot or cold water) flows in the upward direction of the inner tube. The experimental device is equipped with fourteen K-type thermocouples with an accuracy of ±0.1°C which are embedded in various positions. Before taking measurements, thermocouples are calibrated using the software Omega Engineering (2012 version).

2.2 Operating principle

This experimental work concerns two concentric tubes whose annular space is used as an energy storage volume by latent heat generated by melting a phase change material (PCM) at low temperature. In fact, the annular space of these tubes is filled with paraffin as PCM which is characterized by a melting temperature of 56 °C. PCM material it is heated by using water as HTF. Water circulates upward flow in the inner tube and, the circulation is caused by a variable flow pump.

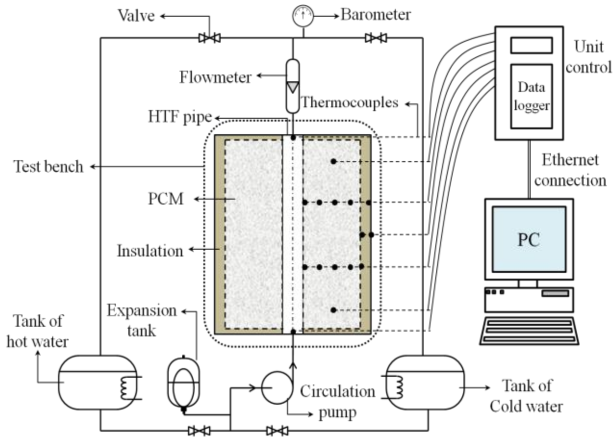


Figure 1-a. Experimental setup of heat storage/recovery.

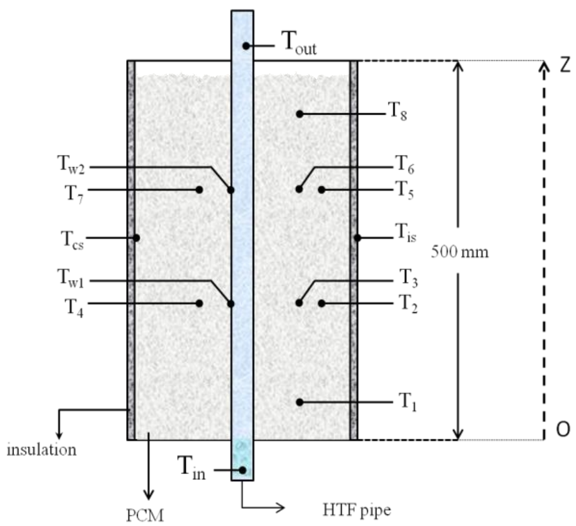


Figure1-b: Schematic of the experimental test bench and thermocouples locations.

The instantaneous variation of temperatures during melting and solidification processes is measured by using the thermocouples integrated in the experimental device (see Figure 1-b). Then, these temperatures are recorded during the cycle period (charging and discharging time) with the help of a specific datalogger.

3. Results and discussion

For a constant mass flow rate Γ= 100 kg/h, figures 2a and 2b show temperature distributions versus time at specific positions T_2 (r=27.5 mm, Z=160 mm) and T_5 (r=27.5 mm, Z=260 mm). These figures exhibit the comparison of thermal behavior between the chosen positions during the charging and discharging processes. As can be seen from the figure 2a which corresponds to the charging period, both increasing tendencies of temperature variations are identical, especially, for the time range from 0 to 1500 seconds thereabouts. After this time, the phase change of paraffin wax starts to take place at two aforementioned positions and hence temperature profiles vary and deviate from each other.
Figure 2b depicts the temperatures evolution at the same previous positions, during the discharging period, for which the stored thermal energy is retrieved. It is obviously clear that the temperature inside the annular space decreases since the thermal energy of PCM field is lost (recovered by HTF).

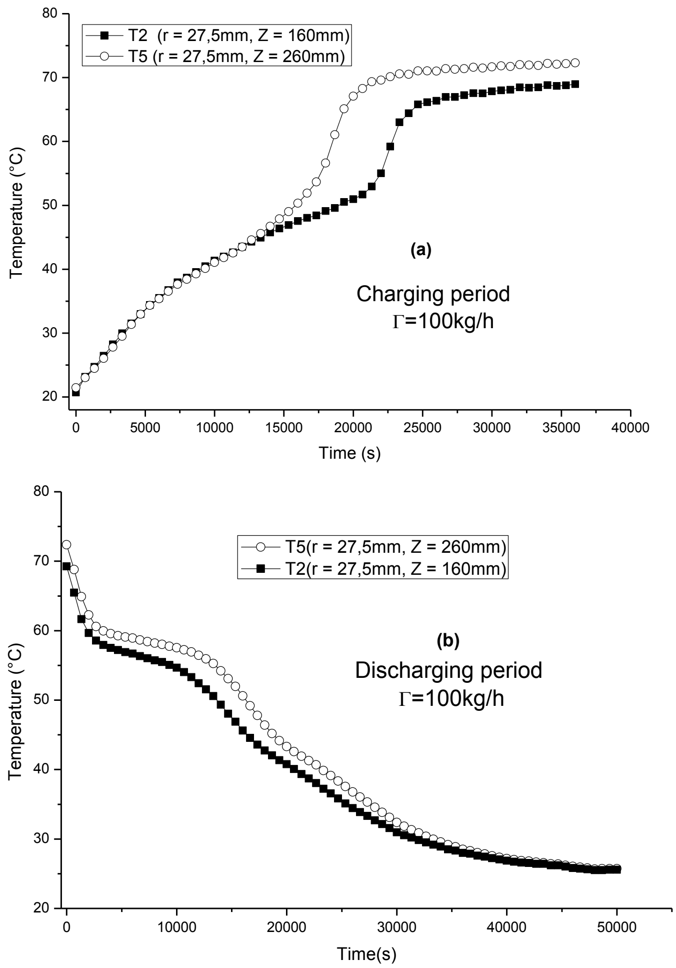
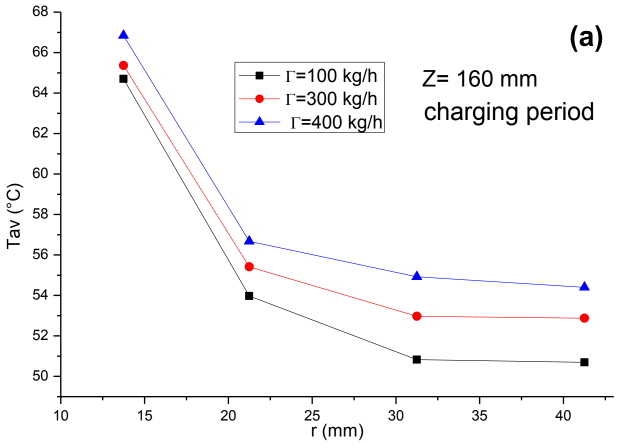


Figure 2: Temperature variations during (a) charging, and (b) discharging periods.

Because of storing (or recovering) process carry out in the radial direction of annular space, temperature profiles inside the paraffin wax, along this axis, are illustrated in figures 3a and 3b. Indeed, for three different mass flow rate values (Γ=100, 300 and 400 kg/h) and at axial position Z=160 mm, these figures show the evolution of time average temperatures for one cycle (charging and discharging periods).



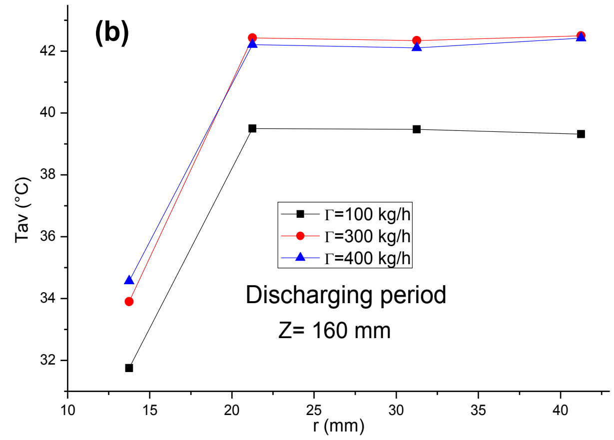


Figure 3. Influence of the HTF mass flow rate on the evolution of time average temperatures inside the PCM, along the radial direction: (a) charging phase; (b) discharging phase.

Figure 3a illustrates that the time average temperature decreases with radial position from the outer wall of the inner tube. Also, it increases with increasing mass flow rate because of improving heat transfer between HTF and inner tube wall. Furthermore, for the recovery period (Figure 3b), it has been observed that the closest positions to the inner wall are colder than those which are near the insulated wall of the external tube. The influence of the mass flow rate on the average temperature is the same for both cases charging and discharging processes.

3. Conclusion

The TES system using the paraffin wax as latent heat storage material all along one cycle (charging and discharging processes) was studied. The results obtained show that inside the PCM, the instantaneous temperature increases versus time during the charging period (storage process) whereas it decreases during the discharging phase (recovery process). Moreover, the time average temperature, during the cycle, is then enhanced at the same time as the storage/recovery capacity. This could be explained by the fact that the convective heat transfer coefficient between the HTF and the annular space is improved by increasing of the mass flow rate.

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