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HEAT TRANSFER ANALYSIS OF LATENT HEAT STORAGE SYSTEM USING D-SORBITOL AS PCM

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ABSTRACT

Thermal energy storage using a phase change materials is an important concept for storing energy during the sunshine hour and using the same energy during off sunshine hour. The latent thermal energy storage employing a Phase Change Material (PCM) is the most effective way of the thermal energy storage due to its advantages of high energy storage density and its isothermal operating characteristics during solidification and melting processes. The main objective of this work is to synthesize thermal energy storage and to evaluate thermal performance of encapsulated D-Sorbitol as PCM with various encapsulation materials (Aluminium, Brass and Copper). The solar energy collected by the Parabolic Trough Collector is used to heat the Heat Transfer Fluid (HTF). When HTF attains the equilibrium temperature at all points then the experimentation has been carried out in the thermal energy storage system with various encapsulation materials like Aluminium, Brass and Copper. The time taken for the preset temperature change in PCM and HTF was recorded during charging and discharging process. The results are showed that the time taken for phase change process in copper encapsulated balls is much faster than aluminium and brass. The average heat transfer rate in HTF during charging process by the use of copper encapsulated balls is 76.025 kW which is 33% and 8.8% higher than brass and aluminium respectively. Comparing all the results and cost per kW of energy transfer in all encapsulated materials, brass encapsulated PCM balls seems to be a good option for thermal energy storage by using D-Sorbitol as PCM.

Keywords: D- Sorbitol, thermal storage tank, heat transfer fluid, therminol 66.

1. INTRODUCTION

Scientists all over the world are in search of new and renewable energy sources. One of the options is to develop energy storage devices, which are as important as developing new sources of energy. Thermal energy storage systems provide the potential to attain energy savings, which in turn reduce the environment impact related to energy use [1].

Many literatures were concluded, the performance of D-Sorbitol as PCM with copper as encapsulation materials. No or less literatures were found on Brass and Aluminium as encapsulation materials. Hence the methodology of this work is to enhance the heat transfer of thermal energy storage system with D-Sorbitol as PCM and with three different encapsulation materials namely brass, copper and aluminium. Since melting temperature of D-sorbitol is around 110ºC, the energy stored by the PCM can be used for heating purposes [2]. The PCM is encapsulated in spherical balls since they can acquire more volume of liquid [3]. The enhancement of heat transfer can be done by introduction of wires, honey comb structure, encapsulations etc [4]. Different encapsulation materials are selected like Copper, Aluminium, and brass to study the performance analysis of Thermal Energy Storage System (TESS). The mixture of phase change material embedded in metal foam is also optimizing the thermal properties of the material for latent heat energy storage [5]. This study also paves a way to utilize the TES in air conditioning system, space heating applications etc.

2. EXPERIMENTAL SETUP AND METHODOLOGY

The components of experimental set up are thermal storage tank, a PTC (Parabolic Trough Collector) and a circulating pump. The PCM and HTF (Therminol-66) are filled in the storage tank which is made up of mild steel with diameter 300 mm, length 400 mm and thickness 6 mm. All parts of experimental set up was insulated with glass wool of 0.10 m thickness and pipe lines are also insulated with same material, 0.05 m thick, and covered with cotton thread. The Therminol 66 is filled in the storage tank and in the piping circuit, the oil leakage was arrested. A PTC with high reflecting surface concentrates the solar radiation to the absorber tube. The heat transfer fluid absorbs heat from the absorber tube, which circulates through the tube. The Figure-1 shows the experimental setup.

The HTF from the PTC enters the thermal storage tank bottom and leaves at top. The properties of HTF, PCM & PTC are listed in the Table-1. During sun shine time, the HTF gains heat and transferred to PCM which is stored in the tank. This process is called charging [6]. During discharging, the PTC is bypassed from the circuit and the cooled oil enters the storage tank and absorbs heat from the PCM. The temperature of HTF at inlet and outlet of the PTC was recorded and the thermal gain of the oil through PTC was calculated. The storage tank oil temperature was recorded in every 10 minutes time interval at three different locations and the heat transfer rate between HTF and PCM. The experimentation is

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repeated by changing the encapsulating materials (copper, aluminium and brass).

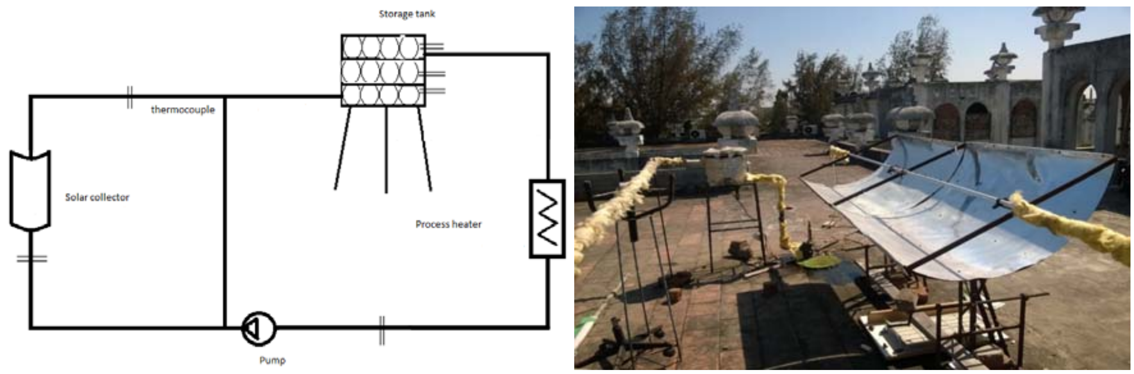

Figure-1. Experimental setup and layout.

Table-1. Properties of PCM, HTF & PTC.

Properties of PCM – D-Sorbitol		Properties of HTF – Therminol 66		Properties of parabolic trough collector (PTC)			
Melting point (°C)	89-95	Density	1005 kg/m^3	Absorber tube length	4.0 m	Concentration ratio	14
Latent heat (kJ/kg)	185	Specific heat	1.495 kJ/kg°C	Outer diameter of absorber tube	79.2 cm	width	1.5 m
Density (kg/m^3)	1524	Thermal conductivity	0.118 W/m°C	Inner diameter of absorber tube	7.62 cm	Support of structure material	M.S.
Specific Heat (kJ/kg °C)	2.49	kinematic viscosity	29.64 x 10^{-6} m^2/s	Aperture of collector	3.0 m	Collector length	4.0 m
Chemical formulae	$C_6H_{14}O_6$	Boiling temperature	359^{0}C	Aperture area	6 m^2	Absorber tube material	Al

3. RESULTS AND DISCUSSIONS

The results obtained from the experimental investigation of performance analysis of the heat transfer characteristics of the latent heat storage system during charging and discharging process with different encapsulation materials (i.e., copper, brass and aluminium) are discussed in detail.

a) Heat transfer analysis in aluminium encapsulation

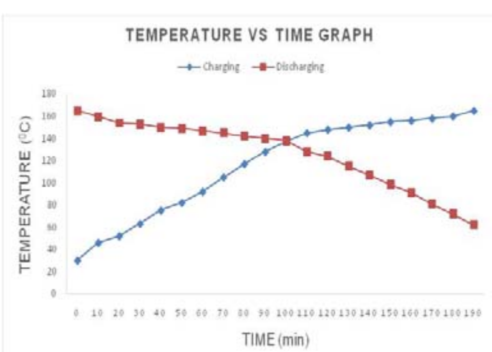

Figure-2. Charging and discharging of PCM in aluminium encapsulation.

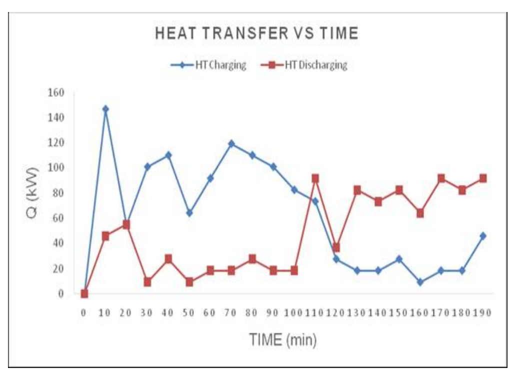

Figure-3. Heat transfer in aluminium encapsulation.

From Figure-2, the temperature of the PCM was noted down after 10 minute intervals. The charging process experiences a sharp increase for the first 100 minutes after which, it increases only gradually till 165°C. The gradual increase towards the end is due to the restriction in the flow of HTF. Similarly, while discharging, the temperature falls at a slower rate till it reaches 140°C. The rate then decreases at a faster rate and finally reaches ambient temperature at the end of 3 hours.

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The faster reduction rate towards the end is because of the sudden expansion of the HTF [7]. From Figure-3, while observing the heat transferred during charging, it was observed that there was a sudden increase initially for the first 15 minutes and then there was an irregular variation until it reaches 50 kW after 190 minutes. The maximum heat transferred was 150 kW and the lowest was 10 kW. The heat exchanged remains high in the beginning but decreases as the process continues. During discharging, the heat transfer remains low till about 100 minutes then it increases. This is contrary to the charging process. The maximum heat transferred is 80kW and the least is 5 kW. It can be inferred that the charging process is more efficient than the discharging process.

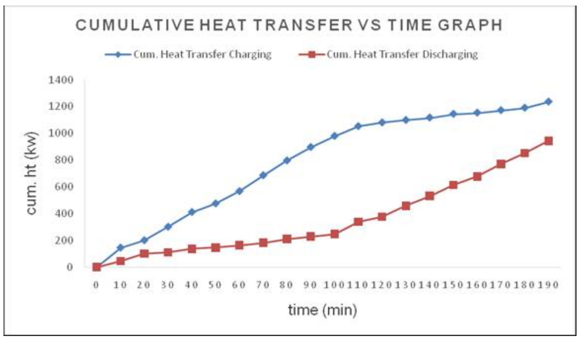

Figure-4. Cumulative heat transfer in aluminium encapsulation.

The total heat transferred was calculated for every 10 minutes interval. In the charging process, the total heat was about 1200 kW. The Figure-4 depicts a sharp rise in the heat transferred during the initial stages and it levels out during the remaining stage. During discharging, the total heat exchanged is about 800kW. During the end of the process, the increase is slightly higher as compared to the start. Hence there is a loss of about 400kW in the whole storage system. These losses can be due to heat lost to the surroundings and other losses.

b) Heat transfer analysis in Brass encapsulation

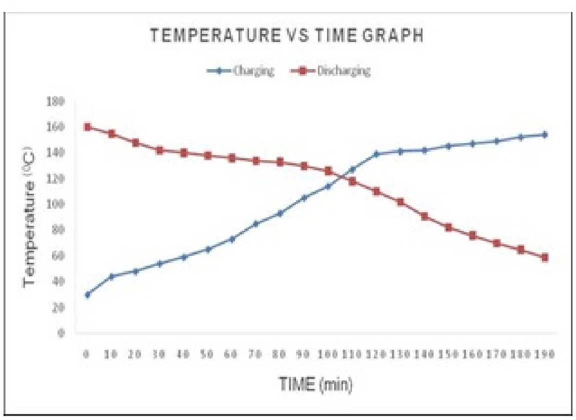

Figure-5. Charging and discharging of brass encapsulation.

The Figure-5 depicts the charging and discharging rates of brass balls. It can be understood that during charging, there is a constant increase of temperature till 140ºC after which the rate starts leveling out for the remainder of the process. The constant temperature towards the end is due to the reduction in the HTF flow. The time taken to complete charging is 190 minutes. On the other hand, during discharging, temperature decreases gradually with continuous fluctuation for the first 100 minutes till about 120ºC. In the later half, the temperature decreases sharply due to the sudden expansion of HTF till ambient temperature [8]. An intersection can also be observed at nearly 100th minute which shows that after 100 minutes the temperature of during charging was equal to the temperature during discharging.

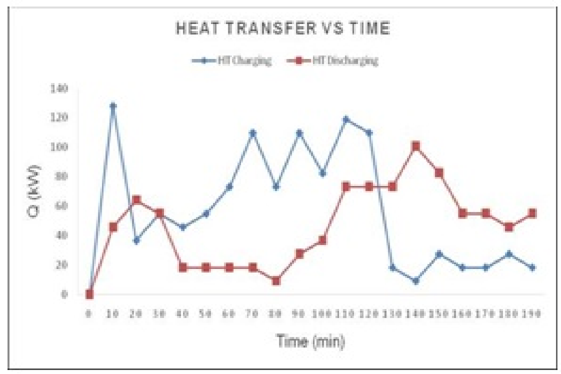

Figure-6. Heat transfer in brass encapsulation.

The Figure-6 represents the Heat transfer in brass encapsulation during charging and discharging processes. During the process of charging, there is a sudden increase initially until it reaches 130 kW and it starts decreasing until it reaches 30 kW after which the heat transfer rate varies in an irregular manner and finally it ends up at 20 kW at the end of 3 hours. On the other hand, during discharging, there is an initial increase till it reaches 70kW after which the rate again varies in an irregular manner and reaches a final value of 70kW. The patterns observed as opposite for charging and discharging.

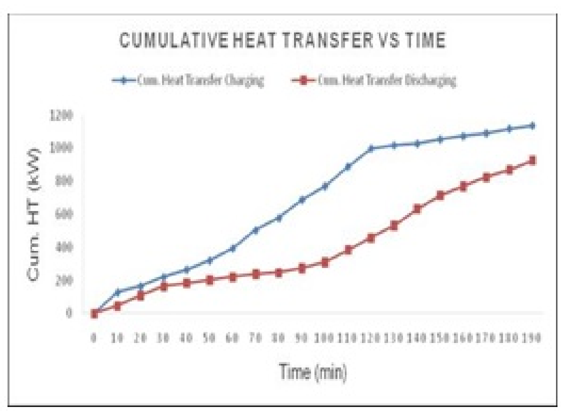

Figure-7. Cumulative heat transfer for brass encapsulation.

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The Figure-7 depicts the total heat transfer for brass encapsulation. During the process of charging, there is a constant increase till it reaches 100kW at the end of 2 hours and then the rate starts leveling until it reaches 1100kW. During discharging, the rate increases with respect to time slowly till it reaches 200kW for the first 100 minutes and then the rate increases in a faster rate and finally it ends up at 800kW at the end of 190 minutes. There is an approximate 200kW loss observed in the lateen heat storage system.

c) Heat transfer analysis in copper encapsulation

The charging and discharging rates of copper encapsulations are shown in the figure 8. The temperature of D-Sorbitol increases constantly for 140 minutes till 150ºC. The temperature then increases negligibly towards the end of the process. This shows the reduction in flow of HTF. During discharging, a gradual decrease is noted till 140ºC after which a sudden decrease of temperature takes place after 140 minutes. This indicates the sudden expansion of HTF. There is an intersection of the two curves at 160ºC that shows the same temperature during charging and discharging at the same point.

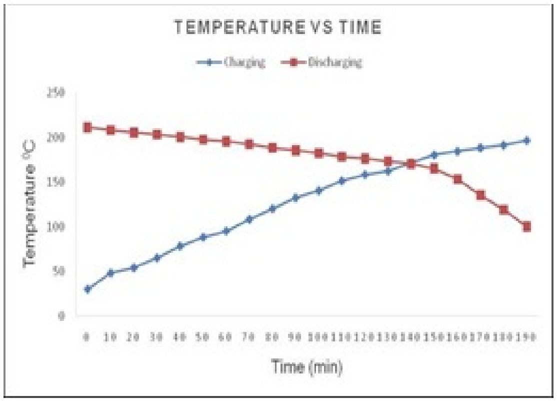

Figure-8. Charging and discharging of copper.

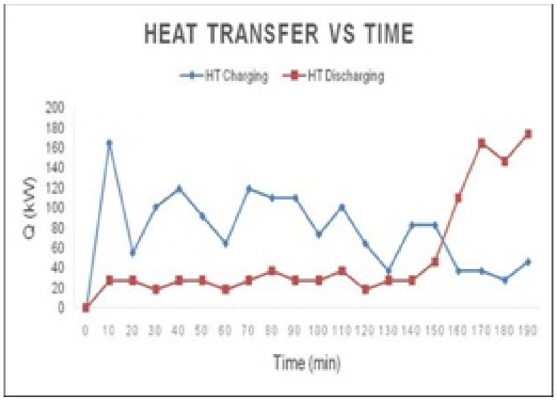

Figure-9. Heat transfer in copper encapsulation.

The heat transfer rate in copper balls is shown in Figure-9. During charging, the heat transfer initially increase in a steep manner till it reaches its maximum value of 175kW and then varies in a periodic manner before it reaches its final value of 40kW after 3 hours. Whereas during discharging, the heat transfer initially stays constant for the first 150 minutes after which a sudden increase takes place and finally reaches a value of 180kW. The charging pattern varies continuously whereas the discharging pattern remains constant.

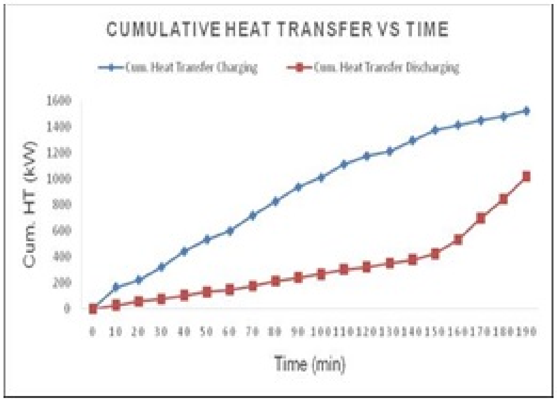

Figure-10. cumulative heat transfer for copper balls.

The total heat transfer for copper balls is depicted in Figure-10. The graph tends to be simple as the charging process increases in a uniform manner with respect to time and reaches a maximum value of 1400kW. During discharging process, the heat transfer increase in a gradual manner till it reaches 400kW after 150 minutes. Then there is a steady increase for the next 40 minutes and finally it ends up in 1000kW. There is a approximate loss of about 400kW in the storage system.

4. CONCLUSIONS

The overall experiment was carried out for three different materials mainly brass, aluminium, and copper. Their heat transfer rate during charging and discharging were taken and cumulative heat transfer rate was also calculated. From the calculated value it is seen that the heat gained during charging was highest for brass i.e. 1657.96 kW and the heat gained during charging was lowest for copper i.e. 1135.84 kW. For discharging purpose the maximum heat loss is in brass i.e. 1016.76 kW. During discharging, the maximum heat loss in surrounding was maximum for brass ball and minimum heat loss was for aluminium ball. Comparing all the three balls and their data obtained brass balls seems to be a good option with suitable properties for carrying experiment using D-Sorbitol as PCM for various applications.

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