Effect of bifurcation in phase change material by heat transfer tube in a horizontal solar thermal energy storage

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Abstract. A horizontal thermal storage that uses a phase change material (PCM) for energy reposition undergoes melting at the base and corners due to minimal natural convection. A storage container is split into two halves using a rectangular duct, which improves convection currents and facilitates heat transfer with a low melting time. The results emphasize the duct design in determining PCM melting. The fluid is held at a constant temperature of 50-60 °C at a flow rate of 5 kg/min. Conventional tube and duct designs are investigated. Thus, PCM melting increases up to 30% with enhanced melting rate. Comparing conventional fluid tube, rectangular duct is beneficial to improve the melting rate through reducing PCM size in the container.

Keywords. Phase change material, Thermal energy storage, Melting, Heat transfer fluid (HTF), bifurcation.

1. Introduction

Sun is an important source and capable of satisfying the demand for our energy requirements. Due to intermittent nature of solar radiation, thermal energy storage (TES) is required to store the solar thermal energy for non-sunshine hours [1]. TES plays a significant role improving utilization of solar energy. Many researchers improved PCM’s thermal conductivity [2]. Material selection and optimization of PCM containers are essential to improve PCM charging for solar thermal applications [3]. Fig. 1 shows the classification of PCM.

TES using fin configurations were perfected to decrease PCM melting duration. The improved PCM storage is suitable for several applications [4-9]. The solar air and water heaters produce more uniform thermal output using PCM and PCM enclosures in solar receiver proved the uninterrupted heat output in high-temperature solar systems [10]. In vertical PCM storage, the fluid tube shape improved the changing. Charging PCM is primary concern in sola systems. From literature, several studies were conducted on different tube modifications/container shapes. Container and tube modifications are beneficial to charge TES. However, splitting PCM by HTF duct isn't much addressed in literature. The repercussions of splitting PCM during a horizontal cylindrical container using an HTF duct are reported with constant flow and three inlet temperatures. The significant results reported.
2. Materials and methods

2.1 Experimental work

TES container is made up of acrylic of 110 mm outer diameter and 280 mm long. HTF tube and duct are made with the same surface area and made up of copper. HTF tube/duct is the chief design part to melt PCM using water from heat sources. HTF tube is modified as the partitioned wall concept. Fig. 2 depicts HTF tube and duct with fluid flow direction. Both the designs are tested with the same fluid conditions. K-type thermocouples measure PCM temperature. The setup comprises an electric heater, TES system, pump, piping, and valves, as depicted in Fig. 3.

![Figure 2. TES configurations: (a) HTF tube, (b) flow duct with baffles.](image)

![Figure 3. Schematic layout of experimental setup.](image)
2.2 Methodology
OM42 is an organic PCM with a melting point of 42°C. While phase change, latent heat is released or absorbed, within the apparatus to remain constant. PCM and HTF duct fitted with the thermocouple inside the acrylic container. After PCM solidified, the TES is insulated. This setup is then installed in the setup by putting inlet and outlet to storage. The setup is fitted with pump and heater. Once the experiment started, the necessary water level and temperature are maintained. At an interval of 10 mins, the readings were taken.

3. Results and Discussion
PCM is charged by passing hot water through duct. The hot water at 50, 55, 60 °C at a flow rate of 5 kg/min is maintained. A thermostat valve maintains water temperature. Molten state of PCM is observed visually and using thermocouple readings. Melting stages are observed as per Fig. 4. Time taken for complete PCM melt is observed at an interval of 10 min. The same experiment is conducted for a concentric HTF tube of diameter 25 mm with the same fluid conditions. The time taken for complete melting is compared for HTF tubes at the horizontal fluid duct. The vertical position of rectangular fluid duct played a crucial role improving convection effects and minimized the solid settling at the TES’s bottom.

![Figure 4](image)

**Figure 4.** Melting phases of PCM using duct design; (a) 40 min, (b) 60 min, (c) 80 min, (d) 120 min.

![Figure 5](image)

**Figure 5.** PCM melting duration in both the configurations at fluid temperature of 50 °C at 5 kg/min.
Figure 6. PCM melting duration in both the configurations at fluid temperature of 55 °C at 5 kg/min.

Figure 7. PCM melting duration in both the configurations at fluid temperature of 60 °C at 5 kg/min.

Figure 8. Melting time reduction with rectangular duct over fluid temperature.
The conventional fluid tube took about 180 min to melt entire PCM at 50 °C and 5 kg/min. But the duct melted entire PCM at 120 min as per Fig. 5. Figure 6 and 7 show the melting duration of PCM under varying fluid temperature of 55 and 60 °C, respectively. Modification of fluid tube reduces overall melting time by 27-33%, as shown in Fig. 8, as per the selected configuration and operating parameters. Fluid temperature is vital in reducing PCM melting duration. Flow rate is considered constant in the current investigation. However, the effect of flow rate is not much like fluid temperature [21, 22]. The partitioned PCM melts faster rate than conventional HTF tube. Further, the melting enhancement is observed on par with the literature [11, 12]. Thus, the present study is beneficial to TES community.

4. Conclusions
The fluid tube and duct configurations were tested using OM-42 at an inlet temperature of 50-60°C with a 5 kg/min. The copper duct showed a significant melting at a reduced time than conventional one. A higher fluid temperature reduces the melting time of PCM. The modified tube shows melting enhancement about 30% than conventional fluid tubes due to more contact area with PCM. Thus, the design we rooted for brought worthy results and manipulated for serving different purposes. Further, other heat transfer enhancement techniques like the fins, nanoparticles, and metal foams with present HTF duct design could improve the thermal storage of PCM.

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