Thermal Analysis of Thermal Energy Storage System Using Spherical Capsule with and with Out Fins

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Abstract:
The aim of this study is to investigate the experimental analysis of the thermal characteritics of a thermal energy storage (TES) unit that combines both sensible and latent heat stored in a bed. A TES unit is created, constructed, and integrated with a constant temperature bath to evaluate t he functioning of the storage unit. For smaller temperature change Latent Heat Storage (LHS) has high storage density, but LHS has many practical problems, for example poor conductivity of Phase Change Materials (PCM). To overcome these introducing fins in PCM holders are best solution. In the current study, research is conducted to estimate the effectiveness of a thermal energy storing system for storing heat energy within spherical capsules containing stearic acid PCM and featuring hollow cylindrical fins inside. Stearic Acid with melting point of 57^0C is used for investigation because local companies readily supply it and it is suitable for thermal storage purposes. The heat transfer fluid which is used to move heat from the source to the TES tank is water. The changes in temp difference of PCM has been examined for two configurations of PCM spherical capsules, one is without fin and another is with internal hallow cylindrical fins. While conducting experiments by increasing flow rate of heat transfer fluid from 2 lpm to 6 lpm the decrease in charging time is observed with a % of 32 and 36 for the case of without and with fin configurations. The quantity of immediate heat retained and the overall accumulated heat retained are greater in a spherical capsule featuring an internal hollow cylindrical fin configuration compared to a configuration without fins.

Keywords: Thermal Energy Storage, Circular fin, Charging and discharging.

1. Introduction

To minimize the discrepancy and timing issues between demand and supply, time-dependent energy supplies must be used efficiently, which requires appropriate energy storage systems. Thermal energy storage (TES) systems deliver a great deal of adaptability because a number of different energy sources, including solar heat, manufacturing waste heat from industries, heat drives, and off-peak power, can be utilized

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singly or in tandem. In specific solar heat uses, Solar radiation is a time-dependent and intermittent energy source, the applications utilizing solar energy need a big energy storage capacity to meet demand for at least 1-2 days. Thermal energy can be stored in three different ways: sensible, latent, and thermochemical. Despite being a straight forward and well-established technology, sensible Because of its low heat storage capacity per unit volume of the storage medium, heat storage is the least efficient method of energy storage.

Small unit dimensions, significant thermal storage capability, and consistent charging and discharging behavior have number of valuable advantages of Latent heat systems of storage that make use of phase transition material as the medium for storage. SHS materials and TES systems have been the focus of a significant amount of investigation, and the technology to use them has also advanced significantly. The general objective of employing a packed bed with HTF fluid flowing through is to reduce storage space or use low-cost materials for huge quantities of thermal storage.

"Beasley and Clark" [1] Have done a wonderful job of examining this strategy within the framework of SHS systems. LHS systems have only begun to attract significant attention in the past 20 years. The performance of thermal energy storage devices using phase transition materials in various geometries has been the subject of several theoretical and practical investigations by numerous researchers.

Saitoh and Hirose [2] used spherical capsules to conduct both theoretical and experimental research of an LHS unit's transient thermal properties. We investigated the effects of changing the following parameters on this storage unit's performance using computational modeling. inlet temperature differential, capsule substantial, PCM, Heat Transfer Fluid flow rate, and capsule diameter. The results were compared to the experimental findings of a 300 l prototype LHS unit. "Sozen et al". [3] performed an investigation of the TES properties of a packed bed that was composed of SHS and LHS composed of a horizontal channel containing PCM particles enclosed in spherical. The energy-transporting medium was refrigerant-12, a perfect gas. PCM was myristic acid, 1% carbon steel was used for the construction of the SHS. According to the investigations, the energy storage capabilities of a few of different styles of packed beds differed significantly. "Bansal and Buddhi" [4] developed an analytical framework employing stearic acid PCM with regard to a solar collector and storage system operating in a quasi-steady-state paradigm.

The results of the experiment unequivocally show that a PCM collection or storage system is superior to a system with separate collectors and storage units. Dincer [5] carried out an investigation into the viability of selecting, evaluating, putting into operation, and operating a thermal energy storage (TES) system for solar thermal operations. A few checklists, selection criteria, methods, suggestions, and for energy storage system installation and operation are also provided. Cho and Choi [6] examined the paraffin's thermal properties in a spherical capsule during the charging and discharging procedures. Paraffin PCM was used in the experiments. Due to the fact that the melting process is characterized by a free convection effect, according to the findings of this research, the inlet temperature and Reynolds coefficient had a greater influence on the mean heat transfer coefficients. Sari and Kamil [7] Experimental research has been done on the thermal performance and phase change stability of stearic acid as a material composed of LHS that is housed inside a vertical cylindrical container. Researchers examined factors such temperature ranges, transition times, the spread of the solid-liquid interface and how heat flow rate affects the stability of stearic acid during phase transitions. Eames and Adref [8] demonstrated the charge and discharge rate experimental findings as well as the time needed to melt and freeze a spherical ice storage device. Nallu swamy et al. [9] a packed bed storage approach that is based on PCM was used in order to carry out an in-depth investigation of the building's air conditioner. It was emphasized that the modes of operations, as well as the benefits of a system of this sort for energy management, were highlighted, and the idea's flexibility for other applications. Subramanian et al. [10] performed a performance analysis using I.C. engine exhaust left-over heat recovery on a combined sensible and LHS system. The numerous uses of this system were emphasized by the analysis of performance metrics such as charging efficiency, charging rate and heat extraction rate. Reddigari et al. [11] experimentally examined how well the TES system performed for different PCM (stearic acid and paraffin) by adjusting the flow rates of HTF and for varying spherical capsule diameters. They found that the maximum temperature of stearic acid was 12% higher than that of paraffin wax and equivalent to the HTF inlet temperature.

2. Experimental setup:

The elements of the experimental configuration consist, a control valve, a flow meter, pumps for circulating and TES tank that is cylindrical in shape and is insulated; it contains phase change material (PCM) that is contained within spherical capsules. Fig. 1 represents the experimental setup schematically. Figures 2 and 3 portray the photographic perspective of the experimental setup. This illustrates the arrangement of the inside of the TES tank are capsules that are round. With a capacity of 57 liters (370 millimeters in diameter and 535 millimeters in height), the TES tank made of stainless steel has the capacity to store five- or six-people's worth of hot water. Glass wool with a thickness of thirty millimeters is used as insulation for the storage tank. With a wall thickness of 2 millimeters and an inner diameter of 70 millimeters, the capsule is spherical in shape. It is constructed of mild steel. In the TES tank, 90 capsules were used altogether. Five rows of the spherical capsules are evenly spaced apart, In addition, a wire mesh is used to support each row. Within the context of the research, each row of spherical capsules functions as a layer.

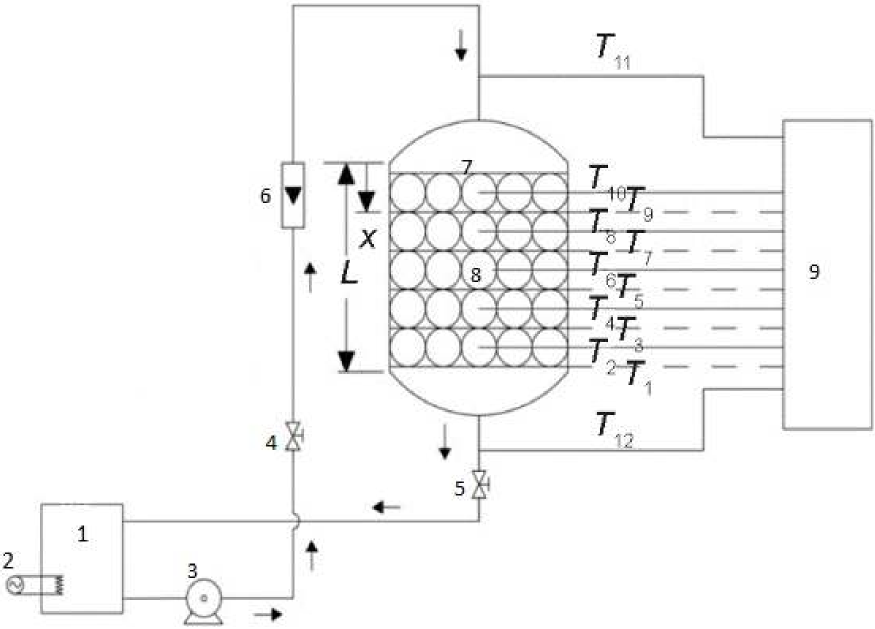

Fig. 1. Graphical presentation of the experimental prearrangement.
1. Hot water source, 2. Heater, 3. Pump, 4&5. Valve, 6. Flow meter, 7. TES tank, 8. Spherical containers, 9. Temperature indicator, T_{11}. Inlet temperature, T_{12}. Outlet temperature, T_1 to T_{10}. Temperatures inside storage tank.

Fig. 2. Configuration of PCM capsules within the TES tank.

The PCM that is used is stearic acid, with a melting temperature of 570 degrees Celsius and a latent heat of fusion of 198 kilojoules per kilogram. Water is used both as a sensible heat storage medium and as a heat transfer fluid (HTF). In present system internal hallow cylindrical fins are arranged to spherical capsule where PCM id stored. The purpose of this is to enhance the rate of convection, which in turn increases How quickly heat is sent out of or received by the system. In this study TES system analysis was made between spherical capsule without fins and with internal hallow fins is analyzed for three flow rates of HTF for stearic acid as PCM in charging and discharging processes.

Table 1. Characteristics of PCM (Stearic Acid)

Phase change material	Melting Temp. In ^{0}C	Latent heat of fusion (kJ/kg)	Density (kg/m^3)		Specific heat (J/kg^{o}C)		Thermal conductivity (W/m^{o}C)	
			In Solid	In Liquid	In Solid	In Liquid	In Solid	In Liquid
Stearic acid	57	198.91	960	840	1600	2300	0.3	0.172

Fig. 3. The experimental setup as seen via a photograph

Table 2. TES tank's specifications and capacity to retain heat

S. No.	Specifications	Value
1	Capacity of the storage tank (Diameter=370mm and height=535mm)	0.0575 m^3 (57 liters)
2	Mass of PCM filled in each spherical capsule	0.155 kg(Stearic acid)
3	Quantity of SHS(water) in the storage tank	37 kg (37 liters)
4	PCM stack inside the storage tank	14 kg(Stearic acid)
5	Total Energy stored in the TES tank (Initial temperature 35°C, Final temperature 70°C)	10.4 MJ

3. Numerical Studies:

3.1 Charging process

The pump used in the circuit circulates the hot HTF from the tank during charging. The PCM within the capsules melts when it absorbs heat. To achieve a suitable rate of heat transfer, there must be a significant enough temperature change between the mean of the HTF and the PCM measurements. The HTF and PCM temperatures are recorded at different points during this operation. Following filling, the exit valve is opened and adjusted to maintain a steady water level in the tank.

At the specified flow rate, the HTF is circulated and maintained until the PCM reaches the same temperature. As for the charging tests, they are performed for the heat transfer fluid (HTF) at flow rates of 2 liters per min, 4 liters per min and 6 liters per min. These experiments are also repeated using a mild steel spherical capsule, both with and without circular hallow fins.

3.2 Discharging process

The technique can be done continuously or in batches. However, it has been observed When there is an intermittent need, batch-based processes tend to work better, according to the literature. A certain quantity of hot water, which is five liters, is extracted from the TES tank, and the tank is then replaced with cold water in the same proportion throughout the process. The quantity of water that is withdrawn from the TES tank in a predetermined amount of five liters in order to make room for the addition of new cold water is referred to as a batch. An further batch of five liters of water is taken out of the TES tank after a wait of twenty minutes to allow for heat transfer from the PCM. Once the total volume of water withdrawn reaches an average temperature of about 45°C, the process is repeated.

A determination is made about the thermal dependability of the system by using the heat energy that is recovered from the entire system. In direction to assess the effectiveness of the model, the theoretical calculations that are shown below are used.

Table 3. Spherical Capsule parameters

Inner diameter	70mm
Outer diameter	74mm
Thickness	2mm
Material	Mild steel
No.of Sphericals in each layer	18

No. of layers	5
Total No. of Sphericals used in TES tank	18X5=90

3.3 The total heat of stearic acid retained in a spherical capsule

$$Q = (m_{st}C_p\Delta t)solid + (m_{st}L) + (m_{st}C_p\Delta t)\ liquid$$

m_{st} = "mass of stearic acid"
C_p = "specific heat of stearic acid"
Δt = "temperature difference"
L = "Latent heat of fusion
Mass of the stearic acid"
Volume of the spherical = 0.179 lit
Clearance given in the spherical = 10%
Total volume of stearic acid taken into account = 0.177 lit
"Mass of the PCM" (m_{st}) = Density × volume = $960 \times 1.77794 \times 10^{-4}$
m_{st} = 0.1706
Total mass of stearic acid used in TES tank= mass of individual spherical x No. of. Balls used in TES tank
= 0.1706 x 90 = 15.361 kg
Q = 0.6144 + 3.055 + 0.883
Q_{st}= 4.5528 mJ

4. Results Analysis:

4.1 Charging Experiment:

The results shown clear difference in charging and discharging process of TES tank with and without fins. There is increasing in charging time around 20% difference compare in both cases.

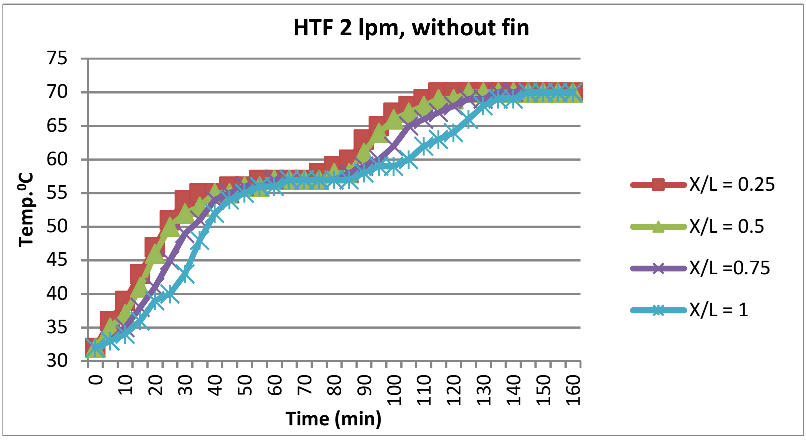

Fig. 4. Charging time of TES tank without fin for HTF 2lpm

The temperature of PCM steadily rises at first, then remains constant during the phase change time before rising again. Charging time is 160 minutes for stearic acid stored in a spherical capsule without fin for 2 lpm. Temperature variations in several TES tank locations are depicted in fig.No. 4

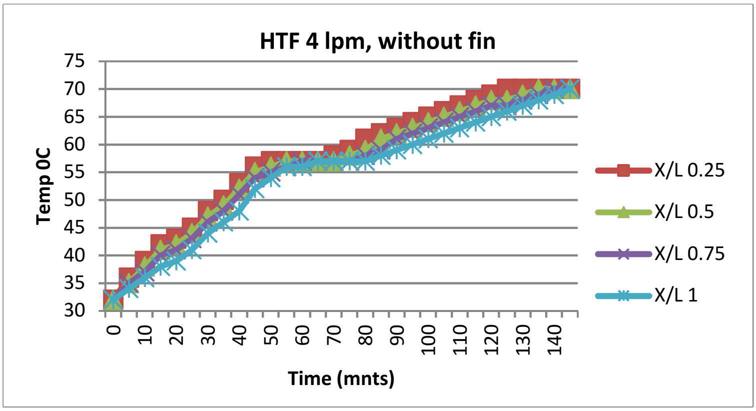

Fig. 5. Charging time of TES tank without fin for HTF 4lpm

Charging time is 140 minutes for stearic acid stored in a spherical capsule without fin for 4 lpm. The temperature variation across various locations within the TES tank is illustrated in fig. No. 5

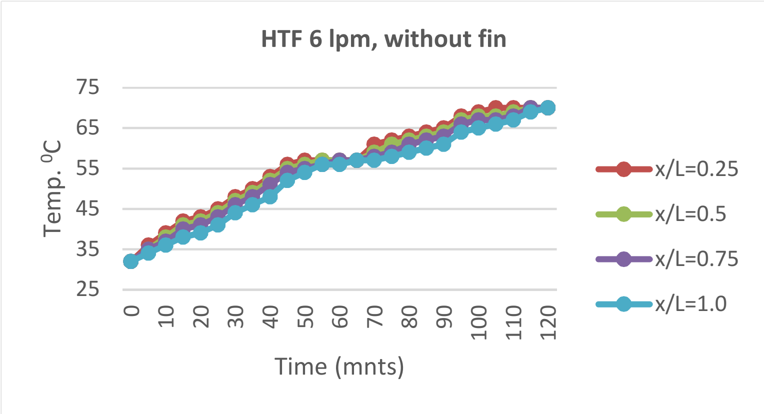

Fig. 6. Charging time of TES tank without fin for HTF 6 lpm

The charging duration for stearic acid contained in a spherical capsule without fins at a flow rate of 6 liters per minute is 120 minutes. Figure 6 depicts the temperature variation at different locations within the thermal energy storage (TES) tank.

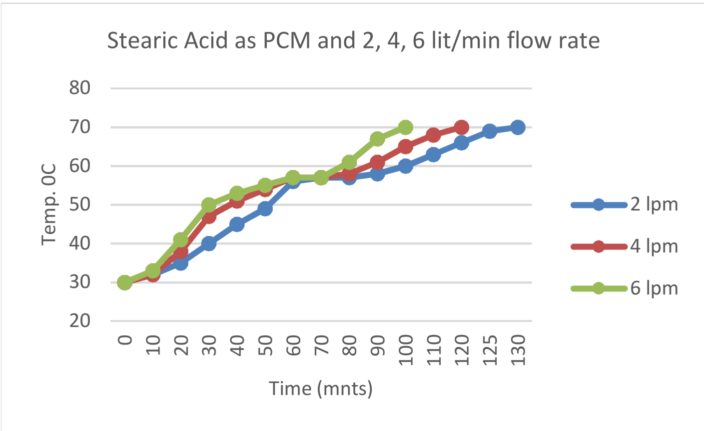

Fig. 7. Charging time of TES tank with circular fin for different flow rates.

There is clear improvement in charging time by introducing circular fins in spherical capsules. Fig. 7 shows the PCM temperature with respect time for 2 lpm, 4 lpm and 6 lpm of HTF flow rates.

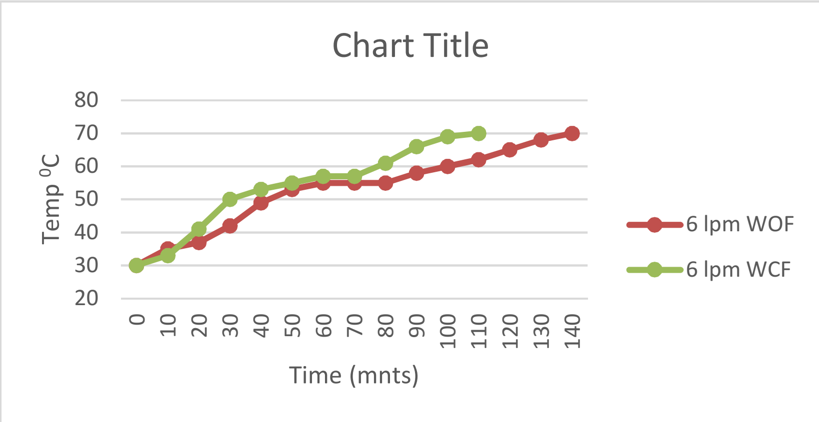

Fig. 8. Variation of charging time of TES tank with and without fin for 6 lpm flow rate of HTF

Overall charging time is significant improvement is observed in TES tank compare with spherical capsule without fin and with fin. There is 20% improvement in charging time for TES tank with circular fin of spherical capsules while compare without fin.

4.2 Discharging Experiment:

Experimental discharges are carried out in order to evaluate the recovery of heat function of the thermal energy storage system (TES). When compared to stearic acid as PCM with a hollow circular fin, Without the fin, the temperature of the liquid extracted from the TES tank is slightly higher in each batch. As a result, the maximum quantity of the heated water that may be removed from the system is greater when using the circular fin of a spherical capsule.

5. Conclusion:

A TES system is developed with a finned spherical capsule to store thermal energy. A circular fin arrangement of spherical capsules is used to encapsulate the PCM. Phase changing material is Stearic acid and the water as HTF is allowed to flow over the surface of the spherical as a sensible heat element. The discharging process continued for nearly 48 hours to reach the room temperature of (34^0) for the spherical containing Stearic acid. From the experiments and the graphs drawn, conclude that optimum TES efficiency observed in spherical capsule with circular fin.

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