Experimental Study of PCM Based Latent Heat Thermal Energy Storage System Using Fins

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1 Introduction

A sustainable and fulfilling future has long been needed by the world. As a result of the world's population's constant growth, there is a sharp increase in the need for energy. However, the supply of energy is constantly under an imposition to provide the needs of every living being on this planet. The search for new and renewable energy sources still goes on today as well. This makes development of energy storage devices for those new energy sources as crucial as developing new sources of energy. By storing the energy in a different form, there would be no need to maintain schedules to generate energy as per the energy demand at a given time, such as varying demand in energy from nuclear power plants during day time and night time, due to the lack of energy storage method. The intermittent availability of thermal energy resources, especially solar energy can be precisely utilized by developing a simplified and effective model of a storage system for a sufficient accumulation and supply of energy as per demand. One of the most efficient approaches for recovering heat from industrial waste and utilising solar energy is latent heat storage in phase transition materials. These systems' principal benefit appears to be their capacity to store a significant quantity of energy in very tiny volumes at a constant transition temperature. Research into heat transfers/exchanges in PCMs during their phase transition in the requisite operating temperature range is thus necessary for the creation of a latent heat thermal energy storage system.

For an implicit achievement of the knowledge of this trending field and to study the amendment of the properties of PCM, several papers from different journals were referred and studied precisely. Amrouche et al. [1] have made a concise review

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of various storage methods for renewable energy systems. They have included a precise study of chemical, electro-chemical, mechanical, thermal and electrical storage systems. Eslami and Bahrami [2] studied the thermal energy storage systems in particular. They asserted that thermal energy can be stored in three different ways: as perceptible heat, latent heat, or thermochemical energy. Thermal energy storage (TES), whether latent or sensible, has been the primary area of study in this work. Zalba et al. [3] has summarized by reviewing many papers based on thermal energy storage using PCMs. It's been determined that PCM makes it possible to store a lot of energy in relatively little spaces. Consequently, it has emerged as one of the least expensive storage media among many storage systems. A. Sharma et al. [4] has reviewed the classification of PCM. While inorganic PCMs can include metallics and hydrated salts, organic PCMs can include a variety of materials like various types of paraffin, eutectic mixtures, fatty acids, esters and numerous other organic compounds. They have compared the different properties of organic and inorganic PCMs and noted that the organic PCMs prove better than the inorganic ones due to their chemical stability, non- corrosive nature, harmonious melting, etc. Boda M. A. et al. [5] discussed various advantages and disadvantages of organic as well as inorganic PCMs and conducted a precise comparison between them. They noted that organic PCMs are more stable and non-corrosive than inorganic ones. However, their low thermal conductivity needs to be taken under concern for improvisation. Various applications of PCMs in the field of solar, medical, textiles, etc. are also included in this paper. Nair et al. [6] focused on the A PCM storage unit's experimental analysis for thermal energy storage. A thermal energy storage system is an essential tool for balancing out the energy supply and demand. It permits the short-term thermal energy storage at either high or low temperatures. These are also essential for energy conservation. Comparisons are made between the charging and discharging (storage) times of two PCMs, paraffin wax and myristic acid. This is done in a straightforward and cheaply constructed experimental setup. Hosseini et al. [7] carried out an experiment to determine the change in heat transfer rate that happened as a result of the phase change that occurs in PCMs when heated over their melting point. They looked into how varied intake temperatures affected how long it took for the PCM to completely melt overall. Their results showed that the convective mode heat transfer becomes more pronounced when phase change occurred, and convection had a higher influence in terms of heat transfer rate as compared to conduction mode of heat transfer. By utilizing both internal and external fins, Al-Abidi et al. [8] investigated how to improve heat transfer for a triplex tube heat exchanger. Various design and operating characteristics including number of fins, fin length, thickness of the fins, PCM unit geometry and Stefan number were examined. The simulation findings show that these parameters significantly affect the amount of time needed for complete melting; the influence of fin thickness on melting rate time is less significant than that of fin length and density. Tiari et al. [9] used a transient 2-Dimensional system to simulate charging a finned heat pipe, latent heat thermal energy storage system with a square-shaped high melting temperature PCM. Numerical studies show that natural convection strongly influences PCM melting.

According to a number of researchers, the main disadvantage is that slow charging and discharging rates are caused by the low thermal conductivities of many PCMs. The PCM's heat transfer rate can be maximized by selecting the fins with the most appropriate geometry and dimensions. The goal of the current work is to examine the charging, discharging, and efficiency of PCM-based thermal energy storage devices with and without fins (annular).

2 Theoretical Analysis

2.1 PCM Characteristics

The comparative study between different PCM materials was done. It was found that Paraffin wax OM46 has the most suited temperature range for the present experiment as the operating temperature range for the heat transfer fluid taken in the current study is around 45 ℃ -55℃. Because of its easy availability, cheap price as well as the chemical stability, OM46, proves to be the most appropriate and hence selected for this project study. Table 1 shows the thermo physical characteristics of PCM. Figure 1 shows the actual image of PCM OM-46 that was procured for use in the current experimentation.

Table 1 PCM properties

S. No.	Material properties	Value of quantity	Unit
1	Melting temperature	321	K
2	Density	917	kg/m^3
3	Specific heat	2020	J/kg-K
4	Thermal conductivity	0.22	W/m–K
5	Viscosity	0.00534	kg/m-s
6	Thermal expansion coefficient	0.00012	K^{-1}
7	Pure solvent melting heat	165,000	J/kg
8	Solidous temperature	321	K
9	Liquidous temperature	324	K

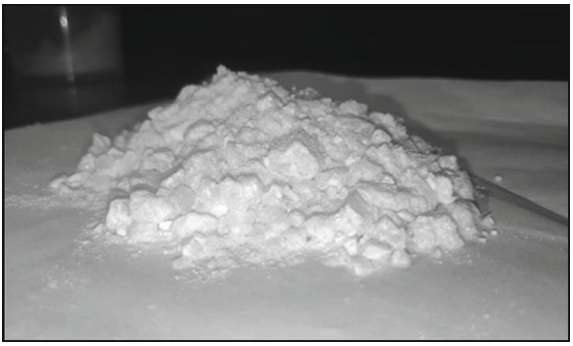


Fig. 1 Phase change material (OM 46)

2.2 Fin Selection

Various types of fins are available for application in heat exchanger such as annular fins, longitudinal fins and pin fins. Literature review shows that among annular, longitudinal and pin fin, the best suited fin was found to be annular fin due to more surface area, radial symmetry [8–10]. The material of tube and fin has taken as copper because of high thermal conductivity.

2.3 Fin Effectiveness and Efficiency

Effectiveness justifies the applicability of fin, and is defined as the ratio of heat transfer with fins to the heat transfer without fins. The calculation of fin effectiveness discussed below.

Outer Diameter of pipe (d_1) = 0.0127 m.

Length of fin (L) = 0.01 m.

Diameter of fins (d_2) = 0.0127 + 2*0.01 = 0.0327 m.

Taking thickness of fins (t) = 0.003 m.

Number of fins (n) = 31.

Spacing between the fins (s) = 0.029 m.

Base Temperature (T_0) = 60 °C.

Surrounding Temperature = T_∞ = 30 °C.

Thermal Conductivity of Copper material = 324 W/m °C (Fig. 2).

The efficiency has been calculated from above graph using two parameters, which are mentioned below.

$$\frac{r_2 + 0.5t}{r_1} = 2.8897 \tag{1}$$

$$(L + 0.5t)\sqrt{\frac{h}{kt}} \tag{2}$$

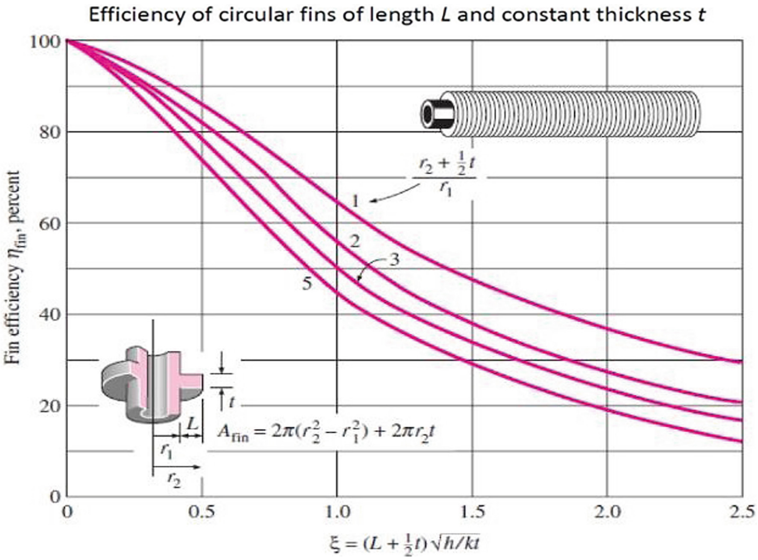


Fig. 2 Variation in efficiency of annular fins [10]

$$\text{Effectiveness of fins} = \frac{Q_{fin}}{Q_{withoutfin}} = \frac{A_{fin}}{A_{withoutfin}} \tag{3}$$

The effectiveness of the fin for present work is found to be 2.004, application of fin justified as it will enhance the heat transfer rate through surface.

2.4 Fabrication of Fins

As previously stated, copper was chosen as the fin material, and fins are fabricated as per the requirement from copper rod with an exterior diameter of 36 mm and a 16.5 mm center hole cut on a conventional lathe machine. Circular rings of varying thickness were then cut and brazed to a conventional copper pipe with a diameter of 0.5 in. Figures 3 and 4 show actual image of a fin manufactured, and finned pipe respectively.

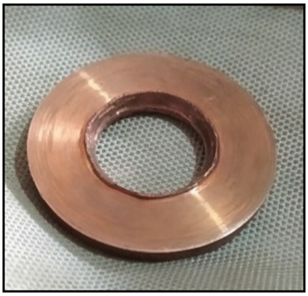


Fig. 3 Fin

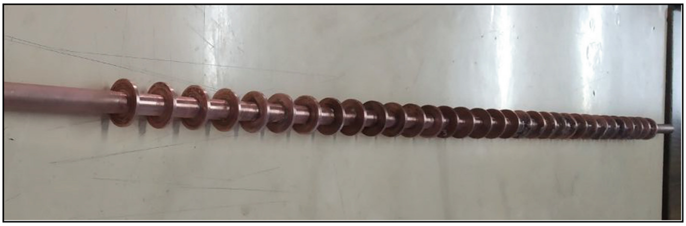


Fig. 4 Finned pipe

3 Experimentation

3.1 Physical Model

The inner tube diameter of the horizontal shell and tube heat exchanger is 0.5 in., and its length is 35 in. Due to its advantageous thermal characteristics, copper has been considered as an inner tube material. The exterior of the shell is covered in asbestos insulating tape and is made of galvanised iron (GI), which helps to keep heat inside. Conventional PCM was used to fill the annular space between the two pipes (GI and copper tube). One configuration includes a fin, whereas the other does not. The inner tube was penetrated by HTF water.

Experiments in the present work were done using two distinct heat cycles: charging and discharging. Figure 5 displays the experimental setup for this study. Although discharging takes place when the PCM returns heat to the working fluid and solidifies, charging takes place when the PCM absorbs heat from the HTF and melts. Initial charging cycle experiments were conducted with a constant 55 °C intake water temperature. The heated water was forced through the copper tube at a rate of 360 L/h until all thermocouples indicated a temperature just above PCM's melting point (Fig. 6).

With a steady intake flow rate of 360 L/h and temperature of 30 °C, the process was repeated for the discharging cycle until the readings of all the thermocouple reached

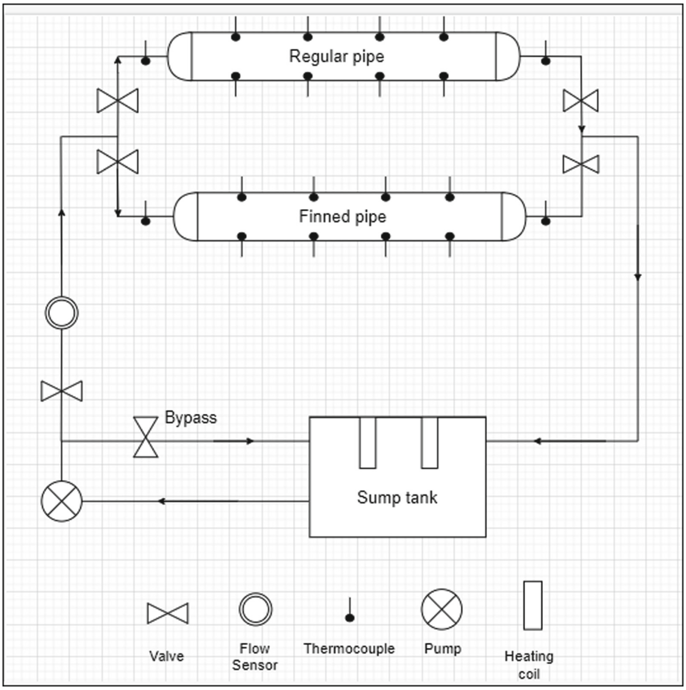


Fig. 5 Line diagram

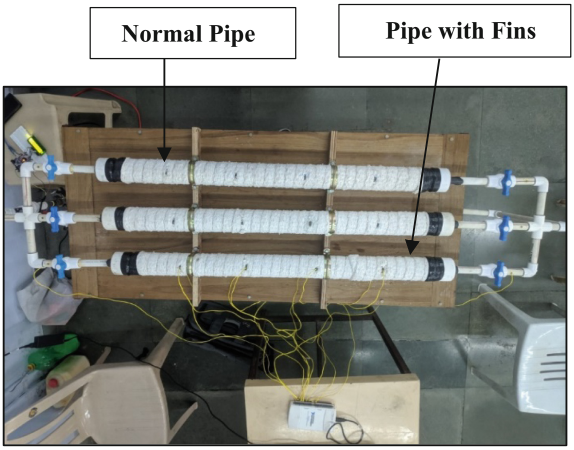


Fig. 6 Experimental setup-top view

room temperature, signifying that the PCM had solidified and the discharging cycle was over. Using the system's Fin Enhanced PCM (FEPCM), the procedure was carried out, and results for the charging and discharging cycles were obtained.

K-type thermocouples were inserted throughout the system at specific points to measure temperature. The thermocouples were connected to the NI DAQ system (National Instruments modelled as NI-DAQ USB 6211) and readings were obtained using the correct pin diagrams. The system was operated for the allotted period of time, with readings shown continuously every second. The positions and arrangement of thermocouples are depicted schematically in Fig. 7, and the DAQ channel notations are listed in Table 2.

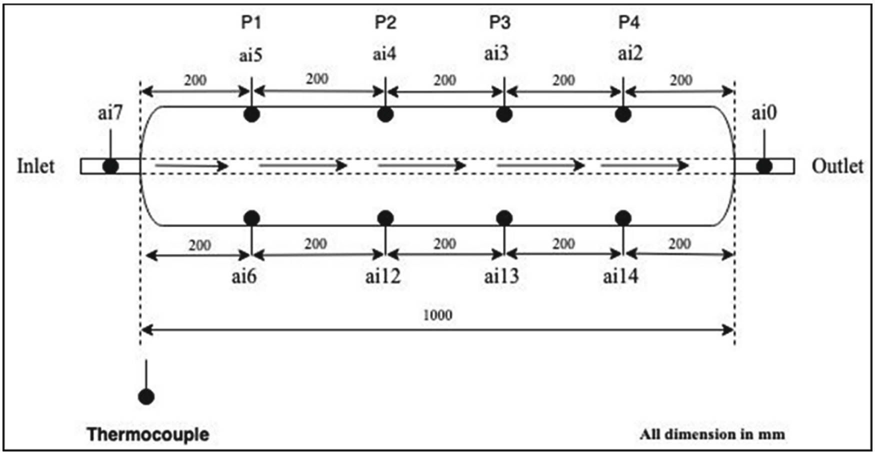


Fig. 7 Location of thermocouples across tube

Table 2 DAQ channels notation with respect to thermocouples position

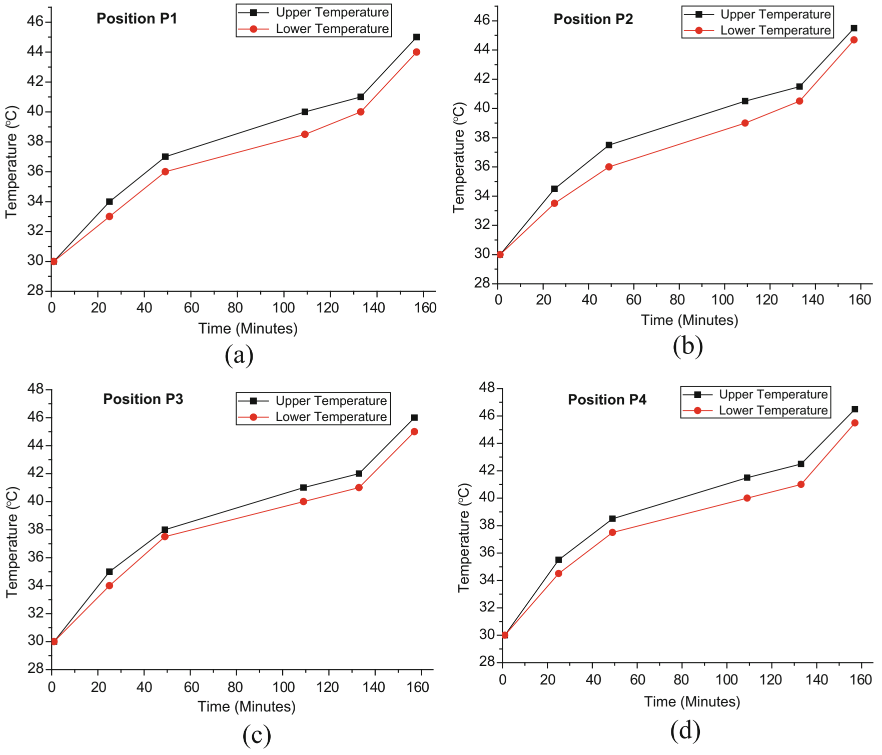
Point	Position	Thermocouple channel
Water	Intake water position	ai7
	Outlet water position	ai0
P1	Top thermocouple	ai5
	Bottom thermocouple	ai6
P2	Top thermocouple	ai4
	Bottom thermocouple	ai12
P3	Top thermocouple	ai3
	Bottom thermocouple	ai13
P4	Top thermocouple	ai2
	Bottom thermocouple	ai14

4 Results and Discussions

4.1 *Charging and Discharging of PCM System (Without Fins)*

Figure 8 displays thermocouple temperature data during the charging cycle of a typical PCM system (without fins). Close examination of the results reveals that the charging time for the system with regular PCM is around 160 min at each thermocouple station (P1, P2, P3, P4). It also reveals that the PCM melting temperature takes the long time to reach at the temperature point closest to the outlet. Additionally, because the PCM moves upward and the colder portion remains below it, the upper temperatures are always higher than the lower temperatures in any site.

The temperature data for the dis-charging cycle were taken after the charging system. Figure 9 shows the temperature discharge cycle graphs as a function of time. It illustrates that the system takes around 105 min to fully discharge and reach room



(a) (b) (c) (d)

Fig. 8 Charging cycle characteristics of a standard PCM system (without fins) at specific locations **a** P1, **b** P2, **c** P3, **d** P4

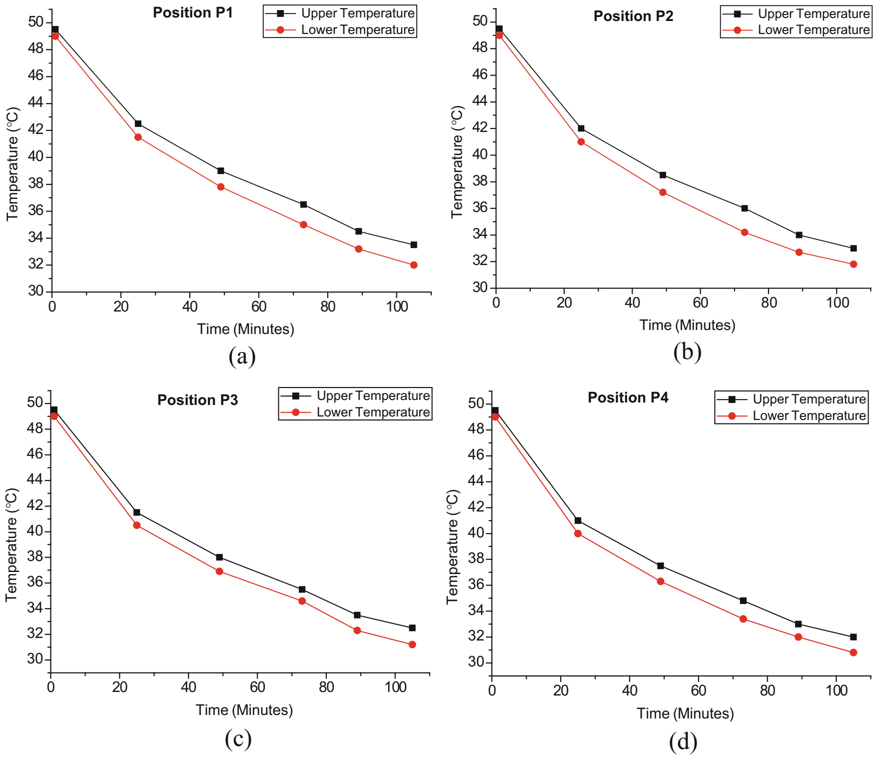
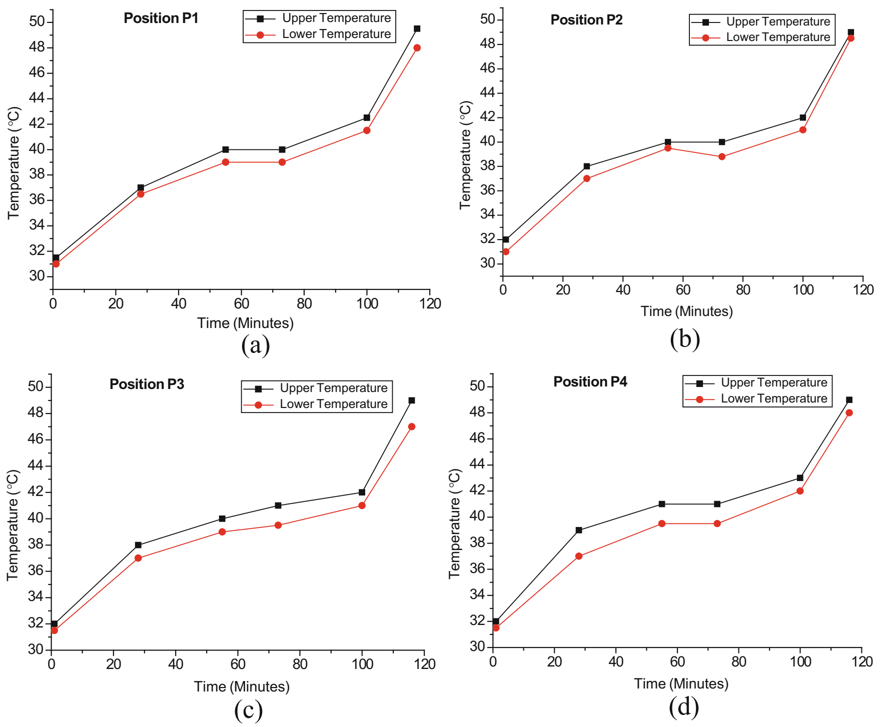


Fig. 9 Discharging cycle characteristics of a standard PCM system (without fins) at specific locations **a** P1, **b** P2, **c** P3, **d** P4

temperature at all thermocouple positions. It can be concluded that the PCM has solidified at this stage.

4.2 *Charging and Discharging of Fin-Enhanced PCM (FEPCM) System*

Figure 10 shows the temperature readings obtained for each thermocouple position (P1, P2, P3, P4) throughout the charging cycle of the FEPCM system. The charging duration is found to be only about 116 min, which is much less than that of a standard PCM system without fins. Furthermore, the discharging duration of this system is only about 62 min, which is significantly less than the first system. Between this example, too, the difference in top and bottom temperatures at each position may be seen in Fig. 11.



(a) (b) (c) (d)

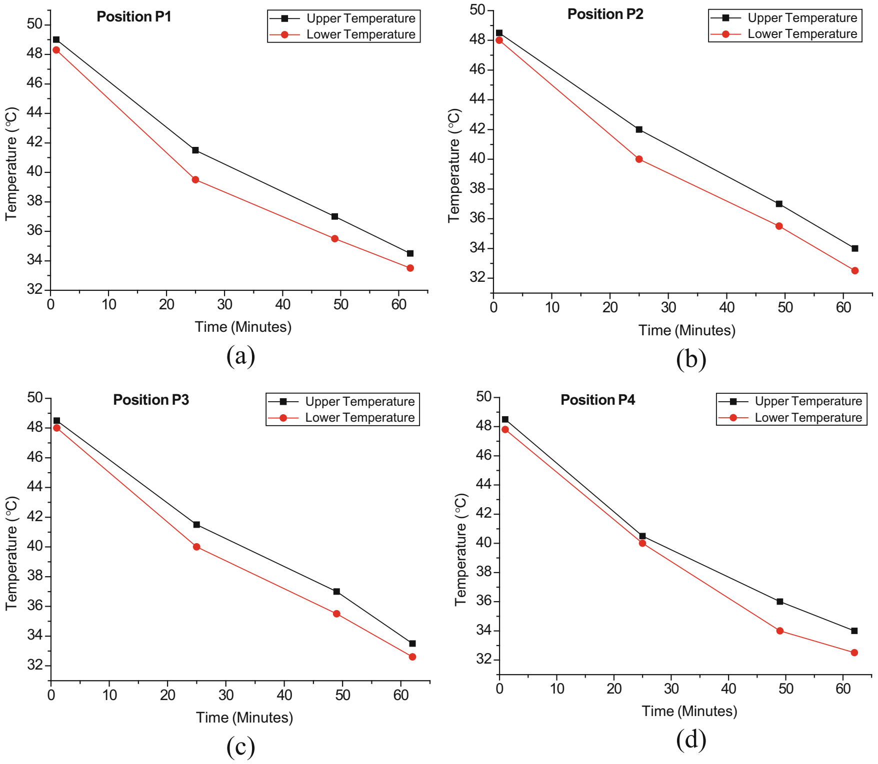
Fig. 10 Charging cycle characteristics of a FEPCM system (with fins) at specific locations **a** P1, **b** P2, **c** P3, **d** P4

Besides that, outlet temperature for both systems is consistently lower than the water inlet temperature during the charging cycle, indicating that the PCM is absorbing heat from the water.

5 Conclusion

A precise interpretation of the results showed that charging time for the heat exchanger with fins was 27.09% lesser than the regular heat exchanger (without fins). Also, regardless of the presence of fins, The heat exchanger's PCM temperature is always higher at the upper point than it is at the bottom point. Solid PCM with lower temperatures settles down while liquid PCM with higher temperatures rises to the top. This is because solid PCM has a higher density than liquid PCM.

The discharging cycle revealed that the time required for complete PCM discharge is 26.36 percent less for heat exchangers with fins, implying that heat retrieval occurs at a faster rate. Additionally, the efficiencies for both the charging and discharging cycles were found to be higher for the finned heat exchanger, demonstrating that the



(a) (b)

(c) (d)

Fig. 11 Discharging cycle characteristics of a FEPCM system (with fins) at specific locations **a** P1, **b** P2, **c** P3, **d** P4

use of fins to increase heat transfer rate is justified because it allows the system to work with higher efficiencies in both cycles.

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