Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Experimental study of TES System with PCM stored in Spherical Capsule with and without Different Shaped Fin Materials

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This experimental study examines the thermal performance of a Thermal Energy Storage (TES) system using Phase Change Material (PCM) stored in spherical capsules, both with and without different shaped fin materials. The primary objective is to evaluate the influence of fin configurations such as Square, Triangular and Circular on heat transfer rates and the phase change behavior of the PCM. Spherical capsules are chosen for their ability to maintain uniform thermal distribution, while the fins are introduced to enhance heat transfer efficiency by increasing surface area. Various fin materials, including brass, copper, and aluminum, were tested for their impact on the system's thermal performance. The study measures key parameters such as melting and solidification times, heat transfer rates, and overall thermal efficiency. Results demonstrate that the addition of fins, particularly those made from high-conductivity materials like copper, significantly reduced phase change times and improved the overall efficiency of the TES system. This study highlights the potential of fin-enhanced spherical PCM capsules in optimizing thermal energy storage systems for applications in renewable energy, waste heat recovery, and temperature regulation in buildings.

1. Introduction

Thermal Energy Storage (TES) systems are increasingly being recognized as a crucial component in enhancing the efficiency and flexibility of renewable energy systems, industrial processes, and climate control applications. These systems store excess thermal energy during periods of low demand and release it during high demand, helping to balance energy production and consumption. Among various TES methods, Phase Change Materials (PCMs) are particularly attractive due to their ability to store and release large amounts of energy during phase transitions (i.e., from solid to liquid or vice versa) at a relatively constant temperature. Global vide researchers' study theoretically, numerically and experimentally, the performance of the thermal energy storage system using vast variety of PCMs that can be suited for storing the latent heat energy for better utility of the solar energy during the day time and used in the night time. Dosapati et.al., (2020) investigated the method of integrating the solar system with the phase change materials to the solar energy during the off-sunshine hours. Reddy et.al., (2012) studied experimentally the use of paraffin and stearic acid as the PCM in the water heating applications. The inlet water temperatures and the mass flow rates were varied to study the comparison of the charging and discharging periods. Li et.al., (2020) made the internal structure of anisotropic graphene sponge that supports to fill the paraffin and maintains stabled shape to withstand longer duration and leak proof during melting. Mohammad et. al., (2018) used fins to enhance the PCM's heat transfer and to reduce the duration of solidification. Patel et. Al., (2018) studied the performance of the storage system that are affected by the ambient room temperature. Sciacovelli et. al., (2016) used Y shaped fins to increase the thermodynamic efficiency. Sreerag et al., (2016) used multiple PCM one with higher melting point and other with lower melting point to increase the efficiency of the solar TES system. Uroš et al., (2015) presented a various type of PCM that can be used for TES system. Warkhade et al., (2016) used different shaped concrete packed bed in small size to make a compatible to store the thermal energy in the form of sensible heat. Samimi et.al., (2019) used the copper foam porous model for PCM enclosures that improves the conduction as well as convection heat transfers. Xu et al., (2019) designed a porous medium of metal foam composites and studied effect of the pore size, density and thermal conductivity to be used as the PCM to enhance the efficiency of the system.

2. Experimental investigation:

Figure 1 and Figure 2 represents the schematic diagram and the photograph of the experimental setup of the TES system which is a insulated cylindrical stainless steel tank filled with a single spherical capsules of size 150 mm diameter and thickness of 2mm. The capsule material is varied with copper, brass and mild steel. PCM is filled in the capsule. The PCM is also varied to study the comparative thermal performance. Paraffin, Stearic acid and Myristic acid are used as the PCM. Thermocouples are used to measure the temperature at various points of the system. The heated water (HTF) is circulated from the solar panel to the TES tank for storage and cooled water is pumped to solar panel for heating. The flow meter is used to measure and flow regulator is used to control and vary the inlet and outlet heat transfer fluid. The stored heat energy is used for heating applications. The experimental study is done with and without inserting fins in the capsule. The fin cross sectional shape is varied as circular, spherical and square.

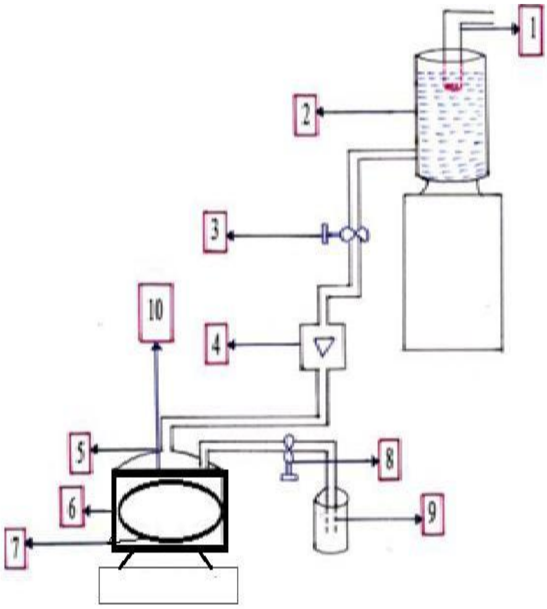

Figure 1: Schematic diagram of TES set up Figure 2: Photograph of TES set up

In CASE:1, The study is done by varying the mass flow rate of HTF as 2, 4 & 6 lpm, and the PCM material is varied as Paraffin, Stearic acid and Myristic acid. In CASE: 2, The fin is also inserted in the capsule to enhance the heat transfer rate. The study is conducted by modifying the cross-sectional shape of the fins and selecting different fin materials to identify the most optimal setup. The charging time required to raise the temperature of the phase change material (PCM) inside the capsules is utilized for storing energy in the form of latent heat during the phase change process.

3. Results and Discussions:

3.1 CASE: 1- Without Fins

3.1.1 Charging process of Paraffin PCM

When the paraffin is filled in the mild steel capsules without fin and the water mass flow rates are varied to 2, 4 and 6 lpm, the charging time of PCM filled capsule is studied. The Figure 3 shows the comparative study of the varied charging duration of different mass flow rates.

3.1.2 Charging process of Stearic acid PCM

When the Stearic acid is filled in the mild steel capsules without fin and the water mass flow rates are varied to 2, 4 and 6 lpm, the charging time is studied. The Figure 4 shows the comparative study of the varied charging duration of different mass flow rates.

3.1.3 Charging process of Myristic acid PCM

When the Myristic acid is filled in the mild steel capsules without fin and the water mass flow rates are varied to 2, 4 and 6 lpm, the charging time is studied. The Figure 5 shows the comparative study of the varied charging duration of different mass flow rates.

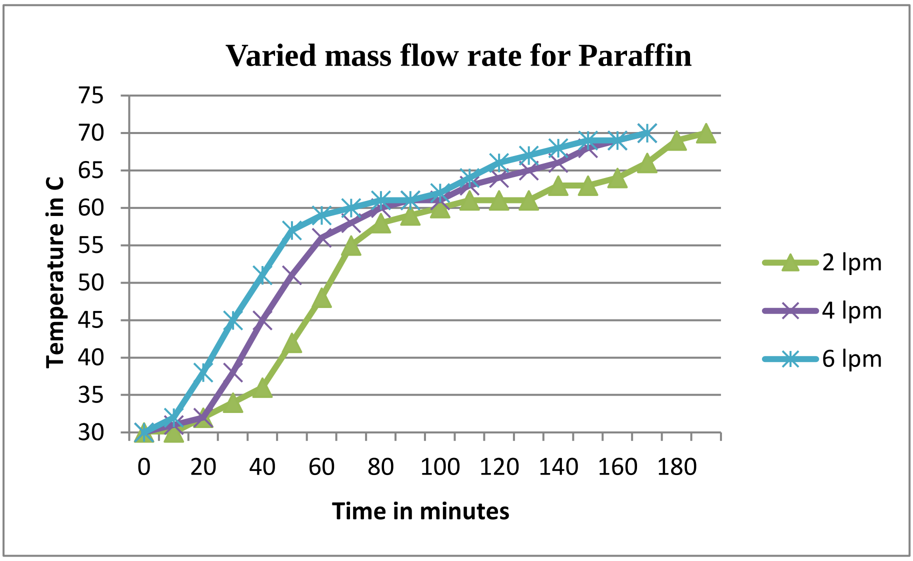

Figure 3: The comparative study of the varied charging duration of different mass flow rates in Paraffin PCM.

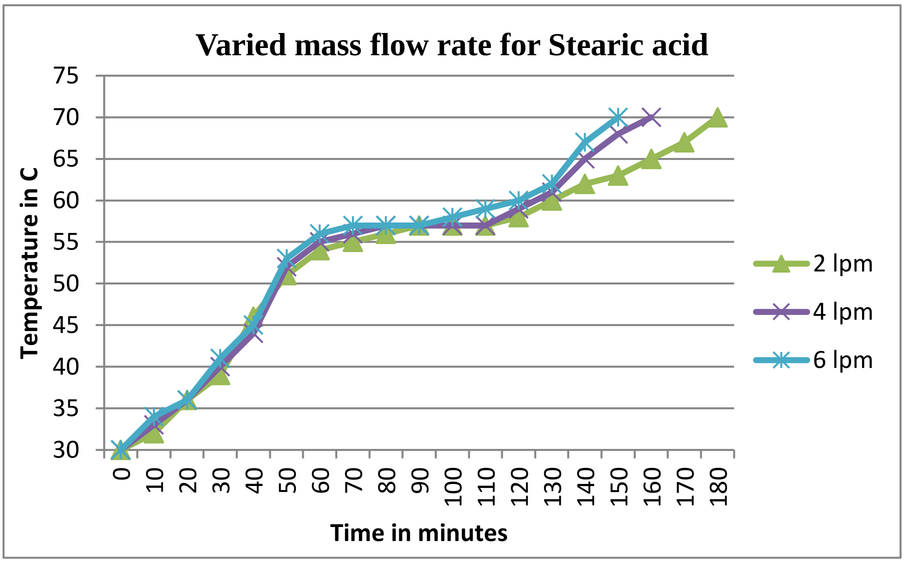

Figure 4: The comparative study of the varied charging duration of different mass flow rates in Stearic acid PCM.

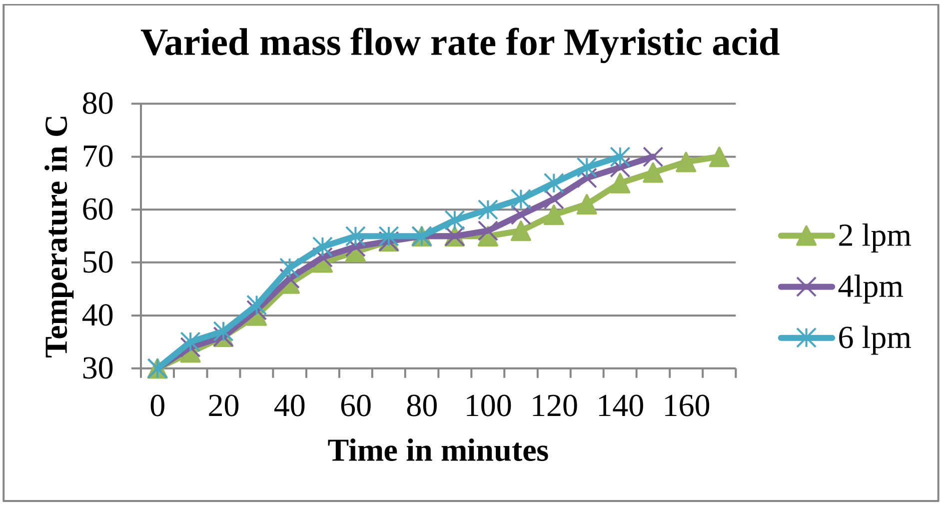

Figure 5: The comparative study of the varied charging duration of different mass flow rates in Myristic acid PCM.

From the above comparative study, it was found that the time taken by the PCM to reach 70^{o}C is less for Myristic acid when the HTF mass flow rate is higher i.e. 6 lpm. But followed by the stearic acid shows the better performance and it is considered for the further experimental study as it is economical, easy availability and non toxic.

3.2 CASE: 1- With varied cross sectional Fin

3.2.1 Charging process of Circular fin in Single ball in Stearic acid as PCM

The circular fin is inserted in the mild steel capsule filled with Stearic acid and the mass flow rate of the HTF is varied as 2, 4 & 6 lpm and the charging duration is studied. Figure 6 represents the graphical distribution of the temperature rise for the time period when the HTF transfers the heat to the single spherical capsule inserted with the circular fin.

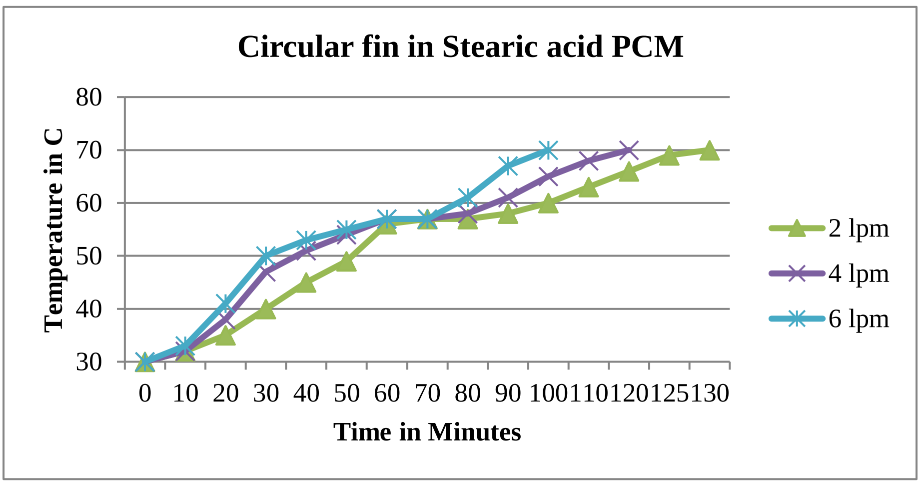

Figure 6: The graphical distribution of the Charging time of Stearic acid PCM capsule with

circular fin.

3.2.2 Charging process of Triangular fin in Single ball in Stearic acid as PCM

The Triangular fin is inserted in the mild steel capsule filled with Stearic acid and the mass flow rate of the HTF is varied as 2, 4 & 6 lpm and the charging duration is studied. Figure 7 represents the graphical distribution of the temperature rise for the time period when the HTF transfers the heat to the single spherical capsule inserted with the triangular fin.

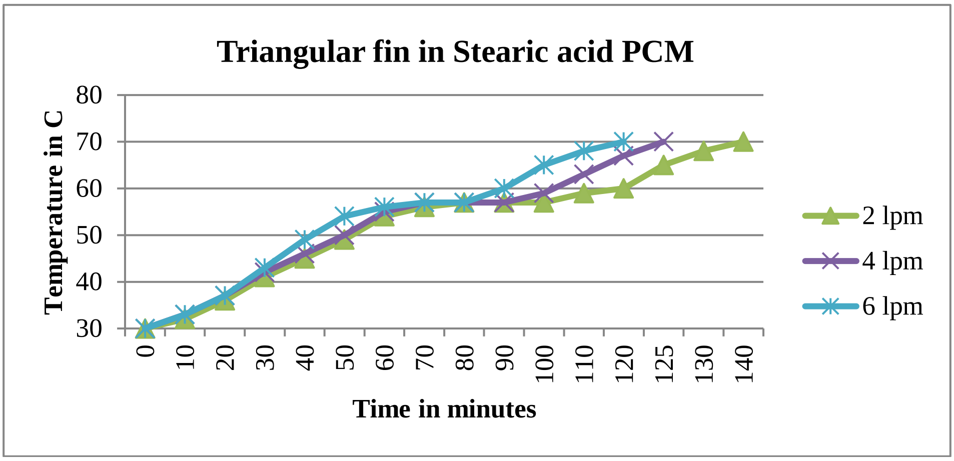

Figure 7: The graphical distribution of the Charging time of stearic acid PCM capsule with Triangular fin.

3.2.3 Charging process of Square fin in Single ball in Stearic acid as PCM

The Square fin is inserted in the mild steel capsule filled with Stearic acid and the mass flow rate of the HTF is varied as 2, 4 & 6 lpm and the charging duration is studied. Figure 8 represents the graphical distribution of the temperature rise for the time period when the HTF transfers the heat to the single spherical capsule inserted with the Square fin.

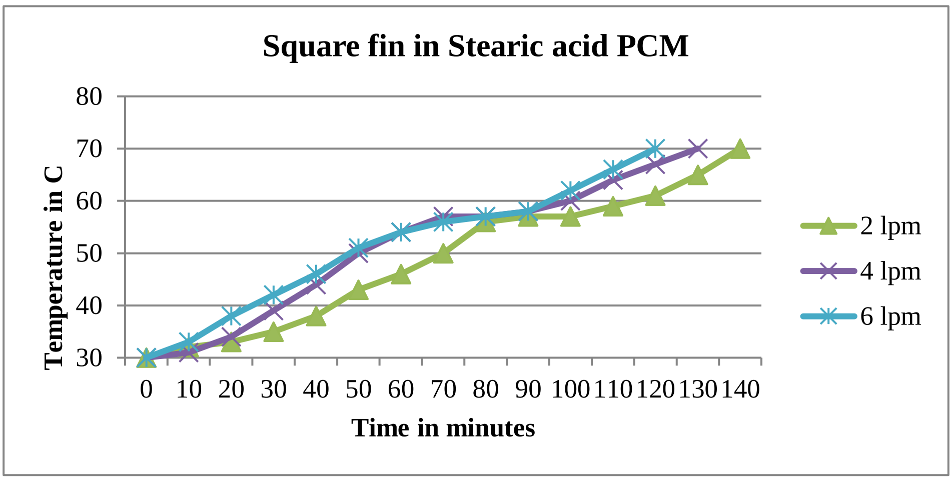

Figure 8: The graphical distribution of the Charging time of stearic acid PCM capsule with

Square fin.

From the above comparison of varied fin cross section, it was found that the circular fin was more effective which takes less time to charge the stearic acid. Hence further study is considered with stearic acid with circular fin by modifying the fin material.

3.3 CASE: 1- With varied circular fin material

3.3.1 Charging process of circular fin of varied fin materials inserted in mild steel capsule with Stearic acid as PCM

The circular fin is inserted in the mild steel capsule filled with Stearic acid and the mass flow rate of the HTF is 6 lpm for varied fin material such as copper, brass and mild steel and the charging duration is studied. Figure 9 represents the graphical distribution of the temperature rise for the time period when the HTF transfers the heat to the single spherical capsule inserted with the circular fin of varied fin materials.

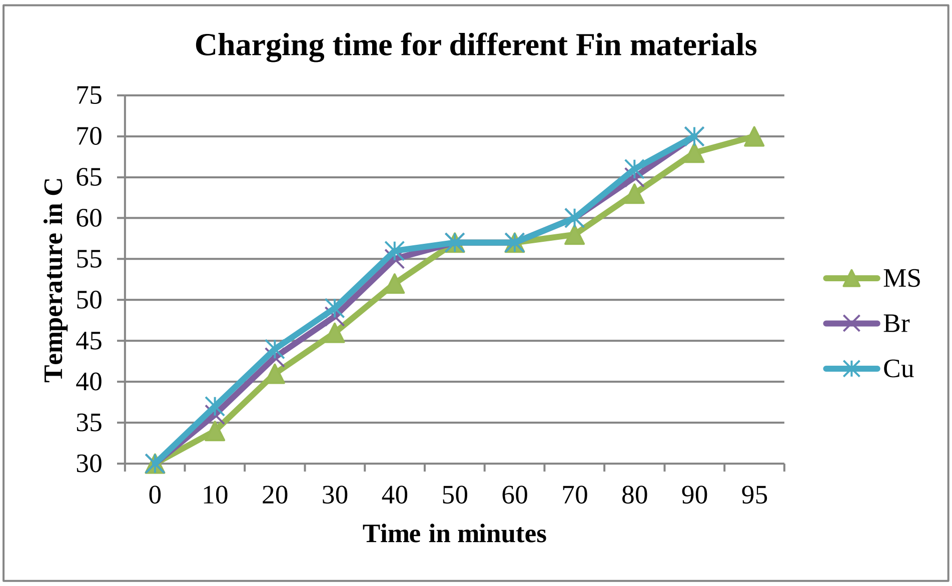

Figure 9: The graphical distribution of the Charging time of stearic acid PCM capsule with circular fin with different fin materials.

From the above results it was found that the copper which has the highest thermal conductivity shows the lowest charging time.

4. Conclusion:

This paper shows the experimental study of the TES system with a single mild steel capsule filled with PCM materials such as Paraffin wax, Stearic acid and Myristic acid. The HTF mass flow rates are varied as 2, 4 & 6 lpm. The results proved that as the mass flow rate of the HTF increases the charging time gets decreases. The study was done with and without inserting fin and found that without fin the myristic acid showed the lesser charging time. Even though myristic showed better result, the stearic acid was selected for the further study which stands latter due to its properties like compatibility, easy availability, easy handling and economical. The fin was inserted and the cross sectional shape of the fin was varied as circular, triangular and square and found that circular fin showed better results compared with the other shapes. The fin material was varied as copper, brass and mild steel and found that copper gives better results due to its higher thermal conductivity.

Finally, this paper concludes that stearic acid filled in mild steel capsules inserted with copper fin in circular shape gives a effective charging duration when the mass flow rate is 6 lpm. This result can be suited for thermal heating applications.

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