ISSN: 2454-9940

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT

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www.ijasem.org

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT

ISSN2454-9940
www.ijasem.org
Vol 16, Issue 1, 2022

Research on the Use of Flat Plate Solar Collectors for PCM-Based Thermal Energy Storage

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Abstract- Solar energy storage device development is of equal or greater importance than new energy source discoveries. The concept of storing solar energy as latent heat has recently come to light as a potential option. A solar thermal storage system using phase change materials is constructed in this research. A phase transition material with a melting/solidification temperature of 60±2ºC is used in the solar heat storage application. As it undergoes phase transitions, the PCM either absorbs or releases large amounts of energy as latent heat. The charging and discharging characteristics of cylindrical encapsulated PCMs are investigated in detail.

Keywords- PCM,charging,discharging,thermalenergystorage,latentheat

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

ISSN2454-9940
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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 a sensible heat storage medium. A PCM made of paraffin wax has a latent heat of fusion of 210 kJ/kg and a melting point of 60 ± 2°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 supportedby wire mesh. The remaining space in the TES tank is filled with water. The total mass of PCM in the TES tankis 15 kg and the mass of water in the tank is 15 kg. The TES tank is well insulated by using 5mm thick coconutcoir to prevent heat loss to the surroundings. The TES tank is connected with an active solar flat plate collectorwhich has a heating capacity of 100 liters per day. The photographic view of the experimental setup and theschematicdiagramoftheexperimental setupareshowninFigure1andFigure2 respectively.

Figure1.PhotographicviewoftheExperimentalSetup

ISSN2454-9940

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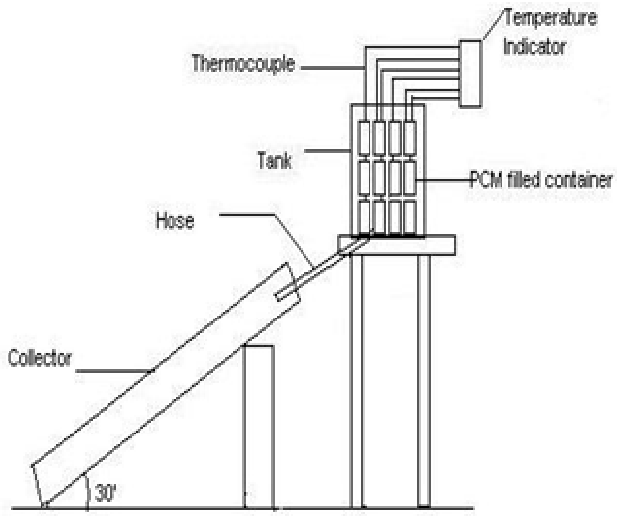

Figure2.Schematicofthe ExperimentalSetup

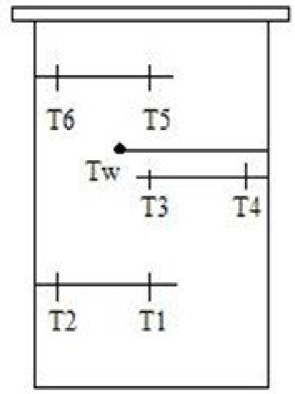

Figure3. Thermocoupleslocationsin TEStank

Thermocouple with a measuring range of 0 to 100°C with an accuracy of ±0.5°C is used to measure tomeasure temperatures of PCM and HTF at various locations in the tank. Figure 3 shows the locations of thethermocouples in the TES tank. The thermocouples located in the PCM containers measure PCM temperaturesat three different horizontal positions. They are represented as T1, T2, T3, T4, T5 & T6 and another onethermocouple located in the tank measure water temperature is represented as Tw. All the thermocouples areconnectedtoadigitaltemperatureindicator whichprovidesinstantaneousdigitaloutputs.

EXPERIMENTALPROCEDURE

The charging and discharging experiments are conducted on the TES system. During the chargingprocess (storing heat energy) the HTF is circulated by natural circulation through the TES tank continuouslyfromthesolarcollector.TheHTFinlettemperaturevariesinaccordance withthesolarinsolationandexchangesits energy to PCM containers. Initially, the energy is stored inside the containers as sensible heat until the PCMstarts melting. As the charging process continues, PCM melts and stores energy as latent heat at a constanttemperature range. Finally, the PCM becomes superheated after the temperature of the PCM increased beyondthe phase change temperature range. The Temperature of the PCM at different locations of the TES tanks andtemperature of the HTF in the TES tank are recorded continuously in every 15 minutes time interval. Thecharging process is continued for a period of 5 hours. In the discharging process (the energy retrieval), theexperiments are carried out by circulating the cold water at a temperature of 30°C continuously through the TEStanktorecover thestoredheatenergy.

RESULTSANDDISCUSSION

Inthis section the temperaturevariations ofthe PCMatvarious locations intheTES tank,thetemperature variation of the HTF in the storage tank and the heat energy stored in the TES tank during chargingprocesses are reported. Also, the outlet temperature of the water and the instantaneous heat energy releasedduring thedischarging processarereported in thissection.

4.1 ChargingProcess

4.1.1 TemperatureTimehistoriesofPCMandHTF

The temperature, time history of PCM and HTF in the TES tank is shown in Figure 4. It is observedfrom the figure that the temperature of the HTF increases gradually until it reaches the temperature of 58 °C andthereaftertheincreaseintemperatureisata slowerratefora periodof2hoursduringwhichthePCMundergo

ISSN2454-9940
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esphase change at the temperature range of 60±2°C. After that, the HTF temperature increases at a faster rate, andit reachesa temperatureof 86°C at the end of5hours.

It is seen from the figure that the PCM temperature increases gradually from 30°C to 58°C. Afterwardsthe increase in temperature is at a much slower rate in the temperature range of 58-62°C during PCM meltingprocess; thereafter, it increases rapidly during heating of liquid PCM. It is also observed from the figure thatthereis no significant temperaturedifferenceof thePCM at various locations in the TES tank during thesensible heating of the solid PCM and also during the phase change period. The reason is that the watertemperature in the storage tank increases gradually in accordance with the inlet temperature of HTF enteringfromthesolarcollectorandthePCMtemperaturealsoincreasesgraduallyalongwithHTFtemperature.

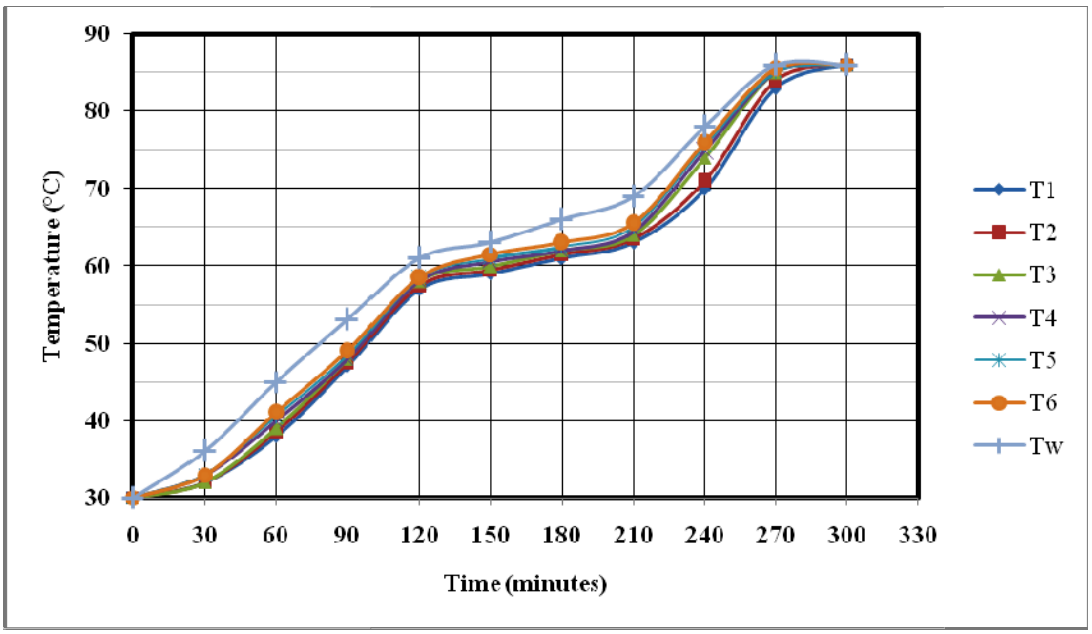

Figure4VariationofPCMandHTFtemperatureswithrespecttotimeduringthechargingprocess

4.1.2 Energystored

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

$$\text{Energysaved} = [m_w C_{pw}(86-30) + m_p L + m_p C_{pp}(86-60)]$$

$$= [15\times4.187\times(86-30) + (15\times210) + 15\times2.5\times(86-60)]$$

$$= 7642 kJ$$

(where m_w–massofwaterinkg, m_p–massofPCMinkg, C_{pw}–SpecificheatofwaterinkJ/kgK, C_{pp}–SpecificheatofPCMinkJ/kgK, L-latent heatofPCMinkJ/kg)

4.2 DischargingProcess

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

4.2.1 VariationofOutletWaterTemperature

Figure 5 represents a variation of outlet water temperature with respect to time during the dischargingprocess.Itisseenfromthefigurethatthetemperature ofthe outlet waterdecreasesatafasterrateuntilthePCMreaches its phase transition temperature as the hot water in the storage tank loses its sensible heat due to themixing of inlet water at a temperature of 30°C. After that, the decrease in the outlet water temperature from 62to 58°C is at a much slower rate for a longer duration as the PCM releases its latent heat. Thereafter, the outletwater temperature starts decreasing. However, the rate of temperature drop is not as high as at the beginning ofthe discharging process. This is due to the low temperature difference between the PCM and inlet watertemperature,thoughthe solidPCMreleasesitssensible heat.

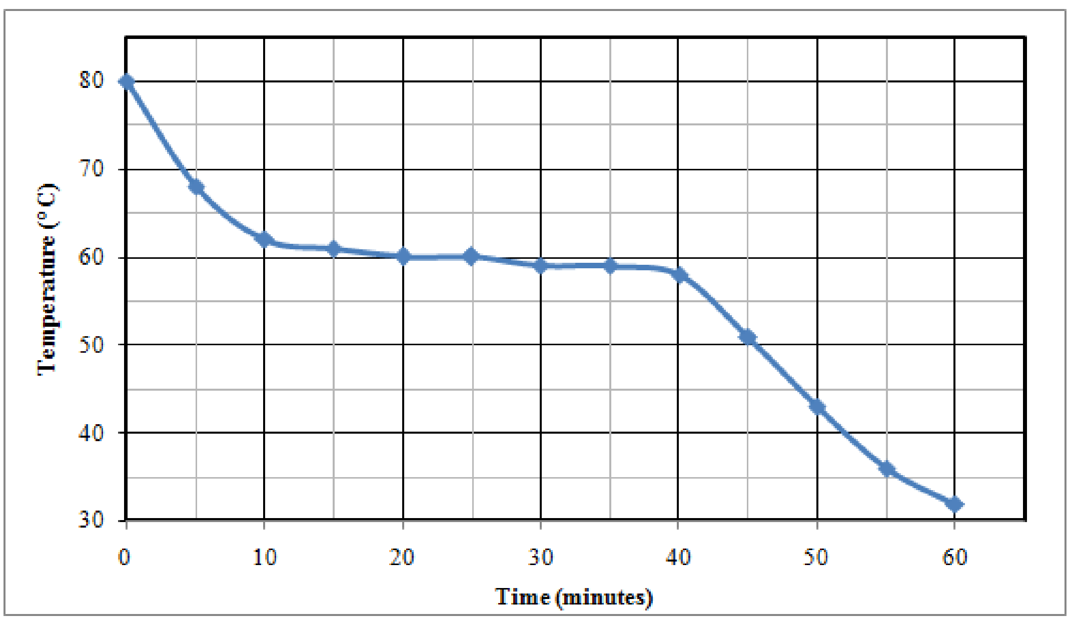

Figure 5Variationofoutletwatertemperature withrespecttotime duringthe dischargingprocess

4.2.2 InstantaneousHeatEnergy

Figure6showstheinstantaneousheatenergyreleasedfromtheTEStankbycirculatingwatercontinuously at an inlet temperature of 30°C with a flow rate of 6 liters/min. The rate of heat recovery is large atthe beginning of the discharging process.Thereafter the heat recovery rate is approximately constant for theduration of 40 minutes as the PCM releases its latent heat. After latent heat released by PCM, the heat recoveryrate is decreasing at a faster rate. This is because of the change in the thermal resistance of the solid.ified layer ofthePCManddecreaseinthetemperature differencebetweenthe solidifiedPCMandHTF.

ISSN2454-9940
www.ijasem.org
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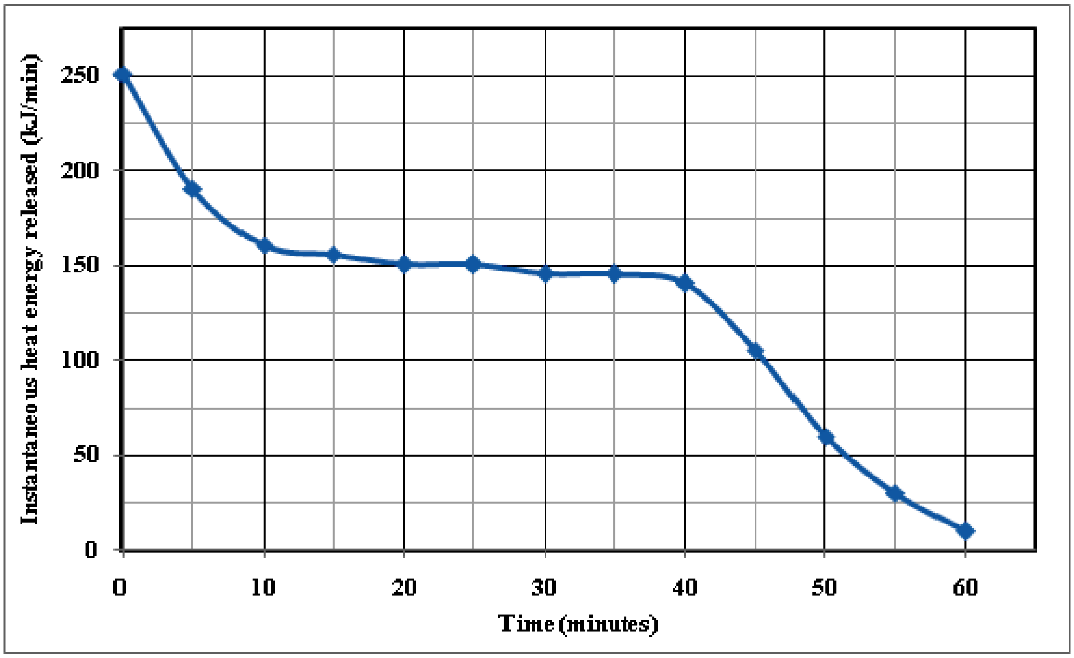

Figure 6Instantaneousheatenergyreleasedfrom the TES tankduringthedischargingprocess

I. 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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