

Experimental Study on PCM based Thermal Energy Storage using Flat Plate Solar Collector

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Abstract. The creation of solar energy storage devices is just as critical as the discovery of new energy sources. One possibility that has emerged in recent years is the storing of solar energy as latent heat. This study builds a solar thermal storage system that uses Phase Change Materials. The solar heat storage application makes use of a phase change material that has a melting/solidification temperature of $60\pm 2^\circ\text{C}$. The PCM either absorbs or releases a lot of energy as latent heat as it changes phases. Cylindrical encapsulated PCMs' charging and discharging properties are thoroughly examined.

Keywords-

PCM, charging, discharging, thermal energy storage, latent heat

INTRODUCTION

Among the many renewable power options, solar power stands out. Direct sun radiation is among the most promising energy sources in many regions of the globe. Technologists are now facing the difficulty of storing solar energy and converting it into the necessary form. Countries like India, which experiences hot weather for the majority of the year, can make better use of solar energy. The most common way to put this energy to use is via solar collectors. Solar collectors that use flat plates to capture sunlight and then transmit that heat to water in a circulating system are the most efficient and cost-effective option.

Also, PCM is used, which takes up a lot of heat from the water in the tank while it undergoes the phase shift and then releases its latent heat as it melts. While sensible heat storage devices have traditionally been the norm, large-scale implementations of latent heat storage units have failed. Lane has done extensive work on phase change heat storage, particularly with salt hydrates [1]. The molecular underpinnings of phase change events, criteria for selecting PCM, and the history of PCM development are all covered in depth in his book. Abhat [2] has done an extensive evaluation of materials that undergo low-temperature phase changes. Research on heat storage units with fixed beds or packed beds that use phase change materials has been conducted by Ananthanarayanan et al. [3] and Beasley and Ramanarayanan [4]. An experimental investigation of the thermal behaviour of a packed bed including a sensible and latent heat storage system that is integrated with constant or variable solar heat sources was carried out by Nallusamy et al. [5]. The combined storage system, which uses batchwise discharge of hot water from the TES tank, is ideal for applications with intermittent requirements, according to their discharge trials. The study on a TES system that combines sensible and latent heat was conducted by Meenakshi Reddy et al. [6]. Two distinct phase change materials are used to investigate the TES system. Paraffin outperforms stearic acid by 5 to 7 percentage points when it comes to charging and discharging performance. Researchers

Bugaje [7] looked at how paraffin wax in plastic tubes responded to heat. Velraj et al. [8] conducted an extensive investigation into several approaches to improving heat transmission for the latent heat thermal storage system. Improvements have been made by using fin arrangement and Lessing rings. Experimental and computational investigations into the melting process of a phase-change material (PCM) in spherical geometry were initiated by Assis et al. [9]. Researching the operation of a Thermal Energy Storage (TES) tank housing PCM cylindrical canisters submerged in water is the primary goal of the current effort. Section II: Experimental Environment The solar collector and thermal energy storage (TES) tank are the main parts of the experimental system. The steel TES tank has a cylindrical form factor, measuring 42 cm in diameter and 50 cm in height. The water serves as both a heat transfer fluid (HTF) and

made of paraffin wax has a latent heat of fusion of 210 kJ/kg and a melting point of $60 \pm 2^\circ\text{C}$. These cylindrical tin canisters hold all of it. A total of seventy-five cylindrical containers make up the thermal storage tank.

with 200 grams of PCM, and these containers are arranged in 3 layers in a TES tank and each layer is supported by wire mesh. The remaining space in the TES tank is filled with water. The total mass of PCM in the TES tank is 15 kg and the mass of water in the tank is 15 kg. The TES tank is well insulated by using 5mm thick coconut coir to prevent heat loss to the surroundings. The TES tank is connected with an active solar flat plate collector which has a heating capacity of 100 liters per day. The photographic view of the experimental setup and the schematic diagram of the experimental



a sensible heat storage medium. A PCM

setup are shown in Figure 1 and Figure 2

respectively.

Figure 1. Photographic view of the Experimental Setup

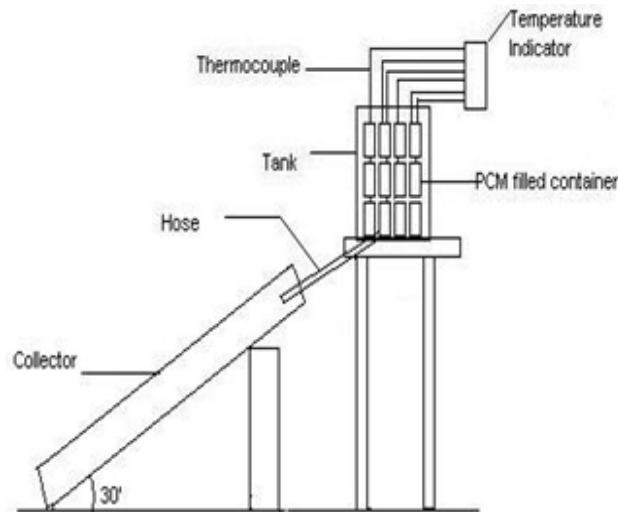


Figure 2. Schematic of the Experimental Setup

Thermocouple with a measuring range of 0 to 100°C with an accuracy of $\pm 0.5^\circ\text{C}$ is used to measure temperatures of PCM and HTF at various locations in the tank. Figure 3 shows the locations of the thermocouples in the TES tank. The thermocouples located in the PCM containers measure PCM temperatures at three different horizontal positions. They are represented as T1, T2, T3, T4, T5 & T6 and another thermocouple located in the tank measure water temperature is represented as Tw. All the thermocouples are connected to a digital temperature indicator which provides instantaneous digital outputs.

I. EXPERIMENTAL PROCEDURE

The charging and discharging experiments are conducted on the TES system. During the charging process (storing heat energy) the HTF is circulated by natural circulation through the TES tank continuously from the solar collector. The HTF inlet temperature varies in accordance with the solar insolation and exchanges its energy to PCM containers. Initially, the energy is stored inside the containers as sensible heat until the PCM starts melting. As the charging process continues, PCM melts and stores energy as latent heat at a constant temperature range. Finally, the PCM becomes superheated after the temperature of the PCM increased beyond the phase change temperature range.

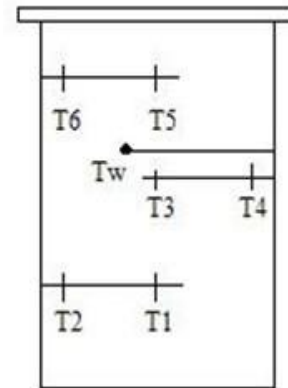


Figure 3. Thermocouple locations in TES tank

The Temperature of the PCM at different locations of the TES tanks and temperature of the HTF in the TES tank are recorded continuously in every 15 minutes time interval. The charging process is continued for a period of 5 hours. In the discharging process (the energy retrieval), the experiments are carried out by circulating the cold water at a temperature of 30°C continuously through the TES tank to recover the stored heat energy.

II. RESULTS AND DISCUSSION

In this section the temperature variations of the PCM at various locations in the TES tank, the temperature variation of the HTF in the storage tank and the heat energy stored in the TES tank during charging processes are reported. Also, the outlet temperature of the water and the instantaneous heat energy released during the discharging process are reported in this section.

4.1 Charging Process

4.1.1 Temperature Time histories of PCM and HTF

The temperature, time history of PCM and HTF in the TES tank is shown in Figure 4. It is observed from the figure that the temperature of the HTF increases gradually until it reaches the temperature of

58
 and thereafter the increase in temperature is at a slow rate for a period of 2 hours during which the PCM undergoes phase change at the temperature range of $60 \pm 2^\circ\text{C}$. After that, the HTF temperature increases at a faster rate, and it reaches a temperature of 86°C at the end of 5 hours.

It is seen from the figure that the PCM temperature increases gradually from 30°C to 58°C . Afterward the increase in temperature is at a much slower rate in the temperature range of $58-62^\circ\text{C}$ during PCM melting process; thereafter, it increases

rapidly during heating of liquid PCM. It is also observed from the figure that there is no significant temperature difference of the PCM at various locations in the TES tank during the sensible heating of the solid PCM and also during the phase change period. The reason is that the water temperature in the storage tank increases gradually in accordance with the inlet temperature of HTF

entering from the solar collector and the PCM temperature also increases gradually along with HTF temperature.

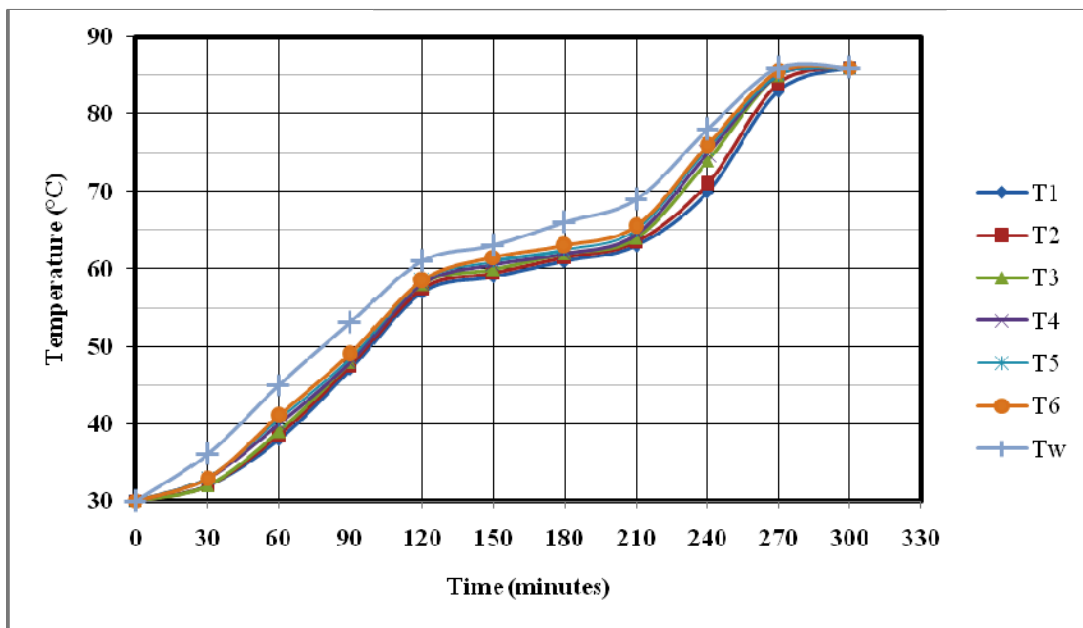


Figure 4 Variation of PCM and HTF temperatures with respect to time during the charging process

4.1.2 Energy stored

It is the amount of heat energy stored in the TES tank during the charging process for a period of 5 hours. It is calculated as follows:

$$\begin{aligned} \text{Energy saved} &= [m_w C_{pw} (86-30) + m_p L + m_p C_{pp} (86-60)] \\ &= [15 \times 4.187 \times (86-30) + (15 \times 210) + 15 \times 2.5 \times (86-60)] \\ &= 7642 \text{ kJ} \end{aligned}$$

(where m_w – mass of water in kg, m_p – mass of PCM in kg, C_{pw} – Specific heat of water in J/kgK, C_{pp} – Specific heat of PCM in J/kgK, L – latent heat of PCM in J/kg)

4.2 Discharging Process

In this process, the cold water with a flow rate of 6 liters/min and at a temperature of 30°C is circulated continuously through the TES tank to recover the stored heat energy. The

variation of outlet temperature of the water with respect to time and instantaneous heat released by the TES system are reported.

4.2.1 Variation of Outlet Water Temperature

Figure 5 represents a variation of outlet water temperature with respect to time during the discharging process. It is seen from the figure that the temperature of the outlet water decreases at a fast rate until the PCM reaches its phase transition temperature as the hot water in the storage tank loses its sensible heat due to the mixing of inlet water at a temperature of 30°C. After that, the decrease in the outlet water temperature from 62 to 58°C is at a much slower rate for a longer duration as the PCM releases its latent heat. Thereafter, the outlet water temperature starts decreasing. However, the rate of temperature drop is not as high as at the beginning of the discharging process. This is due to the low temperature difference between the PCM and inlet water temperature, though the solid PCM releases its sensible heat.

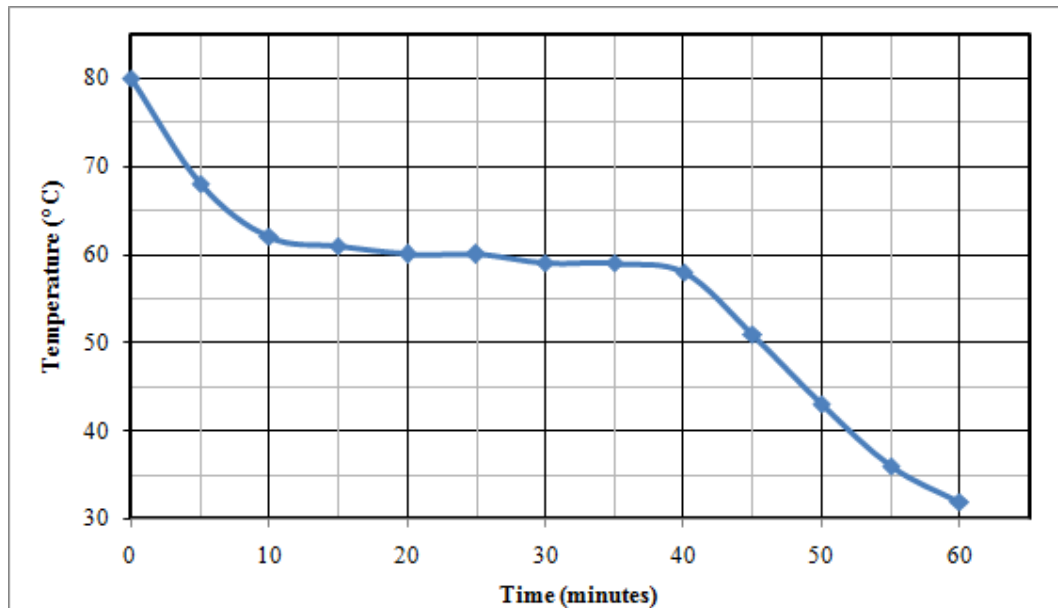


Figure 5 Variation of outlet water temperature with respect to time during the discharging process

4.2.2 Instantaneous Heat Energy

Figure 6 shows the instantaneous heat energy released from the TES tank by circulating water continuously at an inlet temperature of 30°C with a flow rate of 6 liters/min. The rate of heat recovery is large at the beginning of the discharging process. Thereafter the heat recovery rate is approximately constant for the duration of 40 minutes as the PCM releases its latent heat. After latent heat released by PCM, the heat

recovery rate is decreasing at a faster rate. This is because of the change in the thermal resistance of the solidified layer of the PCM and decrease in the temperature difference between the solidified PCM and HTF.

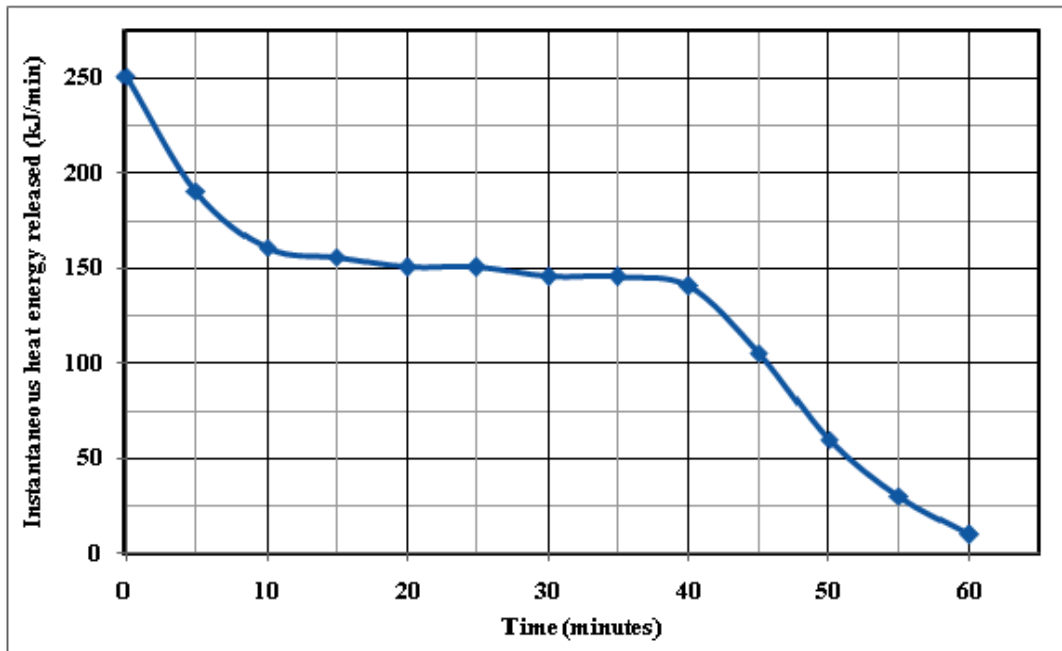


Figure 6 Instantaneous heat energy released from the TES tank during the discharging process

III. CONCLUSION

Only a temperature or density differential can transport HTF from the solar collector to the TES tank. Since this process is time-consuming, the total amount of thermal energy stored in the TES tank is 7642 kJ after 5 hours. During charging, the TES tank stores an average of 424.55 J/s of immediate heat energy. As the PCM releases its latent heat, the rate of heat energy recovery is high at the outset of the discharging process, but it levels off as a result of changes in the solidified layer's thermal resistance and a smaller temperature differential between the PCM and the HTF. Over time, the temperature at the HTF outlet falls steadily.

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